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# Early prelingual auditory development and speech perception at 1-year follow-up in Mandarin-speaking children after cochlear implantation

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ABSTRACT

*Objective:* The primary purpose of the current study was to evaluate early prelingual auditory development (EPLAD) and early speech perception longitudinally over the first year after cochlear implantation in Mandarin-speaking pediatric cochlear implant (CI) recipients. Outcome measures were designed to allow comparisons of outcomes with those of English-speaking pediatric CI recipients reported in previous research.

*Method:* A hierarchical outcome assessment battery designed to measure EPLAD and early speech perception was used to evaluate 39 pediatric CI recipients implanted between the ages of 1 and 6 years at baseline and 3, 6, and 12 months after implantation. The battery consists of the Mandarin Infant-Toddler Meaningful Auditory Integration Scale (ITMAIS), the Mandarin Early Speech Perception (MESP) test, and the Mandarin Pediatric Speech Intelligibility (MPSI) test. The effects of age at implantation, duration of pre-implant hearing aid use, and Mandarin dialect exposure on performance were evaluated. EPLAD results were compared with the normal developmental trajectory and with results for English-speaking pediatric CI recipients. MESP and MPSI measures of early speech perception were compared with results for English-speaking recipients obtained with comparable measures.

*Results:* EPLAD, as measured with the ITMAIS/MAIS, was comparable in Mandarin- and English-speaking pediatric CI recipients. Both groups exceeded the normal developmental trajectory when hearing age in CI recipients and chronological age in normal were equated. Evidence of significant EPLAD during pre-implant hearing aid use was observed; although at a more gradual rate than after implantation. Early development of speech perception, as measures with the MESP and MPSI tests, was also comparable for Mandarin- and English-speaking CI recipients throughout the first 12 months after implantation. Both Mandarin dialect exposure and the duration of pre-implant hearing aid use significantly affected measures of early speech perception during this time period.

*Conclusions:* EPLAD and early speech perception exhibited similar patterns of improvement during the first 12 months after early cochlear implantation. The duration of pre-implant hearing aid use had a significant positive effect on both categories of outcome measures. Consistent post-implant EPLAD trajectories and early speech perception results provide objective evidence that can guide best practices in early intervention protocols.



## 1. Introduction

The advent of universal newborn hearing screening throughout the world and the resulting early identification and intervention programs with cochlear implantation of very young children have great promise in providing early access to speech and language development for these children. Successful case management and habilitation of very young children with cochlear implants (CIs) require the use of objective evidence of the child's progress toward the achievement of appropriately defined developmental goals. These goals may originate from developmental studies of normally hearing children, and/or from studies of outcomes for pediatric CI recipients where best case management and habilitation practices have been used.

The current research attempts to establish objective evidence of progress toward appropriate developmental goals in very young Mandarin-speaking CI recipients during the first year after implantation, as a step toward the establishment of best practices within the cultural and linguistic context of China. Specific developmental goals are defined in terms of early prelingual auditory development (EPLAD) and early speech perception. Early

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developmental goals are defined in relation to the normative trajectory for EPLAD established for normally hearing children [1–3]. Zheng et al. [1] have suggested this trajectory may be universal.

In the case of early speech perception, linguistic diversity precludes the use of a universal normative reference. Instead, the results of pediatric CI outcome studies with best case management and habilitation practices are used. One source of such results is the Child Development after Cochlear Implantation (CDaCI) study in the United States [4,5]. The CDaCI study is a large scale ongoing multicenter longitudinal outcome study of pediatric CI recipients that began in 2002.

Objective assessment of early speech perception in the CDaCI study is accomplished with a hierarchical battery of assessment tools, beginning with the infant–toddler and preschool versions of the Meaningful Auditory Integration Scale, i.e., the ITMAIS and the MAIS, which are administered as structured interviews with parent [1–3]. Next in the hierarchy are the low verbal and standard versions of the Early Speech Perception (ESP) test [6,7], which are closed set word recognition tests. The ESP is followed by the Pediatric Speech Intelligibility [8] test, a closed set sentence recognition test administered either in quiet or in the presence of a competing voice. Additional tests comprising the remainder of the battery are used with older children and thus are not relevant to the current research.

Using the CdaCI hierarchical assessment battery as a guide, a parallel assessment battery in Mandarin has been developed. The Mandarin battery consists of the Chinese translation of the ITMAIS/MAIS [1], the Mandarin low verbal and standard versions of the ESP, LV-MESP and MESP, respectively [9], and the Mandarin PSI or MPSI [10]. This battery is currently being used as the primary speech perception outcome measure in a four-year longitudinal outcome study of pediatric CI recipients at West China Hospital of Sichuan University. The study design includes a normal hearing cohort and a cohort of hearing aid users. The current research addresses first year results for the CI recipients.

The specific objectives of the current research are to provide objective evidence of early auditory development and early speech perception during the first 12 months following cochlear implantation that can be used to establish in China appropriate outcome expectations and evidence-based best practices for case management and habilitation of very young children during this time. For early auditory development, these objectives can be achieved by comparing the current results for Mandarin-speaking children with those for English-speaking children in the CDaCI study [4]. The results for both groups of children can also be compared with the normative EPLAD trajectory [1]. If both groups exhibit comparable early auditory development that compares favorably with the normative trajectory, the Mandarin results can provide appropriate outcome expectations during the first year after implantation.

Likewise, for early speech perception, these objectives can be achieved by comparison of the low verbal and standard measures of early speech perception from the current study with those reported for the CDaCI study. Similar comparisons of measures of pediatric speech intelligibility in quiet and in noise from the current study and from the CDaCI study can also be made. Again, if the results from both studies are comparable, the Mandarin results can also provide appropriate outcome expectations for early speech perception during the first year after implantation. These expectations can also guide the establishment of best practices.

Finally, the design of the current study also allows objective assessment of two other factors that can affect outcomes, and thus can impact best practices: hearing aid use and dialect exposure. The data for each subject include the duration of pre-implant hearing aid use and whether the hearing aid continued to be used after implantation. The effects of these variables on the objective outcome measures are reported. Likewise, the child's exposure to different Mandarin dialects after implantation can also affect outcomes. The talker for the recorded MESP and MPSI test materials is a speaker of Putonghua, the standard Mandarin dialect; however, some of the subjects were exposed primarily to a regional dialect of Mandarin other than Putonghua. The effects of dialect exposure on the objective outcome measures are also reported.

