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Describing the trajectory of language development in the presence of severe to profound hearing loss: A closer look at children with cochlear implants versus hearing aids

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INTRODUCTION

Cochlear implantation has become a common recommendation for parents of children with severe to profound hearing loss. This surgical intervention has numerous reported benefits including improved speech and language skills as well as higher academic achievement.[1–3] In fact, there is evidence that some children receiving cochlear implants before 24 months have attained some aspects of language comparable to their normal hearing peers, but we currently have no indication that implantation between 6 and 12 months results in significantly better language development than those implanted between 12 and 24 months of age.[4–7] Regardless of early implantation, this population of children maintains a substantial amount of variability in language outcomes.[8] Some known predictors of language outcomes include parent level of education and non-verbal cognitive development.[9] The socio-economic levels of many families in cochlear implant research articles are often quite high with a typical average of college education or above (16 years or greater) which may contribute to an upward bias in outcomes or an indication of how family characteristics may relate to treatment choices.

Advances in CI technology and surgical procedures have closely coincided with early intervention initiatives and advances in hearing aid technology as well. In this technological age, it should be noted that many families still choose hearing aids rather than implantation for their child with severe or profound hearing loss. As such, this paper aims to compare the language developmental trends as well as the background characteristics of children with hearing aids (HA) and children with cochlear implants (CI) with severe to profound hearing loss under the establishment of universal newborn screening in the state of Colorado.

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Colorado Population of Children with Hearing Loss

Because universal newborn hearing screening was established early in the state of Colorado (beginning in 1992), by 1997 a vast proportion of the population were being screened for hearing. The age of identification of hearing loss dropped to within the first few months of life. Consistent with these changes in age of identification, a majority of Colorado infants and toddlers began receiving cochlear implants between 12 and 18 months of age as early as the year 2000. Thus, implantation after 2 years of age became a rare occurrence unless the child had an acquired hearing loss or a child who had not been screened for hearing in the newborn period.

One aspect of our study population that is unusual compared to other states is that Colorado represents a state-wide population with children who have been implanted in various programs. At the time of data collection for the current study, there were seven cochlear implant programs in the state, three of the seven programs implanted the majority of the children in the Denver metropolitan area but some of the children were implanted in other areas of the state. The parents of these children chose to enroll their children in the Colorado Home Intervention Program, a public program that provides early intervention services to over 90% of the children identified with hearing loss from birth through three years of age. In addition, almost all children who received cochlear implants also received services through a clinic-based program after implantation and were seen by speech/language pathologists who were certified auditory verbal specialists or auditory-oral specialists with extensive experience.

It is not uncommon for Colorado families to participate in sign language instruction. Over 80 percent of the families in our data source engage in sign language instruction from an individual who was deaf or hard of hearing and native or fluent in American Sign Language. This instruction is generally once a week in addition to their regular early intervention home visits. As a result, prior to the cochlear implantation, many of these children have language skills within the normal range, but frequently their receptive and expressive language is through sign language.

After the implantation, families often receive one home visit, one clinic-based therapy session, and one sign language instruction home visit. Because of the young age of the children, few participate in group sessions before 2.5 years of age. Beginning at 3 years, the home intervention services are discontinued and the child is transitioned to the local educational unit. The vast majority of these children enroll in center-based preschools for children who are deaf or hard of hearing. Some of these programs have hearing peers, but not all of them, and typically, these programs implement a half-day curriculum.

The population from which our sample was drawn is predominately represented with children who were identified with hearing loss as a result of universal newborn hearing screening. The intervention received by the families and children has been relatively consistent and began with services from the Colorado Home Intervention Program. There were no children in our cohort who were implanted before 12 months of age, but nearly all were implanted by 36 months.

Research Questions

The objective of this investigation was to describe the language growth trajectories in children with severe or profound hearing loss with cochlear implants versus those children with the same degree of hearing loss using hearing aids. We specifically addressed the following research questions: (1) Are there systematic differences in the language growth of children with severe to profound hearing loss who received a cochlear implant versus children who used hearing aids, and (2) Do these two groups of children differ in terms of their background characteristics?

MATERIALS AND METHODS

Participants

The study sample included all children with permanent bilateral childhood hearing impairment of at least 56 dB HL who participated in a longitudinal developmental outcome study through the University of Colorado at Boulder. Repeated measures (see outcome measures below) of expressive and receptive language were summarized for each child from 4 to 7 years of age. Developmental data from the infant toddler period was also available for a subset of children in this cohort. For this subsample, we were able to describe elements of language growth from infancy to seven years of age.

