EFFECT OF AGE AT IMPLANTATION ON AUDITORY-SKILL DEVELOPMENT IN INFANTS AND TODDLERS

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ABSTRACT

Objective: The purpose of this study was to investigate the effect of age at implantation on the auditory development of children implanted before age three, and to compare the auditory development of these young implanted children to that of normal-hearing (NH) peers.

Design: Using a repeated-measures paradigm, auditory skill development was evaluated in children who received a cochlear implant (CI) under the age of 3 years before implantation, and at 3, 6, and 12 months after implantation. Data were compared to previously published data from NH cohorts.

Subjects: 107 deaf children (ages 12-36 months) who had been implanted with the Clarion Multi-Strategy cochlear implant during clinical trials in North America participated in the study.

Outcome Measure: Auditory-skill development was assessed using the Infant-Toddler Meaningful Auditory Integration Scale (IT-MAIS), a tool that provides a quantitative measure of auditory development in children as young as newborns.

Results: Implanted infants and toddlers show rapid improvement in auditory skills during the first year of device use regardless of age at implantation—although younger children achieve higher scores. Children who are implanted at a younger age acquire auditory skills nearer to their normal-hearing peers at a younger age. The mean rate of acquisition of auditory skills is similar to normal-hearing infants and toddlers regardless of age at implantation.

Conclusions

Implanting children with profound hearing loss at the youngest age possible allows the best opportunity for them to acquire communication skills that approximate those of their peers with normal hearing.

INTRODUCTION

Recent research indicates that early identification and intervention have a significant positive effect on communication development in very young hearing-impaired children. For example, Yoshinaga-Itano[1] found that babies whose hearing losses were identified and fit with hearing aids before six months of age demonstrated significantly better language scores than children identified after six months of age. In another study, Moeller[2] evaluated vocabulary and verbal reasoning skills in a group of 112 children with hearing loss who were enrolled at various ages in a comprehensive intervention program. At five years of age, children who had been enrolled before 11 months of age demonstrated significantly better vocabulary and verbal reasoning skills than did children enrolled after 11 months of age. Similarly, a positive relationship has been shown between early age at implantation and enhanced cochlear implant performance in children[3,4,5].

There is little information, however, concerning the effect of age at implantation on meaningful listening skills in children implanted as young as 12 months of age. Evaluating device benefit in these young children poses significant challenges. First, they have short attention spans and highly variable levels of compliance. Second, they present with limited skills in understanding and using language. Third, few clinically-useful measures exist to evaluate auditory development in infants and toddlers, regardless of whether they have impaired or normal hearing.

The purpose of this study was two-fold: 1) to investigate the effect of age at implantation on the auditory development of children implanted before age three, and 2) to compare the auditory development of these young children with cochlear implants (CI) to that of normal-hearing (NH) peers. The auditory capabilities of both the implanted and normal-hearing children were assessed and compared using the Infant-Toddler Meaningful Integration Scale (IT-MAIS)[6], a structured parent interview tool developed to yield quantitative results in children as young as newborns. The IT-MAIS scores for NH infants and toddlers already have been published[7].

METHODS

Subjects

107 deaf children who had been implanted with the Clarion Multi-Strategy cochlear implant during clinical trials in North America participated in this study. Clinical centers participating in the trials conducted testing with the approval of their individual Institutional Review Boards. Table 1 lists the demographic characteristics of the CI children.

Test materials

Auditory skills were assessed using the Infant-Toddler Meaningful Auditory Integration Scale (IT-MAIS)[6]. The IT-MAIS was developed and standardized as an assessment tool that provides a quantitative measure of auditory skill development in children as young as newborns. The test is a structured interview schedule that queries parents about their child's spontaneous listening behaviors in everyday situations[8]. Thus clinicians can obtain information about auditory skills without requiring a young child's compliance or attention. In the IT-MAIS, ten questions are posed to parents that sample three different areas of auditory skill development. These three areas include changes in vocalization associated with device use (Questions 1 and 2); alerting to sounds in everyday environments (Questions 3, 4, 5, 6); and deriving meaning from sound (Questions 7, 8, 9, 10). Using information provided by the parent, the examiner scores each question based upon the frequency of occurrence of a target behavior. Scores for each question range from 0 ("never demonstrates the behavior") to 4 ("always demonstrates the behavior"). The total possible points on the IT-MAIS is 40 (10 questions x maximum score of 4).

