ARTICLE

Developmental, Audiological, and Speech Perception Functioning in Children After Cochlear Implant Surgery

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Objectives: To examine changes in audiological, speech perception, and developmental functioning subsequent to cochlear implantation in children with severe to profound hearing impairment, and to identify factors related to those changes.

Design: Prospective, longitudinal analysis to compare functioning of pediatric patients who underwent cochlear implantation before and 1 year after surgery.

Setting: Outpatient pediatric cochlear implantation program in an academic institution (The Listening Center, The Johns Hopkins University School of Medicine, Baltimore, Md).

Patients: Forty consecutive pediatric patients between 1½ and 9 years of age who received a cochlear implant between April 1, 1996, and August 31, 1998, and who also underwent psychological, audiological, and speech perception evaluations immediately before and 1 year after implantation.

Main Outcome Measure: Scores on the Bayley Scales of Infant Development–Second Edition, Stanford-Binet Intelligence Scale–Fourth Edition, Developmental Profile II, Child Behavior Checklist, speech perception categories, and audiological pure-tone thresholds.

Results: Mean (SD) duration of hearing impairment was 37.78 (27.94) months, mean (SD) age at surgery was 50.72 (27.66) months. Significant improvements were found 1 year after surgery in audiological, speech perception, and developmental functioning, but not in nonverbal intelligence or behavior. Greater benefits in audiological and developmental functioning were associated with younger age (<48 months) at implantation.

Conclusions: Patients showed significant improvement in audiological status, overall developmental functioning, and speech perception skills in a short time after surgery. Greatest improvement in speech perception was for children with the least initial impairment, and greatest developmental gains were associated with young age at implantation.

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SEVERE TO PROFOUND hearing losses that are congenital or acquired before development of language are estimated to occur in 0.5 to 3 per 1000 live births.[1,2] Such hearing impairment is often associated with early delays in language development and socialization skills, and later with lower academic achievement.[3-5] Behavioral and attention problems are also more common in children who have severe to profound hearing impairment.[6-9] Although these developmental and behavioral problems are often less severe in children who have deaf parents, where there is a shared, manual communication system,[10] about 90% of children with congenital severe or profound hearing loss are born to hearing parents.[11]

Children with bilateral severe to profound hearing impairment that is sensorineural (not responsive to hearing aids) may be candidates for cochlear implantation, a surgical intervention in which a device implanted near the cochlea sends signals directly to the auditory nerve, enabling the detection of environmental and voiced sounds. The primary role of cochlear implants is to enable speech perception[12] and most children receiving them have shown speech perception gains,[13] although the degree of improvement varies widely and skills develop at individual rates with increasing experience in using the device.[12,14,15] Children with prelingual hearing impairment, in particular, might not show measurable changes in speech perception abilities before 2 to 3 years of experience with the cochlear implant.[16] Improvements in speech perception are often accompanied by gains in other important skills, particularly oral language development.[17,18]

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Behavioral and social benefits have been associated with cochlear implantation, together with related improvements in cognitive skills. Studies have reported improved behavior and visual attention after cochlear implantation,[19-21] as well as significant improvements in nonverbal IQ and visuomotor functioning that were attributed to reduced distractibility and increased attention span.[22] Better interpersonal skills such as increased eye contact, better vocal turn-taking, and decreased gesturing have been seen in children 1 year after receiving an implant.[23,24]

Given the role of cochlear implants in facilitating speech perception, it is natural to assume that postimplantation psychosocial and speech perception improvements are fundamentally linked. Improvements in speech perception could increase receptive and expressive language skills, resulting in better social skills, communication skills, and overall school performance.[8] Related spoken language improvements also have the clear potential to generate positive ripple effects on social and psychological functioning.[25] However, to our knowledge, the necessary relationship between speech perception and psychosocial functioning has not been tested.

The factors influencing psychosocial outcome of cochlear implantation in children have been little studied. However, it is known that success in terms of speech perception and language production is greatest in individuals who received cochlear implants at an early age[14,16,18,26]; who had a short duration of profound deafness; and, at least in adults who became deaf after language acquisition, who have a high IQ.[27] Other important factors include age when deafness occurred, optimal device placement, and oral training methods.[28] Observations of better language outcome for earlier implantation are consistent with neurological evidence of critical periods when the developing central nervous system can most readily use auditory sensory information to form linguistic processing structures.[29,30] Analogous critical periods probably exist for developmental functioning, but the importance of age at implantation on developmental functioning has not yet been studied.