The longitudinal data source from which our sample was drawn represents 65 to 70% of all children born between 1997 to 2004 with normal cognitive abilities in the state of Colorado with bilateral hearing loss. The database was established by recruiting children who met the following inclusion criteria: (a) one or more early intervention assessments on file, (b) normal hearing parents, (c) English had to be the primary home language, (d) hearing loss had to be a bilateral sensory impairment rather than a unilateral or auditory neuropathy classification, (e) no other significant disabilities, and (f) they had to be residents of the state of Colorado. Approximately 90% of families contacted participated in this follow-up project, and a longitudinal database for preschool children with hearing loss was successfully created and maintained.

Language Outcome Measures

The language outcome measures in this investigation included the Test of Auditory Comprehension of Language – 3rd Edition (TACL-3), Expressive One Word Picture Vocabulary Test-3rd Edition (EOWPVT-3), and the Expressive Language subscale of the Minnesota Child Development Inventory (MCDI-EL).[10–12] These instruments were chosen because they maintain a high level of reliability and validity over time, they have been extensively standardized on typically developing children with normal hearing, and because all of these measures have been successfully applied hard of hearing children and sign language users. [2,13,14, 22, 23] The age equivalent score was the metric we used for all analyses and to plot individual developmental trajectories. The use of a norm-based metric is advantageous because it allows the comparison of results for children with hearing loss with their normal hearing peers. It is also fundamentally straightforward to understand and interpret.

Additional Variables

In addition to the language outcome measures described in the previous section, this investigation also summarized and compared several background characteristics for both groups. We were particularly interested in individual characteristics that have previously been associated with language outcomes in deaf and hard of hearing children such as their age of identification and intervention, degree of hearing loss, and non-verbal cognitive ability. The child’s year of birth was included in order to identify any temporal relationships with the introduction to universal newborn hearing screening, and we also included family characteristics such as ethnicity and maternal level of education.

Statistical Analysis

We used a two level descriptive analysis of the longitudinal data to evaluate and compare background characteristic as well as the language outcomes of the two groups of children with severe to profound hearing loss. The analytical approach was threefold. First, we compared the distribution of background characteristics across the CI and HA groups. Next, we fit individual linear growth curves for both preschool measures using ordinary least squares regression. Obtaining individual parameter estimates allowed us to compare intercept (language status) and slope (rate of growth) values for both groups. Finally, we identified everyone in our sample with data in the infant toddler period. For this subgroup, we were able to establish performance categories which were defined by comparing the child's language status at 36 months on the MCDI with their outcomes on the two preschool measures. These performance categories where used to further evaluate similarities and differences between the CI and HA groups. Table 1 outlines the details of the analysis we used to address our research questions.

RESULTS

This data set was time structured with four assessment occasions that took place within two months of the child's birthday. Data collection schedules occurred between the ages of 45 to 87 months. However, not all children were represented at all time points. The presence of incomplete data was primarily a result of children who have not graduated from the study period at the time the analysis was conducted or who started the study when they were five years of age or older.

Sample Characteristics

We identified 87 children with severe, profound, or progressive hearing loss in our preschool database. Thirty-eight were hearing aid users and 49 were cochlear implant recipients. The age of activation for the CI recipients ranged from 12 to 75 months with 69.4% of the sample receiving the implant in the first three years of life. The median age of activation was 30.5 months.

The CI and HA groups were balanced in terms of age of intervention, year of birth, ethnicity, and non-verbal cognitive ability. However, we identified differences between groups in their age of identification and maternal level of education. Specifically, there was a higher percentage of children in the HA group who were identified with hearing loss before 6 months of age (68.4% versus 55.1%), and in terms of maternal level of education, there was a higher percentage of children in the CI group with education levels beyond 16 years. Table 2 provides the frequency distribution for both groups across each background characteristic.

Individual Language Trajectories

There was a large amount of variability observed for both preschool language measures at each age level. In other words, children scored above and below age expectations at each measurement occasion. All subjects demonstrated an increase in their developmental age scores over time. As a group, children with hearing aids deviated more from the age equivalent trajectory on the TACL-3 and EOWPVT-3 than children with cochlear implants. Figure 1 and 2 are the empirical scatterplots of developmental age as a function of chronological age for both language measures. These figures have a fitted group trajectory in dark grey and an age equivalent reference line in black.