Procedures

Parents of CI children were administered the IT-MAIS four times: pre-implant (based upon their child's use of hearing aids), and at 3-, 6-, and 12-months post implantation. Clinical staff at each child's CI center conducted the test. To ensure consistency of test administration and standardization of parent responses, the IT-MAIS protocol contains numerous written probes to which clinicians must adhere. In addition, all clinicians had received prior training in the administration of the test, thus further reducing inter-examiner variability. Each child's IT-MAIS score at each test interval was converted to a percent correct score (total score ÷ 40 x 100).

For data analysis, CI subjects were divided into three groups based upon age at implantation. Group 1 (n = 45) consisted of children implanted between 12 and 18 months of age. Group 2 (n = 32) consisted of children implanted between 19 and 23 months of age. Group 3 (n = 30) consisted of children implanted between 24 and 36 months of age (Table 1). IT-MAIS scores from each group were compared with NH IT-MAIS scores that were obtained from the parents of 109 NH children ages .5 to 36 months (mean age: 12.5 months). Parents of these NH subjects were administered a translated version of the IT-MAIS in Hebrew or Arabic (Kishon-Rabin et al, 2001).

RESULTS

The primary aim of the study was to compare the effect of age at implantation on auditory skill development and performance. Figure 1 shows the average performance on the IT-MAIS for the three groups of CI children before implantation and at 3 and 6 months post implantation. The mean IT-MAIS scores for all three groups were near zero prior to implantation but improved rapidly over time with increased use of the device. There appear to be no differences in mean scores over time between the two earliest-implanted groups (Groups 1 and 2) whereas the mean scores for Group 3 are lower than scores for Groups 1 and 2.

The second aim of the study was to compare auditory skill development in CI children to NH children of the same chronological age. To make these comparisons, individual IT-MAIS scores for each of the three CI groups were plotted together with IT-MAIS data obtained from the 109 NH children between the ages of 0.5 and 36 months (Figure 2-4). For simplicity, only the mean and ± 2 standard error values are plotted for the normal-hearing children. Each CI group's data were fit with exponential functions, as shown in Figures 2, 3, and 4 for Groups 1, 2, and 3, respectively.

Rapid improvement in IT-MAIS scores over time is evident for all three age groups following implantation. For the youngest children (Group 1), the data could be fit by an exponential curve ($r = .82$, $p < .01$), as seen in Figure 2. Notably, 70% of the variance in Group 1 data was attributable to implant use (as indicated by months post-CI) and over two-thirds of the children fell within the normal distribution of IT-MAIS scores after six months of implant experience. A few of them reached the normal range after only three months of listening with the implant.

Results for the Group 2 children, implanted between 19 and 23 months of age, are plotted in Figure 3. These data also could be fit by an exponential curve ($r = .80$, $p < .01$) and 65% of the variance was attributable to CI use. About one-third of the children fell within the normal distribution of IT-MAIS scores after six months of implant experience. In contrast to Groups 1 and 2, the IT-MAIS scores from Group 3 children, implanted between 24 and 36 months, showed such great variability that the data could not be predicted by length of CI use in any systematic way. Moreover, almost all Group 3 scores continued to fall below the NH range after six months of CI use.

Figure 5 shows the mean data from the three groups of children plotted as a function of hearing age. Hearing age reflects months of implant use for the implanted children, and chronological age for the normal-hearing children. The mean scores indicate that the implanted children acquired auditory skills at a similar rate as normal-hearing children, independent of age at implantation. However, as is evident in Figures 2-4, there is large inter-subject variability.

DISCUSSION

Three main findings emerge from this study. First, mean IT-MAIS scores from implanted infants and toddlers indicate rapid improvement in auditory skills during the first year of device use regardless of age at implantation, although younger children achieve higher scores. Second, children who are implanted at a younger age attain auditory skills nearer to their normal-hearing peers at a younger age, as measured on the IT-MAIS. When children receive cochlear implants at an older age, factors other than implant use begin to influence their ability to achieve auditory milestones. Third, the mean rate of acquisition of auditory skills is similar to normal-hearing infants and toddlers regardless of age at implantation.