The present investigation is an ongoing prospective, longitudinal study that seeks to determine the changes in audiological, speech perception, and developmental functioning at 1 year subsequent to cochlear implantation in a sample of children who have severe to profound hearing impairment, and to identify possible factors related to those changes. Based on the preceding discussion, the following hypotheses are proposed:

1. Cochlear implantation should result in improved audiological and speech perception abilities at follow-up, although these improvements may not be closely correlated.

2. Cochlear implantation should result in improvements in developmental functioning, especially in areas closely related to language abilities, such as communication, social, and academic functioning.

3. Greater improvements in both speech perception and developmental functioning should be seen with younger age at diagnosis, earlier age at implantation, shorter duration of hearing impairment, longer experience using the cochlear implant, and higher preimplantation intellectual functioning.

4. Changes in developmental functioning and behavior should be related to changes in audiological status and speech perception.

METHODS

SUBJECTS

Subjects were 40 consecutive pediatric patients who received a cochlear implant at The Listening Center, The Johns Hopkins Hospital, Baltimore, Md, between April 1, 1996, and August 31, 1998. All cochlear implantation candidates at The Listening Center are routinely given a hearing aid trial for at least several months; surgery is considered only for those who experience no significant benefit from the trial. Generally, candidates have sensorineural hearing loss deemed severe (speech reception thresholds of 75-90 dB) or profound (speech reception thresholds of >91 dB), despite the use of well-fit, powerful hearing aids. More importantly, however, candidacy was considered for those in whom binaural amplification failed to promote age-appropriate communication behaviors in infancy or language acquisition in later childhood. To meet test age requirements, study subjects were restricted to patients between 1½ and 9 years old at the time of the preimplantation evaluation. All subjects had hearing parents. This study was approved by the institutional review board at The Johns Hopkins University School of Medicine.

PROCEDURES

All patients at The Listening Center undergo audiological, speech perception, and psychological evaluations both immediately before and about 1 year after cochlear implantation. The preoperative psychological evaluation is conducted with hearing aids in place.

MEASURES

Audiological Functioning

Thresholds for hearing were determined based on behavioral responses. Visual-reinforced (head turning) or play-audiometry procedures were used, as appropriate for the subject's developmental stage. Stimuli were presented as warble tones in a sound field in a sound-treated booth. Preimplantation hearing was assessed both with and without binaural amplification. After cochlear implantation, thresholds were determined with the speech processor at "user settings"—those providing a functional, comfortable listening level.

Speech Perception

Speech perception ability was assessed with a variety of measures designed to assess language level across early childhood stages. These included parental surveys and age-appropriate tests of speech perception presented with live voice.[2,28] Test results were converted, according to procedures described elsewhere,[4,28] to a speech perception category score ranging from 1 (the lowest level of simple detection) to 6 (consistent open-set recognition, for which the listener verbally responds accurately to a question without first being presented with possible responses).

Table 1. Subject Characteristics of 40 Subjects With Severe to Profound Hearing Impairments

Variable	Mean (SD)	Range
Age at initial diagnosis, mo	13.80 (10.77)	1-60
Age at first use of hearing aids, mo	16.95 (11.71)	2-67
Age at cochlear implant surgery, mo	50.72 (27.66)	18-103
Duration of hearing impairment, mo	37.78 (27.94)	5-100
Age at preoperative evaluation, mo	48.70 (27.76)	18-105
Age at postoperative evaluation, mo	63.04 (27.76)	30-117
Interval between surgery and postoperative evaluation, mo	14.46 (3.17)	12-24

Psychological Measures

Nonverbal Cognitive Functioning. Nonverbal cognitive functioning was assessed using a subset of the Stanford-Binet Intelligence Scale–Fourth Edition[31] or, in subjects younger than 2 years, a subset of the Bayley Scales of Infant Development–Second Edition.[32] The appropriate score is identified in the data analysis as the "SB/BSID Nonverbal IQ."