Intercept and slope estimates were also calculated for every child with three or more measurement occasions which included 24 and 34 children in the HA and CI groups, respectively. On average both groups demonstrated a rate of language growth that exceeded the age equivalent value of 1 for both instruments. The model estimates also showed that CI group had language scores that were 6 months higher than the HA group on the

EOWPVT-3. Table 3 summarizes the mean parameter estimates for both language instruments across groups.

Language Performance Categories

There were 56 children identified in our sample who also had longitudinal expressive language data in the infant/toddler period. Twenty-three were in the HA group and 33 were in the CI group and their language age at 36 months was 26 and 29 months, respectively. This information was used in conjunction with the preschool data to describe children according to the following performance categories: Gap Closers, Age Equivalent, Gap Openers and Delayed. For category specifications see Table 1. We found that there were more Gap Closers and fewer Gap Openers in the CI group compared to the HA group in terms of both the TACL-3 and EOWPVT-3. Figure 3 and 4 provide a breakdown of the sample for these specific performance categories for the TACL-3 and EOWPVT-3, in that order. Table 4 summarizes the distribution of children with hearing aids versus cochlear implants by number and percentage for this subsample with data from birth to 84 months.

DISCUSSION

The Colorado children with severe to profound bilateral permanent hearing loss and normal non-verbal cognitive development were evaluated longitudinally with two language tests. One was a measure of expressive vocabulary and the other measuring receptive understanding of English grammar and syntax. Their average language estimates at 84 months of age were nearly identical to the test's normal hearing sample for receptive language and seven months delayed for expressive vocabulary. Additionally, these children demonstrated a mean rate of growth from 4 years through 7 years on these two assessments which were equivalent to an age equivalent trajectory or better, at or above 1.0.

A significantly lower mean score at 84 months of age on the Expressive One Word Picture Vocabulary test was found for children with predominantly severe hearing loss using hearing aids as compared to children with cochlear implants. Therefore, a more in-depth analysis of the data were required in an attempt to explain this finding. The primary difference between the hearing aid and the cochlear implant groups were in a small percentage of children, those who were called "gap openers" and "gap closers". Children with cochlear implants were more likely to be "gap closers" and less likely to be "gap openers", while the reverse was true for the children with hearing aids. It may be that this small group of children with hearing aids might have benefited from a cochlear implant. However, with "gap openers", these children were functioning at age level in the birth through 48 month period and the gap only began to emerge after four years of age. In other words, only 3% of the children with CIs as compared to 17.4% of the children with HAs were "gap openers" on the EOWPVT-3. However, 21% of the children with CIs as compared to 8.7% of the children with HAs were "gap closers", not quite three times as many, but approaching that difference.

There was also a slightly higher percentage of children in the HA group below the 10th percentile on the TACL-3 (8% vs 4%) and EOWPVT-3 (18% vs 16%). The percentage of children in the HA group performing below the 10th percentile on the expressive vocabulary test was approaching three times the number anticipated given the variability observed in the sample from which the instrument was normed.

Parents and therapists are frequently optimistic that children will close developmental gaps. This longitudinal study indicates that most children with severe to profound hearing loss, about 8 out of 10, maintain their rate of developmental growth regardless of implantation. Therefore, any gaps in development that are present at 48 months of age will likely persist

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into the early school years, and only 1 to 2 out of 10 are expected to close these developmental gaps by 7 years.

Additionally, the characteristics of the “gap closers” are quite interesting. About 55% have mothers whose educational level is at a college degree or greater. There were no children in this performance category with maternal education levels below high school. We also found that “gap closers” tended to have either severe or progressive hearing loss designations. One aspect we also considered in terms of performance was the role of bilateral implantation. There were 8 children in the CI group that received a second implant within the time frame of data collection but only one of these children was considered a gap closer, 3 maintained the age equivalent, and 4 were in the delayed group. The time difference between the first and second activation was 40 months which reduces the ability for this particular study to effectively detect the role of bilateral implantation.