Specifically, mean IT-MAIS scores show that the two groups of children implanted before age two showed significantly faster rates of progress and higher scores than did the children implanted between two and three years of age. However, there were no significant differences in mean IT-MAIS scores between the two youngest groups. At first glance, comparison of mean data suggests that there is no advantage to implanting a child at 12-18 months of age, as opposed to implanting at 19-24 months of age. The rate of auditory-skill acquisition is the same. However, when IT-MAIS scores from Group 1 and Group 2 children are compared to normal-hearing infants and toddlers, a clear distinction emerges between the two youngest groups. Specifically, it is apparent that the youngest Group 1 children achieved IT-MAIS scores within the normal range at earlier post-implant intervals (and thus younger ages) than did children in Group 2. Similarly, children in Group 2 achieved auditory milestones at earlier ages than did children in Group 3.

What advantage might there be to the attainment of auditory milestones at ages closest to those achieved by NH children? There are three primary advantages: First, the goal of any intervention is for the child to master skills as close as possible to the time that he or she is biologically intended to do so, taking advantage of developmental “windows” of opportunity. This results in developmental synchrony.

Second, our primary interest in the development of auditory skills is the fact that such skills form the foundation for spoken language competence. Thus, delayed auditory development almost certainly leads to delayed language. And although we did not assess language in this study directly, recent studies[9] suggest similar age-at-CI effects on language that were found in this study on auditory development. Third, mastery of any developmental skill depends upon cumulative practice. The more delayed the age of acquisition of a skill, the farther behind children are in the amount of cumulative practice they have had to perfect that skill. For example, a third grader who is a non-reader may be given intensive, concentrated reading instruction and score on tests at the third grade reading level after intervention. But, what that child has missed out on are the hundreds of hours of cumulative reading practice that other students have had by third grade. Such practice is essential for building language, cognitive and experiential knowledge, and for reaching automaticity of skills. We would argue that the same holds true for cumulative auditory practice in children with CIs.

In summary, children implanted under age three demonstrated impressive auditory skill development during the first year of device use. These data suggest that implanting children with profound hearing loss at the youngest age possible allows the best opportunity for them to acquire communication skills that approximate those of their NH peers.

Table 1. Demographic characteristics of 107 children implanted with the Clarion Multi-Strategy cochlear implant during North American clinical trials.

GROUP	1	2	3
n	45	32	30
Age at implant	12-17 months	19-23 months	24-36 months
Mean preimplant pure-tone average: implant ear	116 dB HL	107 dB HL	110 dB HL
Mean preimplant pure-tone average: non-implant ear	115 dB HL	109 dB HL	113 dB HL

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FIGURE LEGENDS

Figure 1. Mean IT-MAIS scores over time by age at implantation (12-18 months: red, 19-23 months: yellow, 24-36 months: green).

Figure 2. Individual IT-MAIS scores by age for children in Group 1 (12-18 months of age at implantation). Preimplant scores are in yellow (mean score: yellow diamond), 3-month scores are in blue (mean score: blue diamond), 6-month scores are in red (mean score: red diamond), and 12-month scores are in green (mean score: green diamond). Blue line is best-fit exponential function for those data over time. Mean normal data ± 2 standard errors are shown by the black solid and dotted lines.

Figure 3. Individual IT-MAIS scores by age for children in Group 2 (19-23 months of age at implantation). Preimplant scores are in yellow (mean score: yellow diamond), 3-month scores are in blue (mean score: blue diamond), 6-month scores are in red (mean score: red diamond), and 12-month scores are in green (mean score: green diamond). Red line is best-fit exponential function for those data over time, blue 12-18 month best-fit curve is reproduced from Figure 2. Mean normal data ± 2 standard errors are shown by the black solid and dotted lines.

Figure 4. Individual IT-MAIS scores by age for children in Group 3 (24-36 months of age at implantation). Preimplant scores are in yellow (mean score: yellow diamond), 3-month scores are in blue (mean score: blue diamond), 6-month scores are in red (mean score: red diamond), and 12-month scores are in green (mean score: green diamond). An exponential function could not be fit to these data, blue 12-18 month best-fit curve is reproduced from Figure 2, red 19-23 month best-fit curve reproduced from Figure 3. Mean normal data ± 2 standard errors are shown by the black solid and dotted lines.