## 2. Methods

### 2.1. Subjects

Children implanted between the ages of 1 and 5 years at the West China Hospital of Sichuan University participated in the study. Inclusion criteria included bilateral profound sensorineural hearing loss and absence of inner ear malformation, with the exception of enlarged vestibular aqueduct. All subjects were also required to comply with the outcome assessment protocol and schedule without missing more than one follow-up visit. All subjects were recipients of devices manufactured by Cochlear Corp.

### 2.2. Design

Subjects were evaluated at baseline before their CIs were switched on and at 3, 6, and 12 months after activation with the Mandarin Auditory Pediatric Protocol (MAPP). Baseline evaluations were performed in the Hearing Center at West China Hospital, and follow-up evaluations were performed by five staff members in the Hearing and Speech Laboratory. Each outcome measure was administered by a staff member available at the time who had not seen the results of the other measures. Thus, the opportunity for observer bias was minimal.

MAPP is a hierarchical battery of tests that assess early prelingual auditory development (EPLAD) and early speech perception. The battery includes the Infant-Toddler Meaningful Auditory Integration Scale/Meaningful Auditory Integration Scale (ITMAIS/MAIS) translated to Chinese by Zheng et al. [1], the Mandarin Early Speech Perception (MESP) test [9], and the Mandarin Pediatric Speech Intelligibility (MPSI) test [10]. In addition, a dialect exposure checklist was completed for each child. This checklist required both parents and teachers to report the percentage of time their communication with the child used Putonghua, the standard Mandarin dialect, or other regional Mandarin dialects. See Zheng et al. [9] for additional details about the dialect exposure checklist.

This battery was used because it comprises the only standardized, norm-referenced, objective speech perception assessment tools available for young Mandarin-speaking children [11]. The battery was designed to parallel the English hierarchical speech perception battery currently used in the Child Development and Cochlear Implantation (CDaCI) study in the United States [4,5]. Each of the tests comprising the battery is described briefly below.

### 2.3. ITMAIS/MAIS

ITMAIS/MAIS is a structured parent interview questionnaire used to investigate early EPLAD for very young children [3]. The interview consists of 10 questions about behavioral evidence of the children's auditory development. ITMAIS is designed for children under the age of 3 years, and the MAIS for children from 3 to 6 years of age. Only the first two items differ between the ITMAIS and MAIS. The remaining eight items ask about spontaneous detection of and response to sounds, and about spontaneous and meaningful recognition and discrimination of sounds. Responses to each question are scored on a scale of 0–4, depending on the frequency of the behavior in question, for a maximum raw score of 40. Obtained scores are expressed as percentages. Three scores are calculated for the ITMAIS and MAIS: the Overall score (all 10 items), the Detection subtest score (items 3–6), and the Recognition subtest score (items 7–10). The ITMAIS and MAIS were not scored if more than three items were unanswered, or if more than one item was unanswered on either of the subtests. The ITMAIS and/or MAIS were no longer administered once the child reached ceiling on either test.

### 2.4. MESP

The MESP test is a closed set word test that evaluates the earliest evidence of speech perception in a child [9]. It is based on the English Early Speech Perception test [6,7]. It is administered as soon as the child can be tested with a closed-set procedure. The test includes both a standard and a low verbal version. The MESP consists of six categories, including Sound Detection (Category 1), Speech Pattern Perception (Category 2), Spondee Word Perception (Category 3), Vowel Perception (Category 4), Consonant Perception (Category 5), and Tone Perception (Category 6). The Low Verbal MESP (LV-MESP) consists of four categories [6,7]. The first three are the same as in the MESP, and the fourth category is Simple Word Perception. The main difference between the two versions is that the standard version uses a picture-pointing task and recorded test materials, while the LV-MESP version uses actual objects and live-voice test materials. The vocabulary for the LV-MESP items is a subset of those in the MESP.

Both tests are scored according to the highest category reached by the child. The child advances to the next category if their score on the current category is significantly above chance. (Criterion scores for the advancement to the next category are given in Table 4 of Zheng et al. [9].) At each evaluation interval, the MESP was always administered first. If the child reached Category 1, but could not be tested with the Category 2 words because of vocabulary limitations, the LV-MESP was administered. Once the child could be tested on Categories 2 and above with the MESP, testing at each evaluation interval began with the highest category reached during previous testing. MESP testing was terminated once the child reached ceiling on Category 6.

### 2.5. MPSI

The MPSI test is a closed-set recorded sentence test administered in quiet and in the presence of a competing voice at various signal/noise ratios (SNRs) [10]. It is based on the English Pediatric Speech Intelligibility test [8]. Testing with the MPSI was attempted once the subject reached Category 3 on the MESP. MPSI sentence lists were first administered in quiet, and then in the presence of a competing voice at successively more difficult SNRs, beginning at +10 dB SNR and progressing in 5 dB steps to −10 dB SNR. Subjects progressed to the next more difficult condition when their score for the current condition was significantly greater than chance performance (i.e., 41.7% at $p < .05$). Additional details about test procedures and scoring rules are found in Zheng et al. [10]. The MPSI is scored according to the final SNR reached by the subject.

### 2.6. Test procedures

The structured interviews were conducted face-to-face with the subjects' parents. Responses were later entered into the software for scoring and recordkeeping. The low-verbal speech perception tests were administered live-voice to the subject, and, again, subjects' responses were later entered into the software in the same manner. The other speech perception tests were administered semi-automatically with the testing software. Speech presentation level was set at 65 dB(A). The testing software, picture plates, and other test materials are described in Zheng et al. [1,9,10]. All of the subjects' CIs were at their typical use settings, which had been validated by measuring aided sound field thresholds prior to testing.

Administration of the complete assessment protocol required several hours, depending on the number of tests required and the status of the child. Structured interviews typically require about 20 min to administer, each speech perception test in this study typically required 30 min. Test time for the speech tests depends on the number of categories tested and on the number of SNRs tested.

### 2.7. Data analyses

Several types of data analyses were performed, depending on the number of subjects who had been successfully tested with each outcome measure in the hierarchical battery. Some of the tests in the battery, such as the MPSI and the more difficult categories in the MESP, are intended for use with children with more than one year of hearing experience. Thus, it is unlikely that a large number of children can be evaluated with these measures within the first year after implantation. At the same time, it is likely that other tests in the battery, such as the ITMAIS/MAIS and the LV-MESP, can be used throughout the first year after implantation. Only the ITMAIS/MAIS provided adequate first-year data for systematic analyses comparing auditory development for recipients with that of normally hearing children. These data were also adequate for analyses of the effects of age at implantation and duration of pre-implant hearing aid use.