It is appears that acceleration of language development is possible and could result from cochlear implantation (approximately 20% of the population), but it is more likely for children with better hearing pre-implantation (severe and progressive hearing losses) and mothers with higher levels of education (sixteen years or greater). These results are consistent with previous research findings. Geers reported good language and speech benefits for children who have progressive or acquired hearing loss and Tomlin et al found that children with CIs had better expressive language development the earlier they were implanted with the youngest children between 10–15 months of age.[(2,3)] Age of implantation accounted for 14.6% of the variance in expressive language growth as measured by the Minnesota Child Development Inventory and Preschool Language Scale. Connor et al also reported that children implanted before the age of 2.5 had significantly faster language growth rates in vocabulary and speech production.[(8)]

Recent publications evaluating receptive syntax and grammar understanding have yielded very different results from our current study. Recall that the receptive syntax and grammar understanding scores of the Colorado children were very similar to the norms of the test by both age scores at 84 months and rate of language development from 4 to 7 years. Duchesne, Sutton & Bergeron studied 27 French-speaking children who had undergone cochlear implantation between one and two years of age.[(24)] Although the standardized tests were given in the French normed versions, the EOWPVT-3 and TACL-3 are considered earlier versions of the same tests. Of these 27 children, 14 of them were old enough to be tested between 5 and 8 years of age. Seven of the 14 children had EOWPVT scores at or above the 50th percentile and only 3 children were below the 15th percentile on this test. Nine of the 14 children had word comprehension scores at or above the 50th percentile. There were also differences for the comprehension of spoken syntax and grammar. Nine of the 14 children were below the 15th percentile on the Elaborated Sentences subscale. Seven of the 14 children were below the 15th percentile on the Grammar and Morphology subscale. Seven of the 14 children were below the 15th percentile on the Receptive Vocabulary Test.

In summary, the results of this longitudinal study describes the population outcomes of children with hearing loss in a state system with an accountability and tracking system and a state-wide early intervention system. This analysis represents two of several developmental instruments that were used to assess the communication skills of these children. The Colorado statistics lead to several conclusions. Children who are educated through oral-aural combined with sign language instruction can, as a population, achieve age appropriate language levels on expressive vocabulary and receptive syntax ages 4 through 7 years. This language development is possible when most of the children are implanted from 12 months of age to 24 months of age. Language development is easier to maintain than to accelerate from birth through 84 months of age, which represented approximately 80% of our sample.

In subsequent articles we do not intend to define children whose language scores are within one standard deviation of the mean of typically developing children as delayed, though they are below age equivalency. They were given that descriptor for the purposes of this analysis only. Future articles will report the auditory skills, speech production, expressive syntax and other developmental areas including social skills.

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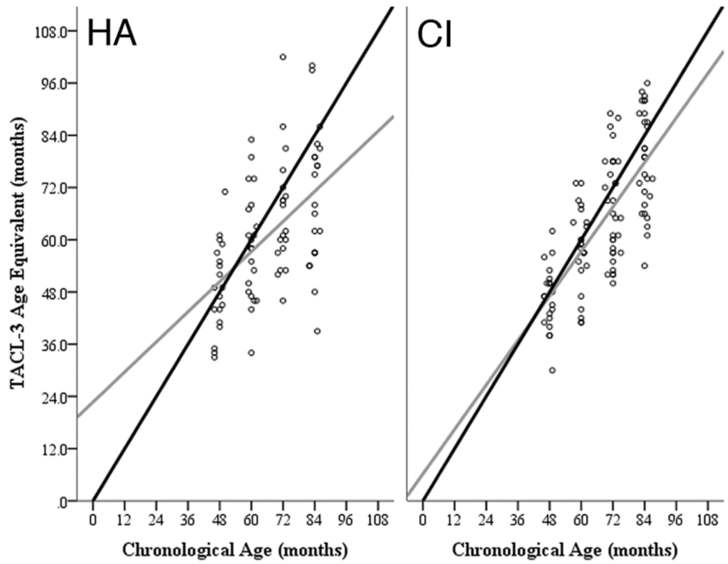

Figure 1.

Scatterplot of chronological age (in months) plotted against the TACL-3 age equivalent score. The right figure represents children with cochlear implants and the left figure represents children with hearing aids. The black reference line is the age equivalent line with a slope of 1 and the grey line is a group fitted trajectory.