Figure 5. Mean IT-MAIS scores for implanted and normal-hearing children as a function of hearing age (months of implant use for implanted children, chronological age for normal children). Blue

line: 12-18 months of age at implantation, red line: 19-23 months of age at implantation, green line: 24-36 months of age at implantation. Mean normal data ± 2 standard errors are shown by the black solid and dotted lines.

Figure 1

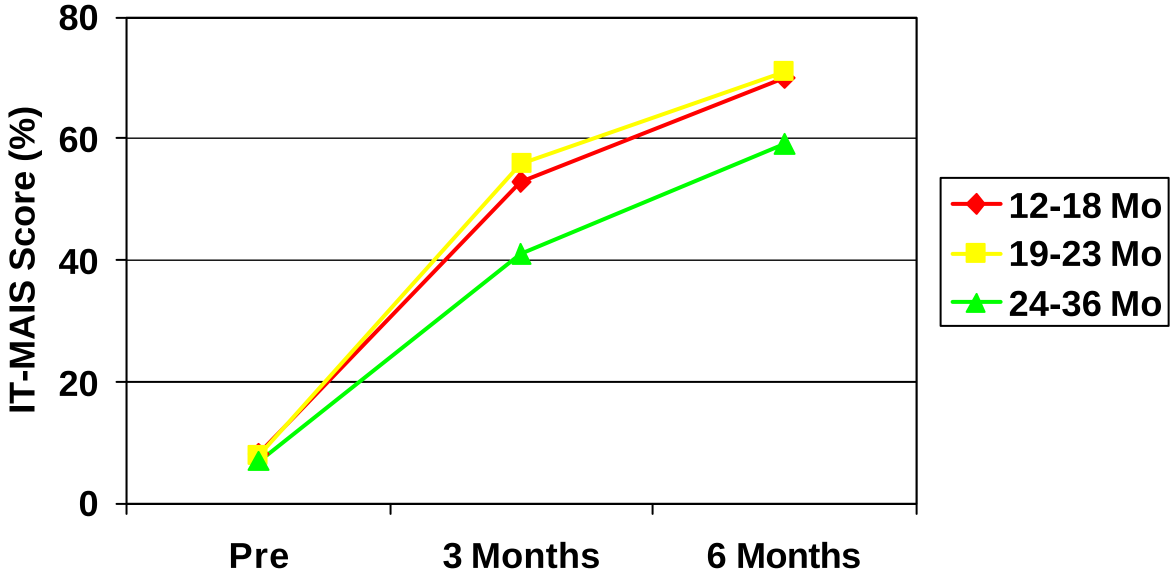

80
60
40
20
0
IT-MAIS Score (%)
Pre
3 Months
6 Months
12-18 Mo
19-23 Mo
24-36 Mo

Figure 2

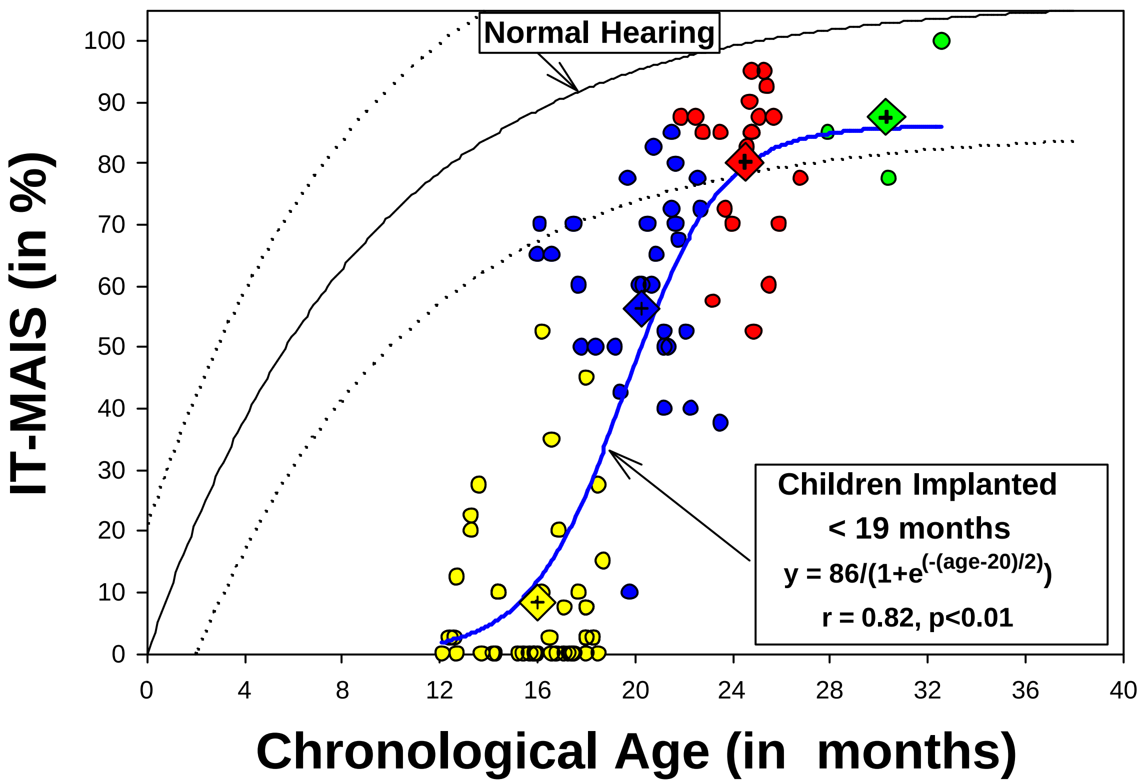

Normal Hearing
Children Implanted
< 19 months
y = 86/(1+e^(-(age-20)/2))
r = 0.82, p<0.01
IT-MAIS (in %)
Chronological Age (in months)
0
10
20
30
40
50
60
70
80
90
100
0
4
8
12
16
20
24
28
32
36
40