## 3. Results

### 3.1. Sample characteristics

A total of 39 pediatric CI recipients with profound sensorineural hearing impairment satisfied the inclusion criteria. Risk factors associated with this diagnosis included high fever (9), hypoxia (4), ototoxicity (3), premature childbirth (1), and unknown (22). All of the subjects were implanted between April 2007 and March 2009. Table 1 reports the gender distribution within each age at implantation group. The total number of males and females in the sample, as well as the total number of subjects in each age group, is also reported. The fact that there were no females in the 1–2 years age at implantation group should not be interpreted to mean that females were generally implanted later than males. In fact, there were numerous females CI recipients in this age range in the clinic population who, for various reasons, did not meet the inclusion criteria for the study, e.g., not having reached the 12-month evaluation interval. Nor should these data suggest that females may have been subject to longer hearing aid trials prior to implantation. The average duration of hearing aid use prior to implantation for males was 20.2 months, as compared with 16.7 months for females.

The pediatric intervention protocol at West China Hospital of Sichuan University recommends a hearing aid trial prior to

**Table 1**
Age and gender distribution of sample.

| Gender | Age at implantation | | | | Total |
|---|---|---|---|---|---|
| | 1–2 years | 2–3 years | 3–4 years | 4–6 years | |
| Male | 4 | 7 | 5 | 8 | 24 |
| Female | 0 | 5 | 7 | 3 | 15 |
| Total | 4 | 12 | 12 | 11 | 39 |

**Table 2**
Duration of hearing aid use prior to implantation as a function of age at implantation. Dashes are entered in cells where the age at implantation does not allow hearing aid use of the specified duration.

| Duration of hearing aid use | Age at implantation | | | | Total |
|---|---|---|---|---|---|
| | 1–2 years | 2–3 years | 3–4 years | 4–6 years | |
| <6 months | 2 | 1 | 2 | 0 | 5 |
| 6–12 months | 2 | 3 | 4 | 1 | 10 |
| 12–18 months | 0 | 2 | 3 | 1 | 6 |
| 18–24 months | 0 | 3 | 1 | 2 | 6 |
| 24–30 months | – | 3 | 2 | 1 | 6 |
| >30 months | – | 0 | 0 | 6 | 6 |
| Total | 4 | 12 | 12 | 11 | 39 |

implantation surgery. Uniform compliance with this protocol by subjects in the current study allowed analyses of the impact of pre-implant hearing aid use on post-implant performance. Table 2 summarizes the duration of hearing aid use prior to implantation as a function of the age at implantation. The cells in the table contain the number of children in each age group who used hearing aids for different durations before implantation. Durations are expressed in 6-month intervals. Note that some combinations of durations and implant ages cannot occur. Such cells are marked with a "—" symbol.

### 3.2. Early prelingual auditory development (EPLAD)

The MAIS and ITMAIS define comparable measures of EPLAD, differing only in 2 of the 10 items that comprise each measure [1]. Children over the age of three years at the time of testing were administered the 10 ITMAIS items plus the two MAIS items that differed from the ITMAIS items. Both the ITMAIS and MAIS scores were calculated and the better scores were used. ITMAIS and MAIS tests were pooled for the analyses. Consequently, unequal numbers of tests were available at each evaluation interval: 36 at baseline, 39 at 3 months, 35 at 6 months, and 37 at 12 months.

Fig. 1 displays the mean ITMAIS/MAIS performance in the current study for baseline and each of the follow-up intervals (3, 6, and 12 months) plotted as filled diamonds. The results for males and females in the current study have been pooled in these analyses since the largest gender difference in means was 3.4%, and the average gender difference across all intervals was 0.6%. Similar results from Eisenberg et al. [4] are also displayed as open triangles. Note that 3-month data were not available for that study. Both of these data sets are plotted as a function of post-implant interval.

The continuous solid line trace displayed in Fig. 1 is the mean normative developmental trajectory for overall ITMAIS performance in the first 24 months after birth. Zheng et al. [1] reported the equation for this trajectory fitted to ITMAIS scores from the cross-sectional study of 120 normally hearing children. The continuous broken line traces in the figure display the 5th and 95th percentiles for the distribution of performance about the mean trajectory in normally hearing children. Zheng et al. [1] observed that the normative trajectory, based on children from Mandarin speaking families in China, is almost identical to that observed for children from Hebrew and Arabic speaking families in Israel [2], suggesting that EPLAD may follow the same course in all normally hearing children, regardless of culture and language. Viewed from this perspective, both the current results and those reported by Eisenberg et al. [4] can be compared with the same normative trajectories. These comparisons show that both sets of CI data fall near the 95th percentile of the distribution for normally hearing children. Statistical comparisons of mean

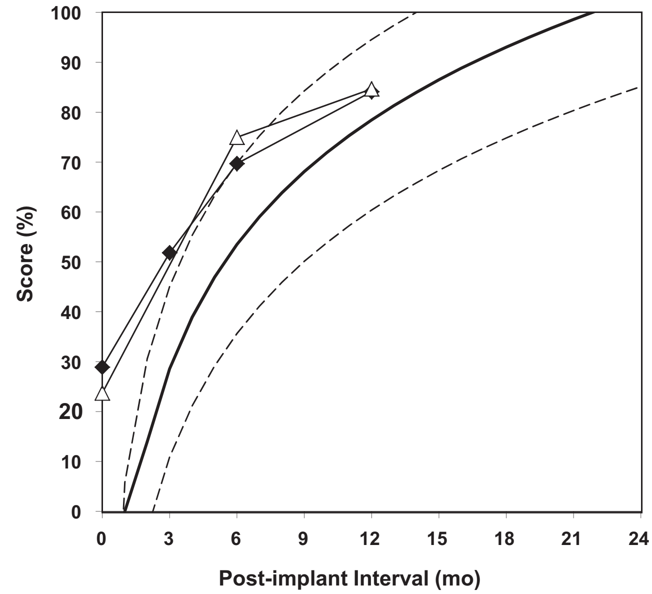


**Fig. 1.** Mean ITMAIS/MAIS scores for the current study (filled diamonds) and for the Eisenberg et al. [4] study (open triangles). The mean normative developmental trajectory (heavy solid line) and the 5th and 95th percentiles (thin dashed lines) representing the distribution of performance for normally hearing infants are also shown Zheng et al. [1]. Standard deviations for the means from the current study are 23.6%, 24.4%, 19.4%, and 13.7%, ranging from baseline to 12-month follow-up.

performance for Mandarin subjects at 3, 6, and 12 months after implantation with mean normative performance at these intervals revealed that the scores for pediatric CI recipients were significantly higher than those for normally hearing children at each interval, as determined from $t$-tests ($p < .001$ at 3 and 6 months, $p = .008$ at 12 months).