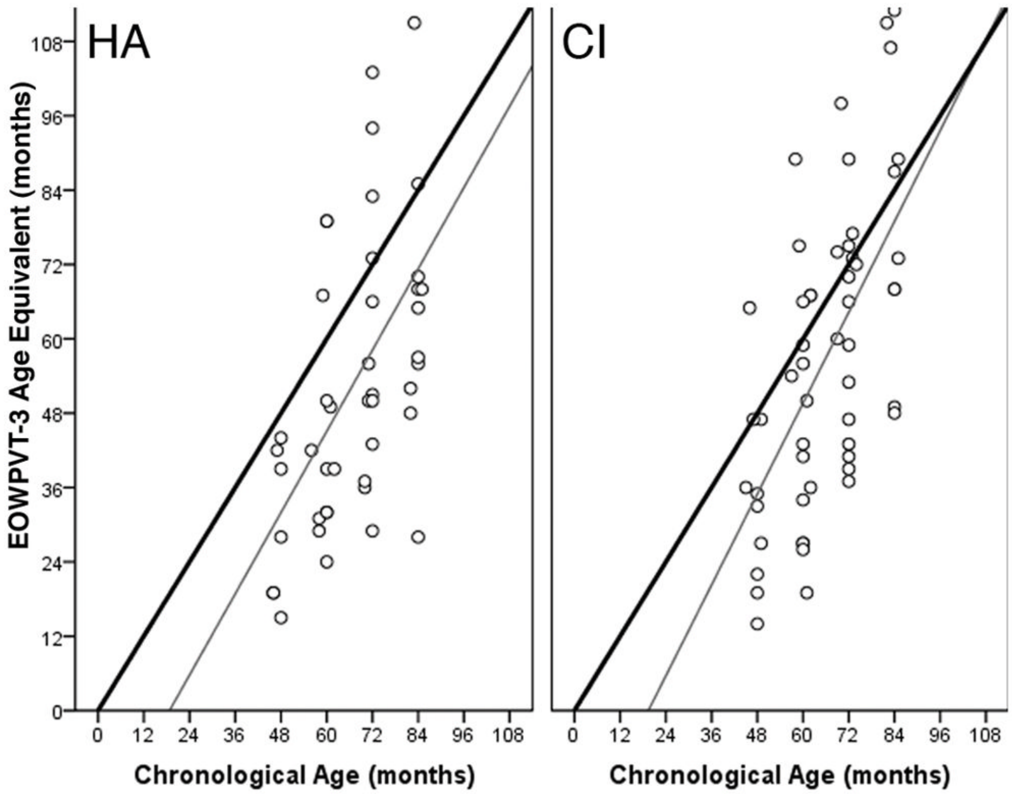

Figure 2.
Scatterplot of chronological age (in months) plotted against the EOWPVT-3 age equivalent score. The right figure represents children with cochlear implants and the left figure represents children with hearing aids. The black reference line is the age equivalent line with a slope of 1 and the grey line is a group fitted trajectory.

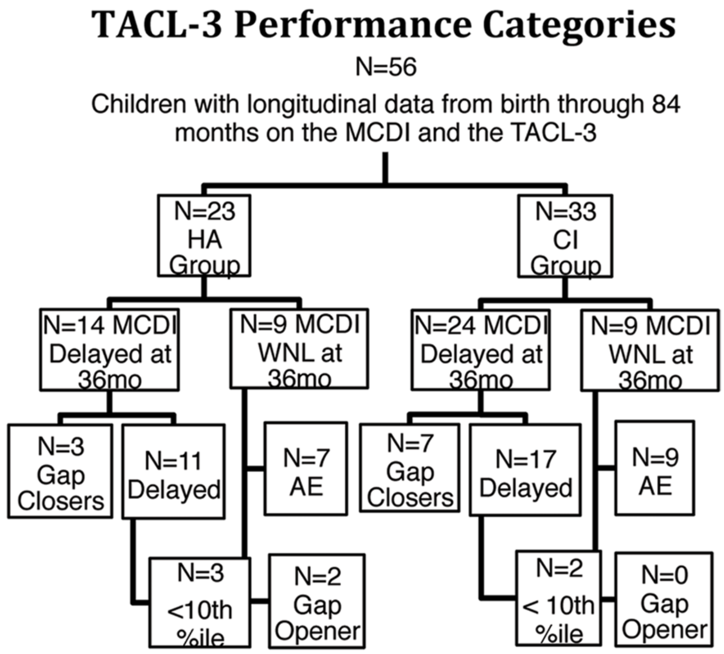

Figure 3.

Language performance flowchart for a subset of children with longitudinal data from birth to 84 months on the MCDI and TACL-3. AE represents the Age Equivalent category and WNL corresponds to language scores that are within normal limits.