Figure 3

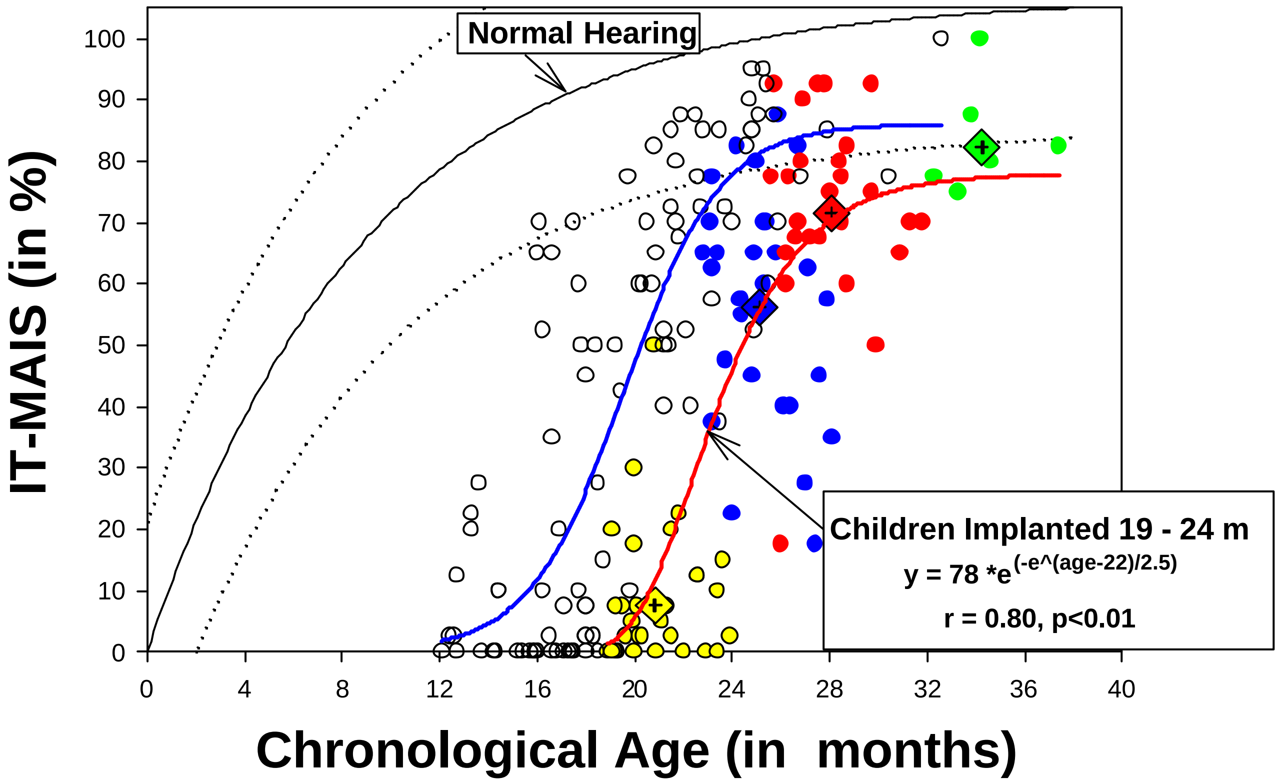

Normal Hearing
Children Implanted 19 - 24 m
y = 78 *e(-e^(age-22)/2.5)
r = 0.80, p<0.01
IT-MAIS (in %)
Chronological Age (in months)
0
10
20
30
40
50
60
70
80
90
100
0
4
8
12
16
20
24
28
32
36
40