Figs. 2 and 3 display mean Detection and Recognition subtest scores, respectively, for subjects in the current study.

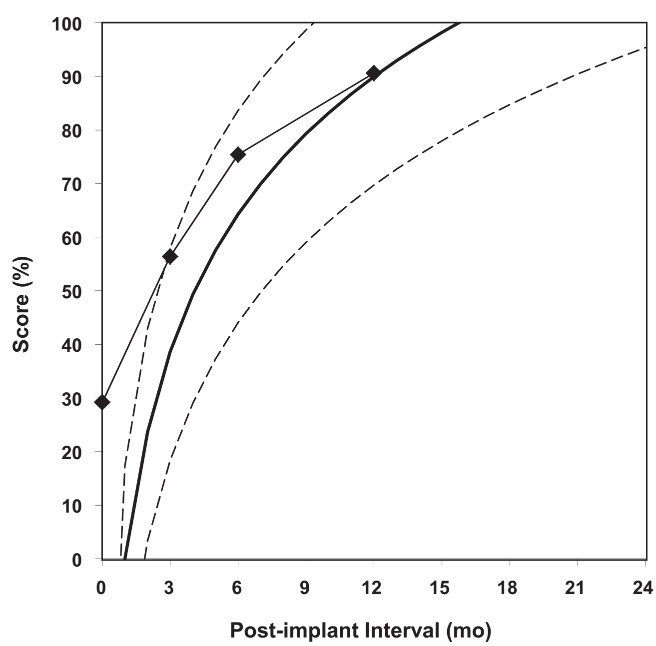


**Fig. 2.** Mean Detection ITMAIS/MAIS scores for the current study (filled diamonds). The normative developmental trajectory for detection is also shown. See Fig. 1 caption for details. Standard deviations are 23.1%, 24.4%, 19.7%, and 10.9%, ranging from baseline to 12-month follow-up.

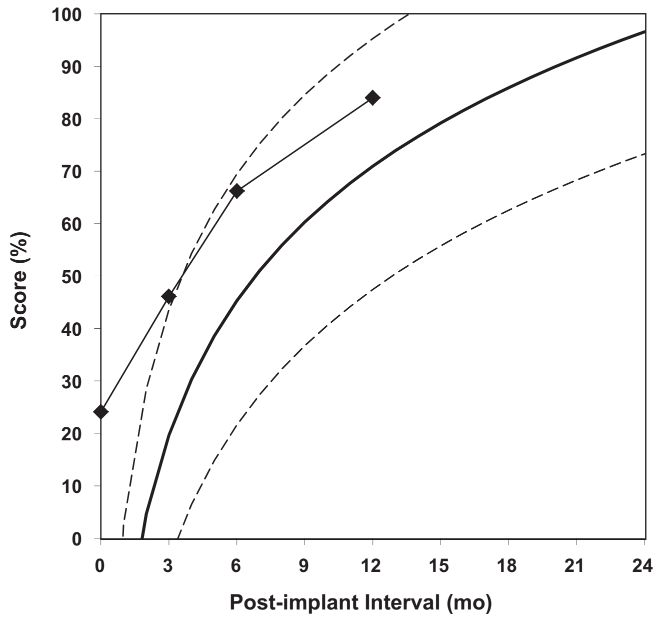


**Fig. 3.** Mean Recognition ITMAIS/MAIS scores for the current study (filled diamonds). The normative developmental trajectory for recognition is also shown. See Fig. 1 caption for details. Standard deviations are 27.9%, 34.5%, 29.0%, and 18.2%, ranging from baseline to 12-month follow-up.

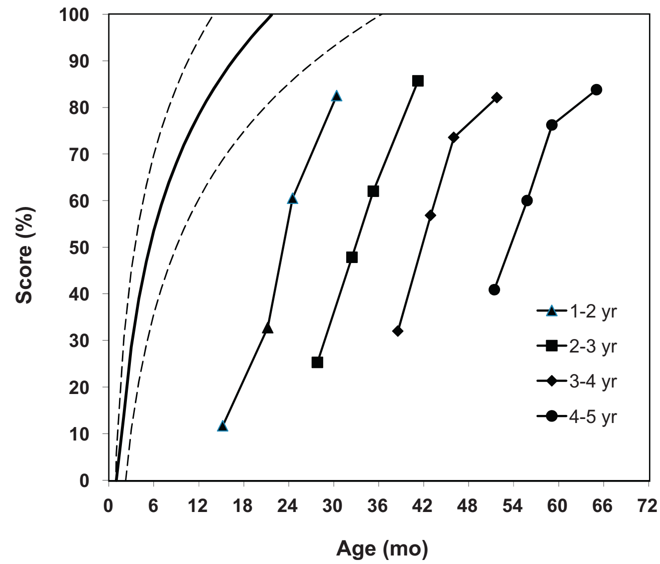


**Fig. 4.** Mean ITMAIS/MAIS trajectories plotted as a function of chronological age. The grouping parameter is age at implantation, as shown in the figure legend. The mean normative developmental trajectory (heavy solid line) and the 5th and 95th percentiles (thin dashed lines) representing the distribution of performance for normally hearing infants are also shown Zheng et al. [1].

These data are displayed in the same manner as in Fig. 1. Comparable scores from Eisenberg et al. [4] are unreported. Detection scores for the pediatric CI recipients in the current study were near the 95th percentile of the distribution for normally hearing children and significantly higher than the norms at 3 and 6 months, as determined from $t$-tests ($p < .001$ at 3 months, $p = .001$ at 6 months). The 12-month mean Detection score for CI recipients fell on the trajectory for mean normative performance and did not differ significantly from the normative value at 12 months.

Mean Recognition scores for subjects in the current study were near the 95th percentile of the distribution for normally hearing children and significantly higher than the mean performance of these children at 3 and 6 months, as determined from $t$-tests ($p < .001$). Mean Recognition scores at 12 months dropped below the 95th percentile but remained significantly higher than the normative value at 12 months, as determined from a $t$-test ($p < .001$).