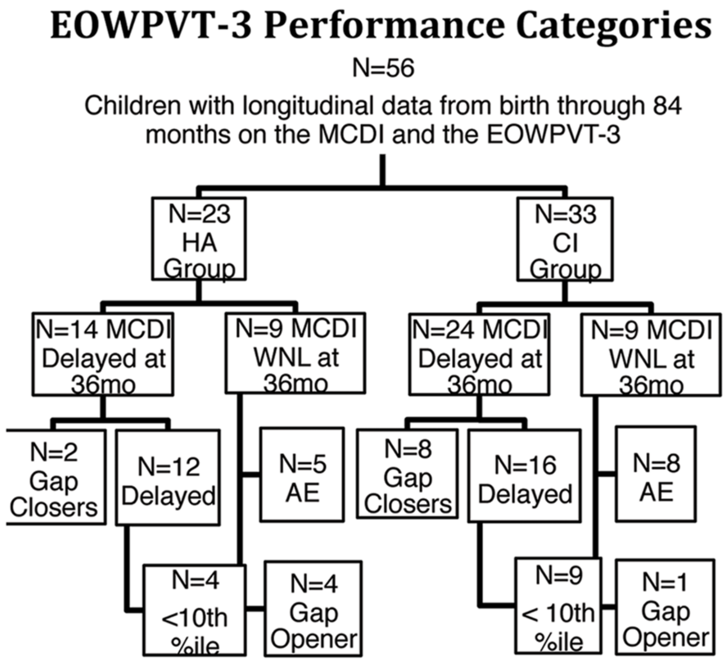

Figure 4.

Language performance flowchart for a subset of children with longitudinal data from birth to 84 months on the MCDI and EOWPVT-3. AE represents the Age Equivalent category and WNL corresponds to language scores that are within normal limits.

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Table 1

Descriptive Analysis Outline

	Description	Purpose
Part 1:	Cross tabulations were used to determine the number of children across each characteristic for both groups.	To determine similarities and differences in background characteristics across the CI and HA groups
Part 2:	Individual linear trajectories were fitted for both the TACL-3 and EOWPVT-3 and compared across groups.	To determine a common function to describe language growth in order to compare growth curves between CI and HA groups.
Part 3:	Outcome scores on the MCDI-EL along with the individual parameters calculated in Part II were used to classify the sample into four different performance categories.*	To facilitate the interpretation of language development from the infant/toddler period through the preschool period across the CI and HA groups.

*The performance categories were defined as follows: (1) *Gap Closers* were children with a borderline to delayed language status in the infant period and age equivalent estimates by 84 months; (2) *Age Equivalent* category represented children who had language estimates within normal limits at 36 months and maintained age equivalent values at 84 months; (3) *Gap Openers* were children with normal language estimates in the infant period who were below the age equivalent at 84 months; and (4) *Delayed* category included children with borderline to delayed language estimates in the infant period who were below the age equivalent at 84 months.

Table 2

The distribution of background characteristics for children with hearing aids (HA Group) versus cochlear implants (CI Group).

Child Characteristic	HA Group		CI Group	
	n	**%**	***n***	**%**
Age ID				
<= 6 months	26	68.4	27	55.1
> 6 months	12	31.6	22	44.9
Age Intervention				
<= 12 months	24	63.2	29	59.2
13–24 months	8	21.1	16	32.6
>24 months	6	15.7	4	8.2
Non-verbal CQ				
< 70	2	5.3	2	4.1
>= 70	36	94.7	44	89.8
Maternal Education				
<12 years	2	5.3	4	8.2
=12 years	17	44.7	13	26.5
13–15 years	5	13.2	9	18.4
>=16 years	14	36.8	23	46.9
Ethnicity				
Caucasian	29	76.3	30	61.2
Hispanic	7	18.4	10	20.4
Other	2	5.3	9	18.4
Year of Birth				
1992–1997	3	7.9	1	2.0
1998–2004	35	92.1	48	98.0

Table 3

Mean comparisons of the linear parameter estimates for children with hearing aids and children with cochlear implants

	TACL-3		EOWPVT-3	
	CI	HA	CI	HA
Intercept*	81	83.5	80	74
Slope**	1.04	1.08	1.33	1.15

*The intercept is defined as the language age score at 86 months for the TACL-3 or EOWPVT-3.

**The slope is defined as the rate of language growth between 48 and 84 months where a value of 1 represents typical development.

Table 4

Distribution of children with hearing aids versus cochlear implants by number and percentage for each performance category for the TACL-3 and EOWPVT-3.

	TACL-3		EOWPVT-3	
	CI	HA	CI	HA
Total Gap Closer	7 (21%)	3 (13%)	8 (24%)	2 (9%)
Age Equivalent	9 (27%)	7 (30%)	8 (24%)	5 (22%)
Gap Opener	0 (0%)	2 (9%)	1 (3%)	4 (17%)
Delayed	17 (52%)	11 (48%)	16 (49%)	12 (52%)
Total	33	23	33	23