Figure 4

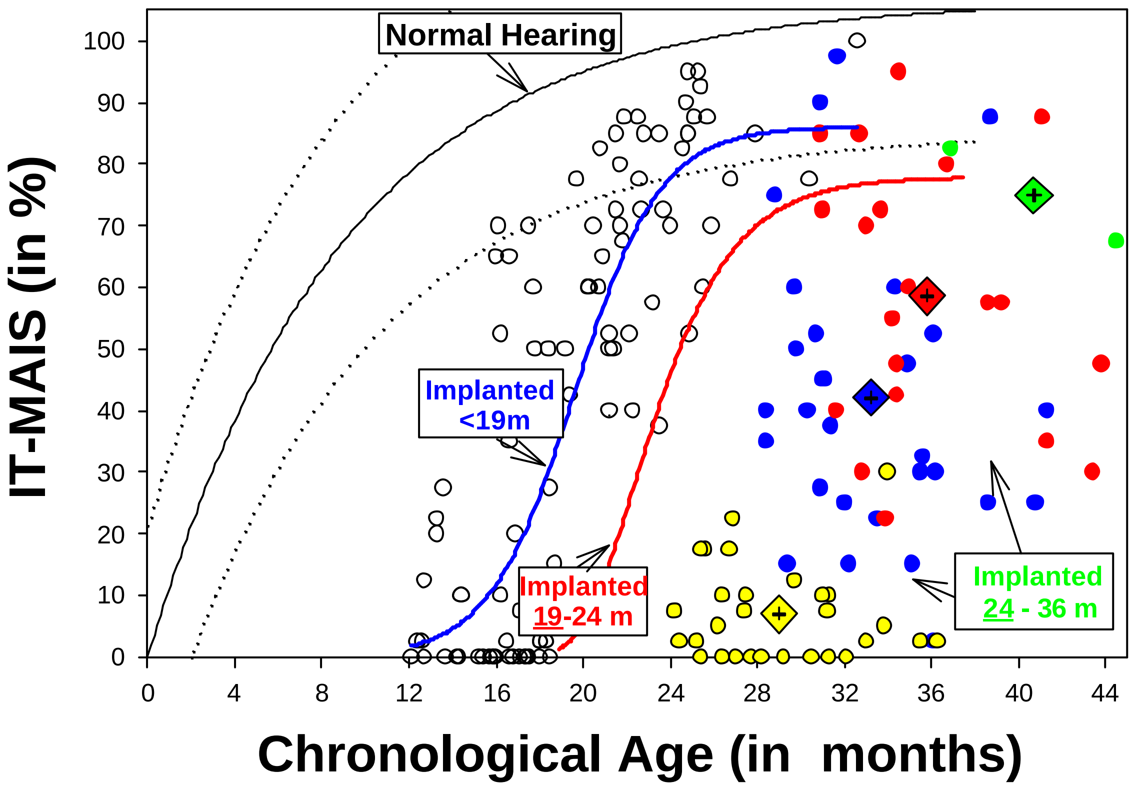
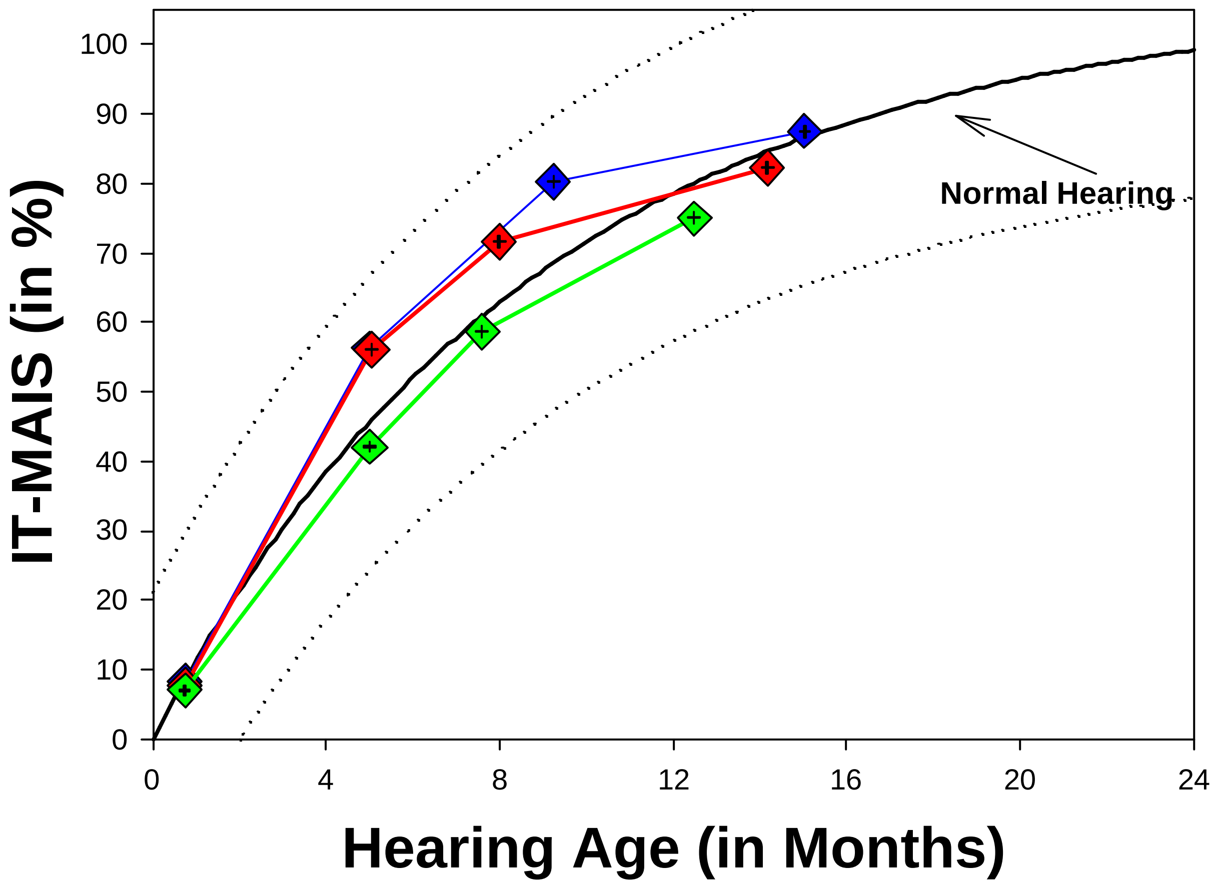

Normal Hearing
Implanted
<19m
Implanted
19-24 m
Implanted
24 - 36 m
IT-MAIS (in %)
0
10
20
30
40
50
60
70
80
90
100
0
4
8
12
16
20
24
28
32
36
40
44
Chronological Age (in months)

Figure 5



100
90
80
70
60
50
40
30
20
10
0
IT-MAIS (in %)
Normal Hearing
0
4
8
12
16
20
24
Hearing Age (in Months)