Scores can also be analyzed as a function of chronological age. Mean scores at each evaluation interval for subjects in four groups defined by age at implantation are displayed as a function of chronological age in Fig. 4. This figure displays the mean normative trajectory (heavy solid line) and the 5th and 95th percentiles (thin broken line). In addition, mean scores at baseline and each of the follow-up intervals are shown for subjects in the current study. These means are plotted separately for each implant age group using the symbols displayed in the figure legend. The traces connecting these means define unique EPLAD trajectories for each implant age group. These trajectories exhibit a consistent pattern as age at implantation increases. Baseline scores increase from approximately 10% for subjects implanted at 1–2 years of age to approximately 40% for subjects implanted at 3–4 years of age. Baseline scores are highly correlated with age at implantation ($r^2 = 0.96$) and with duration of pre-implant hearing aid use ($r^2 = 0.69$). The slope of the linear regression function predicting baseline scores from age at implantation is approximately 9.5% per year.

Scores at 3 months post-implant remain highly correlated with age at implantation ($r^2 = 0.81$), and the slope of the regression function predicting these scores from age at implantation is essentially unchanged (9.4% per year). Scores at 6 months post-implant also remain highly correlated with age at implantation ($r^2 = 0.79$); although the slope of the prediction equation decreases to 6.1% per year. By 12 months post-implant, both the correlation and the slope relationships between age at implantation EPLAD reach values of approximately 0.00.

This pattern of results suggests that the effects of age at implantation and, to a lesser extent, duration of pre-implant hearing aid use have a significant influence on EPLAD during the first 3–6 months after implantation. After 6 months, these factors no longer exhibit such influence, as experience with the CI becomes the primary factor influencing EPLAD.

Regardless of age at implantation, EPLAD reaches a level of approximately 80–85% within the first 12 months after implantation. These comparisons indicate that the rate of EPLAD after implantation is greatest for subjects implanted at 1–2 years, as compared with later-implanted subjects. In fact, the slopes of the EPLAD trajectories for each implant age group resemble the slope of the trajectory for normally hearing infants, with the most rapid increases occurring in the first months after implantation.

The post-implant trajectories are offset from the normative trajectory by the age at implantation. These offsets can be removed by shifting the post-implant trajectories into alignment with the normative trajectory. The magnitude of the shift is determined from the difference between the test age and the normal equivalent age corresponding to the obtained test score. Zheng et al. [1] provide a formula for calculating the normal equivalent age given an ITMAIS/MAIS test score. These differences were calculated for the four scores defining each trajectory, and the average of these differences defined the magnitude of the shift for each trajectory.

Fig. 5 displays the shifted trajectories for each post-implant group super imposed on the normative trajectory for EPLAD. The same symbols are used to identify each age group as in Fig. 4; although it difficult to distinguish separate traces because of their overlap with the normative trajectory. Correlations of the actual scores defining each post-implant trajectory with scores on the

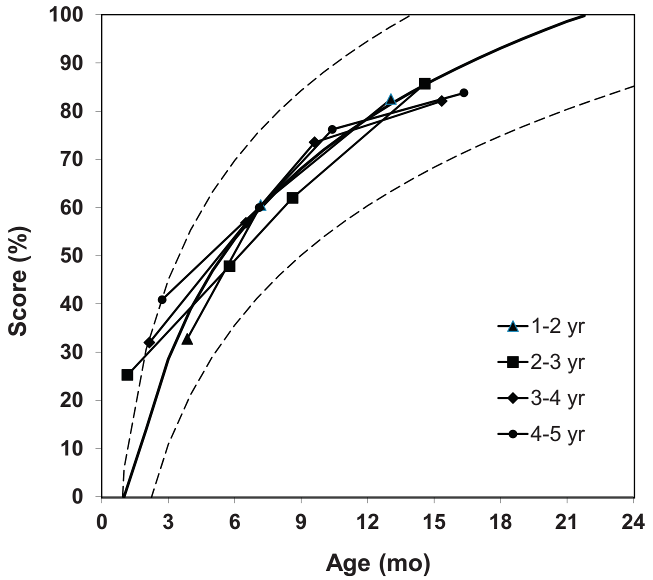


**Fig. 5.** Post-implant mean ITMAIS/MAIS trajectories for different ages at implantation, as shown in the figure legend, overlaid on the normative trajectory reported by Zheng et al. [1].

normative trajectory at the same normal equivalent age were high ($r^2 \geq 0.98$ for all post-implant trajectories). This analysis shows that the EPLAD trajectories after implantation are highly similar to the normative trajectory; although the initial baseline scores vary as a function of age at implantation. In other words, EPLAD follows a normal developmental trajectory over at least the first 12 months after implantation for children 1–5 years of age at the time of implantation.

This pattern of rapid auditory development after implantation can be compared with that prior to implantation seen in the between-subject comparisons of baseline scores. These scores increase from approximately 12% to 40%, a 28% improvement, between 12 and 54 months of age, a timespan of approximately 3.5 years. This 28% increase over 3.5 years prior to implantation contrasts markedly with improvements of 40–70% over 1 year after implantation.

### *3.3. Early speech perception: words*

Early speech perception of words was measured with either the LV-MESP or the MESP. At each evaluation interval an attempt was made to administer Category 2 of the MESP (Speech Pattern Perception). If the Category 2 words were in the vocabulary of the child or the child was able to learn the Category 2 words at the time of testing, the MESP was administered. If the child was unable to learn the Category 2 words, they were tested with the LV-MESP.

All testing at baseline (unaided or with a hearing aid) required the LV-MESP. Of the 32 subjects evaluated, almost half (46.9%) did not reach Category 1, Speech Sound Awareness. Most of the remaining subjects (37.5%) were able to reach this category, while approximately 15% reached one of the higher categories. At 3 and 6 months 25 and 24 subjects required the LV-MESP, and at 12 months 12 subjects required this test. At each interval more than half of these subjects reached only Category 1, but increasing numbers also were able to reach Category 4, Monosyllabic Word Perception.

Only 2 subjects were tested with the MESP at 3 months: 4 subjects at 6 months; and 21 subjects at 12 months. Over two-thirds of the subjects tested at 12 months reached Category 5, Consonant Perception, or Category 6, Tone Perception. Note that normally hearing children under the age of two years often cannot be tested with the MESP [9]. Thus, it is not unexpected that many CI recipients also could not be tested with the MESP during the first year after implantation.

Aided sound field thresholds at 12 months (average of 500, 1000, 2000, 4000 Hz) were less than 40 dB HL for 36 subjects and between 40 and 45 dB HL for two subjects. Test data were unavailable for one subject.

Both the LV-MESP and MESP results from the current study can be compared with the comparable results reported by Eisenberg et al. [4]. Table 3 summarizes these comparisons. This table, as well as several subsequent tables, summarizes the first year results from the current study in comparison with similar results from the CDaCI study, as reported by Eisenberg et al. [4]. For each study, the percentage of subjects in the sample who were tested with the specific outcome measure (low-verbal MESP in this case) is displayed, together with the average score obtained by these subjects. These data are reported at baseline, 6 months and 12 months. (Recall that 3-month data are not available for the CDaCI study.) Average scores were computed as weighted means using the category number as the score and the number of children reaching the category as the weight, divided by the total number of children tested at each interval.

**Table 3**
Comparison of Mandarin and English results for the low-verbal versions of the MESP from the current study and for the ESP, as reported by Eisenberg et al. [4]. The columns labeled "Percent" report the percent of subjects at each evaluation interval who could be evaluated with the low-verbal version of the MESP. The columns labeled "Average" report the average score obtained by those subjects.

| | Current study ($N=39$) | | Eisenberg et al. [4] ($N=42$) | |
|---|---|---|---|---|
| | Percent | Average | Percent | Average |
| Baseline | 43.6 | 1.6 | 23.8 | 1.7 |
| 6 months | 61.5 | 2.2 | 28.6 | 2.6 |
| 12 months | 30.8 | 2.3 | 47.6 | 2.8 |

The percentages of children evaluated with the LV-MESP at baseline and 6 months in the current study were approximately double the values reported by Eisenberg et al. [4]; although the average scores were quite similar. However, a smaller percentage of children in the current study were evaluated with the LV-MESP at 12 months than in the Eisenberg et al. study (30.8% vs. 47.6%), although, again, average scores were similar. The lower percentage of LV-MESP testing in the current study is, at least in part, a consequence of the related finding that a higher percentage of the current subjects could be tested with the MESP at 12 months.

Table 4 has the same layout and content as Table 3, except that it reports scores for MESP and ESP. The percent of children evaluated with the MESP at baseline was very small in both studies. At 6 months the percentages were also comparable; although the average score reported by Eisenberg et al. [4] (3.8) was slightly higher than the value in the current study (3.0). The largest differences between the two studies are seen in the results at 12 months. Almost twice as many subjects in the current study could be evaluated with the MESP (56.8% vs. 28.6%), and average

**Table 4**
Comparison of Mandarin and English results for the MESP from the current study and for the ESP, as reported by Eisenberg et al. [4]. See Table 3 caption for a description of the column headings.

| | Current study ($N=39$) | | Eisenberg et al. [4] ($N=42$) | |
|---|---|---|---|---|
| | Percent | Average | Percent | Average |
| Baseline | 0.0 | – | 2.4 | 3.0 |
| 6 months | 10.3 | 3.0 | 14.3 | 3.8 |
| 12 months | 53.8 | 4.8 | 28.6 | 3.9 |

**Table 5**
Distribution of MESP performance as a function of dialect exposure to Putonghua. The column labeled "Dialect Exposure" reports the percentage of time reported by parents and teachers that the child used Putonghua to communicate. The second and third columns report the number of children in each dialect exposure category reaching either Categories 1–3 or Categories 4–6 on the MESP. The final column reports the total number of children in each dialect exposure category.

| Dialect exposure | Categories 1–3 | Categories 4–6 | Total |
|---|---|---|---|
| >95% | 3 | 18 | 21 |
| 50–95% | 6 | 3 | 9 |
| <50% | 2 | 1 | 3 |
| Total | 11 | 22 | 33 |

scores were higher in the current study (4.8 vs. 3.9). Of the 21 subjects in the current study who were evaluated with the MESP, two-thirds reached either Category 5 or 6 at 12 months. The first four categories of the MESP and ESP are comparable, while Categories 5 and 6 of the MESP are more difficult [1,9,10]. These considerations suggest that direct comparisons of the 12-month average scores may be confounded by the lower ceiling on the ESP.

Analyses of the dialect exposure checklist completed for 33 of the 39 subjects indicate that the percent of time subjects were exposed to Putonghua, the standard Mandarin dialect used for the recorded MESP test materials, affected MESP performance. Dialect exposure was quantified by averaging the percentage of caregiver–child/child–caregiver Putonghua usage and the percentage of teacher–child/child–teacher Putonghua usage. These percentages were classified in three categories: extensive Putonghua usage (>95%), mostly Putonghua usage (50–95%), and mostly other dialect(s) (<50%). The distribution of MESP scores for each of these groups is summarized in Table 5. MESP scores are divided into two groups, Categories 1–3 and Categories 4–6. Categories 1–3 include word tests, while Categories 4–6 include more difficult minimal-pair segmental and tone tests. The distribution of MESP scores differed significantly, depending on the extent of Putonghua usage ($\chi = 0.009$, $p = .004$). Most subjects with extensive Putonghua usage reached the more difficult categories, while fewer than half of the remaining subjects reached these categories.

Pre- and post-implant hearing aid use can help to explain the performance differences between those subjects tested with the MESP within the first 12 months and those subjects who could only be tested with the LV-MESP. Fig. 6 displays the distribution of pre-implant hearing aid use, expressed in 6-month intervals, for the 12 subjects who could only be tested with the LV-MESP and for the 21 subjects who could be tested with the MESP. Of the subjects in the former group, 92% had less than 18 months of hearing aid experience and 75% had less than 12 months of experience. Of the subjects who could be tested with the MESP, 67% had more than 18 months of hearing aid experience. These differences in hearing aid experience were statistically significant, as determined from a $\chi^2$ test of independence ($p = .026$). Moreover, none of the subjects who were tested with the LV-MESP at 12 months used a hearing aid in combination with their CI, while 10 of the 21 subjects tested with the MESP at 12 months used a hearing aid on their unimplanted ear.

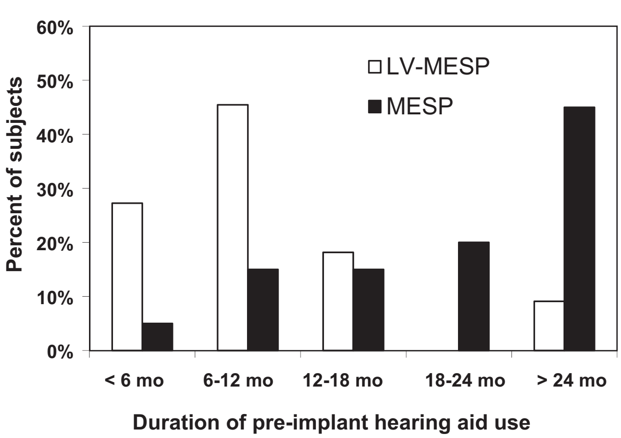


**Fig. 6.** Distribution of duration of hearing aid use for subjects who could only be tested with LV-MESP at 12 months and subjects who could be tested with MESP at 12 months. Duration of pre-implant hearing aid use is categorized in 6-month intervals ranging from less than 6 months to more than 24 months.

### 3.4. Early speech perception: sentences

Early speech perception of sentences was measured with the MPSI test [10]. Subjects were administered the MPSI test once they reached Category 3, Spondee Word Perception, on the MESP. The MPSI sentence lists were administered first in quiet, and then in the presence of a competing voice at successively more difficult signal/noise ratios (SNRs), beginning at +10 dB SNR and progressing in 5 dB steps to −10 dB SNR. Subjects only progressed to the next more difficult condition if their score was significantly above chance in the current condition, or greater than 41.7%.

Table 6 reports the percentage of subjects tested with the MPSI test in quiet at each evaluation interval together with their average score. The layout and content of the table are the same as Tables 3 and 4. Comparable data for the PSI test, as reported by Eisenberg et al. [4] for subjects in the CDaCI study, are also displayed. Since chance performance levels are different for the PSI (chance = 20%) and the MPSI test (chance = 16.7%), average scores are expressed as the difference between the raw score and the chance score. Although an average baseline score is reported for the CDaCI study, this average is not significantly above chance performance for the PSI test. (A score of 50% or greater is required to exceed chance performance with $p < .05$, based on the binomial theorem.) By 12 months approximately one-third of the subjects in both studies could be tested in quiet and obtained similar average scores.

Table 7 reports the percentage of subjects who were tested in noise with the MPSI test at 12 months together with their average score. Separate results are reported for signal/noise ratios (SNRs) of +10 dB, 0 dB, and −10 dB. Comparable data for the PSI test, as reported by Eisenberg et al. [4] for subjects in the CDaCI study, are

**Table 6**
Comparison of Mandarin and English results for the MPSI test in quiet from the current study and for the PSI test in quiet, as reported by Eisenberg et al. [4]. See Table 3 caption for a description of the column headings.

| | Current study ($N = 39$) | | Eisenberg et al. [4] ($N = 42$) | |
|---|---|---|---|---|
| | Percent | Average | Percent | Average |
| Baseline | 0.0 | – | 7.1 | 43% |
| 6 months | 10.3 | 33% | 11.9 | 66% |
| 12 months | 33.3.9 | 66% | 28.8 | 60% |

**Table 7**
Comparison of Mandarin and English results for the MPSI test in noise from the current study and for the PSI test in noise, as reported by Eisenberg et al. [4]. The first column labeled "SNR" reports the signal/noise ratio used to administer the test. See Table 3 caption for a description of the remaining column headings.

| SNR | Current study ($N = 39$) | | Eisenberg et al. [4] ($N = 42$) | |
|---|---|---|---|---|
| | Percent | Average | Percent | Average |
| +10 dB | 30.8 | 59% | 21.4 | 72% |
| 0 dB | 28.2 | 29% | 21.4 | 41% |
| −10 dB | 10.3 | 15% | 14.3 | 12% |

displayed as well. Again, differences between raw scores and chance scores are reported. Perhaps the most striking difference between the two studies is the percent of subjects who could be tested at 0 and positive SNRs. Approximately 60% of subjects in the current study could be tested in these conditions, while about 40% of subjects in the CDaCI study could be tested; although subjects in the comparison study obtained higher scores. Note also that the criteria for advancement to more difficult SNRs were stricter in the current study (41.7% or greater) than in the comparison study (20% or greater), making it more difficult for the current subjects to advance to more difficult SNRs.

## 4. Discussion

Observed outcomes within the first year after cochlear implantation fall into two categories, as seen both in the current study and in the first year results reported for the CdaCI (Eisenberg et al., 2008). The first outcome is related to EPLAD and provides evidence of the prelingual ability to respond meaningfully to sound, while the second outcome provides the first evidence of early speech perception. Evidence of early auditory development is more complete and detailed during the first year of implantation than evidence of early speech perception, which is only beginning to emerge at this time. Each of these outcomes is discussed separately below.

### *4.1. Evidence of early prelingual auditory development (EPLAD)*

Previous research with normally hearing children suggests that the pattern of early development over the first two years after birth may be universal (e.g., [1]). These findings make it possible to compare the current results for Mandarin-speaking children with both the normative developmental trajectory and with the results for English-speaking children reported by Eisenberg et al. [4]. Such comparisons reveal that the pattern of overall EPLAD is similar for Mandarin- and English-speaking children. Both groups exhibit initial post-implant average scores of 20–30%, which increase to about 80% over the first 12 months. These scores, reported as a function of post-implant interval, can be compared with the normative EPLAD trajectory, reported as a function of chronological age. When post-implant interval is used as the time scale for CI recipients and chronological age is used as the time scale for normally hearing children for such comparisons, the assumption is that CI recipients begin hearing at the time of implantation and normally hearing children begin hearing at birth.

The fact that initial post-implant scores were well above 0% in both samples suggests that some auditory development has occurred prior to implantation. Evidence of pre-implant auditory development is seen throughout the first 12 months. Overall EPLAD scores for Mandarin-speaking children were significantly above the normative trajectory at all post-implant intervals. Detection scores exhibited a similar pattern for Mandarin-speaking children; although performance at 12 months fell on the normative trajectory. The pattern of Recognition scores more closely resembled that of the Overall scores. Mean Recognition scores were also significantly above the normative trajectory at all post-implant intervals.

These findings indicate that the duration of time after implantation, often referred to as "hearing age," should not be equated with chronological age in normally hearing children, because the duration of even severely limited hearing ability can allow some auditory development to occur. The results summarized in Fig. 5 demonstrate this most clearly, showing overall EPLAD as a function of chronological age for groups of children falling in different age ranges at implantation. Children implanted at 1–2 years of age had initial scores of about 10%, while children implanted at 4–6 years of age had initial scores of about 40%. Recall that all of the children in the study wore hearing aids prior to implantation.

Thus, with hearing aid use auditory development increased at a rate of about 10% per year prior to implantation, and both age at implantation and duration of hearing aid use were significantly correlated with improvements in EPLAD. However, neither age at implantation nor duration of hearing aid use predicted the final level of EPLAD—all of the age at implantation groups reached approximately the same level at 12 months, approximately 80%. This value corresponds to the level of EPLAD seen in normally hearing children at 12 months of age.

The youngest implanted children exhibited the steepest trajectories after implantation. Evidence of the effects of implant age on EPLAD slope is most clearly seen when the trajectories for each age group are shifted into alignment with the normative trajectory using the difference between test age and the normal equivalent age corresponding to the obtained test score. The normative trajectory is steepest during the early months after birth, and levels off gradually during later months. Likewise, children implanted early experience rapid auditory development (steeper slopes), while children implanted later experience slower auditory development (shallower slopes).

To summarize, these findings have several clinical implications. First, auditory development can occur prior to implantation; although at a slower rate than after implantation. Use of hearing aids prior to implantation is recommended for this reason, as well as for many other well-established reasons. Second, equating post-implant duration, i.e., "hearing age," with chronological age in normally hearing children can be misleading because it fails to consider the occurrence of auditory development prior to implantation. Third, regardless of age at implantation, implant recipients are expected to reach EPLAD scores of 80% on average within 12 months after implantation, which is comparable to that of a 12-month old normally hearing child. Finally, measures such as ITMAIS/MAIS, provide a useful means of assessing early auditory development within the first months after implantation. Measures obtained from CI recipients can be compared with the expected EPLAD trajectory to monitor early progress.

The use of structured parent interviews, such as ITMAIS/MAIS, to monitor early auditory development after implantation provides an important practical alternative to behavioral aided threshold measures in those regions of world where pediatric audiology resources are limited or non-existent. Evidence from the current research can be used to define objective milestones and expectations for clinical management of pediatric CI recipients during the first year after implantation.

### *4.2. Evidence of early speech perception*

Use of a hierarchical battery of tests allowed the results from the current study to be compared the results from the large multicenter CDaCI study conducted in the United States over the last several years [4,5]. The current study used (intentionally) similar methods of hierarchical assessment to evaluate early speech perception, beginning with low-verbal closed set recognition of simple common words, and progressing to closed-set recognition of short sentences in the presence of a competing voice at different SNRs. Given this method of assessment, the most appropriate interpretation of the current results was made by comparing the numbers of children in each study reaching each level in the hierarchy and the average scores obtained at each level. Early speech perception scores cannot be compared to universal norms, as with early auditory development, because such norms do not exist across languages. However, each of the tests in the hierarchical battery has been designed to parallel as closely as possible the tests used in the CDaCI study, providing a basis for direct comparisons.

The first measures of early speech perception are the low verbal versions of the MESP and ESP. Recall that these measures were administered only if the child was unable to be tested with the Category 2 (Speech Pattern Recognition) materials in the standard version of the tests. A larger percentage of the subjects in the current study needed to be tested in this manner at baseline and 6 months than in the CDaCI study; although average scores at each test interval were about the same in both studies. At 12 months 30.8% of the subjects in the current study were evaluated with the low verbal test, as compared to 47.6% in the CDaCI study. Again, average scores were similar in both studies. The percentage of subjects tested with LV-MESP in the current study decreased as the duration of the post-implant interval increased. The same percentage increased over post-implant test intervals in the CDaCI study.

The LV-MESP results, like the EPLAD results, demonstrate the importance of hearing aid use both before and after implantation. The vast majority of children who required testing with the LV-MESP at 12 months had limited hearing aid use before implantation: 75% had less than 12 months of use before implantation and 92% had less than 18 months. Moreover, none of these children used a hearing aid in combination with their CI at the 12-month test. This pattern of hearing aid use contrasts markedly with that of children who could be tested with the MESP at 12 months: two-thirds of these subjects had more than 18 months of hearing aid use before implantation, and almost half used a hearing with their CI at the 12-month test. Thus, the benefits of pre-implant hearing aid use during the first 12 months after implantation are seen both in the measures of early auditory development and in the earliest measures of speech perception.

The current MESP results compare favorably with the ESP results from the CDaCI study. Baseline and 6-month performance were similar across studies, both in terms of the percentage of subjects who could be tested and their average Category scores. Scores at 12 months were higher in the current study by approximately one category, and almost twice the number of subjects was tested with the MESP than with the ESP. The difference in average scores is likely due to the lower ceiling on the ESP.

The final measures of early speech perception that can be compared across the two studies are the Mandarin and English versions of the PSI. Performance in quiet was comparable across evaluation intervals; although more children could be tested at baseline and 6 months in the CDaCI study than in the current study. Performance in noise, as determined by the most difficult SNR at which the child could be tested, varied slightly across the two studies; however, no consistent pattern of differences was evident.

The early speech perception results, like the early auditory development results, have several clinical implications. First, the positive impact of both pre- and post-implant hearing aid use is evident in the early speech perception results, as it was in the early auditory development results. Again, this is yet another reason to include hearing aids as an integral part of early intervention protocols. Second, about half the children (43.6–61.5%) required evaluation with the LV-MESP before reaching 12 months, while only about 10% could be evaluated with the MESP during this time. This suggests that the LV-MESP could be used directly before 12 months, without first attempting a Category 2 MESP test, as an efficient means of evaluation early speech perception before 12 months. Third, and perhaps most important, the results from the current study exhibit many important similarities when compared with the CDaCI study in the United States. These similarities imply that the initial objective results after early intervention with CIs are comparable across two diverse cultural environments and languages, one tonal (Mandarin) and the other non-tonal (English). Such similarities also imply that future research findings and treatment advances, regardless of their origin, may be applicable to other diverse environments and languages. This is a promising finding that can lead to more rapid establishment of best practices throughout the world for early objective outcome assessment. These initial findings are, however, limited to the first 12 months after implantation. Additional longitudinal research that documents the ongoing development of speech and language in diverse cultural and linguistic environments is needed as well.

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