The Stanford-Binet Intelligence Scale–Fourth Edition yields 3-factor scores (each with a mean [SD] of 100 [16]), but the present study used only the Nonverbal Reasoning/Visualization factor score, which reflects the ability to interpret and organize visually perceived material, to perform basic mathematical operations using visual cues, and to demonstrate visuomotor skills.[33]

The Bayley Scales of Infant Development–Second Edition yields 4-facet scores (expressed as a developmental age, which is based on the highest developmental age level at which the child displays mastery), but the present study used only the Cognitive facet score, which assesses nonverbal problem-solving skills. In the present study, a developmental quotient (DQ) was calculated by dividing the estimated developmental age by chronologic age and multiplying by 100 or DQ= [(developmental age/chronologic age) × 100].

Adaptive/Developmental Functioning. The Developmental Profile II (DP-II) is a parent-report inventory of adaptive skills designed to assess a child's capabilities in the following 5 functional domains: physical, self-help, socialization, academic, and communication.[34] The inventory includes skills appropriate for children aged birth to 9½ years. The DP-II yields developmental age equivalents in each of the 5 domains assessed, which were converted to DQ scores according to the formula presented above. The mean of the 5 domain DQs was designated the total DQ and used as an index of overall adaptive/developmental level.

Behavioral Functioning. The Child Behavior Checklist is a written parent-report measure designed to assess behavioral and emotional problems in children aged 2 to 18 years,[35,36] or as young as 18 months for serial assessments.[36] The Child Behavior Checklist yields normalized T-scores (mean [SD], 50 [10]) in several specific areas as well as a total T-score. Higher scores indicate greater behavioral problems, with T-scores of greater than 60 denoting clinically significant problems. The same parent was asked to complete the Child Behavior Checklist at both the preimplantation and postimplantation evaluations.

STATISTICAL ANALYSIS

Paired *t* tests were used to compare mean pure-tone thresholds at 4 frequencies for the total sample before implantation (with and without hearing aids) to those at 1-year follow-up. Means of the pure-tone thresholds were calculated at each of the frequencies as well as of all 4 frequencies.

A paired *t* test was used to compare speech perception scores before implantation with those at follow-up. To identify factors affecting postimplantation speech perception scores, a 1-way analysis of variance (ANOVA) was conducted that included the initial level of hearing impairment (severe or profound), cause of hearing impairment (congenital or meningitis), preimplantation communication method (oral, sign exclusively, total communication), and type of cochlear implant device.

Paired *t* tests were used to compare preimplantation and postimplantation scores in nonverbal cognition, adaptive/developmental functioning, and behavior. The effect of subject age at surgery on those 3 areas was examined using a 2 × 2 repeated-measures ANOVA, dichotomizing the sample by age at surgery so as to equalize the number of subjects in the 2 age groups. Age groups were compared using χ^2 analysis in terms of level of preimplantation hearing loss, preimplantation speech perception scores, and change in speech perception scores at follow-up. A similar repeated-measures ANOVA was conducted to study the relationship between age at implantation and change in mean pure-tone threshold performance between preimplantation aided trial and follow-up evaluation.

To study factors affecting outcome, a change score was defined for each child by subtracting preimplantation from postimplantation scores. Pearson product moment correlations were conducted to determine whether change scores were related to age at diagnosis, age at surgery, duration of hearing impairment, time from surgery to follow-up evaluation, or preimplantation SB/BSID Nonverbal IQ. One-way ANOVA was used to determine the relationship between change scores and cause of hearing impairment, level of preimplantation hearing loss, type of preimplantation communication method, and type of cochlear implant device. Pearson product moment correlation was used to examine the relationship between change scores in speech perception and adaptive/developmental skills (DP-II total and domain scores).

All statistical analyses were performed using the Statistical Package for Social Sciences Version 10.0.[37] All reported *P* values used 2-tailed tests of significance; $P<.05$ were considered statistically significant. All data are given as mean (SD).

RESULTS

SUBJECT CHARACTERISTICS

Subject characteristics are summarized in **Table 1** and **Table 2**. All subjects had severe or profound unaided hearing impairment and had used hearing aids for a mean of 33.76 (27.21) months before surgery. Almost all subjects (95%) had prelingual deafness. The mean age at surgery was 50.72 months; the sample can be divided into 2 roughly equal age groups at 48 months. Before surgery, all subjects were either receiving early intervention services or were enrolled in part- or full-day school programs appropriate for their age and level of functioning.

TEST RESULTS

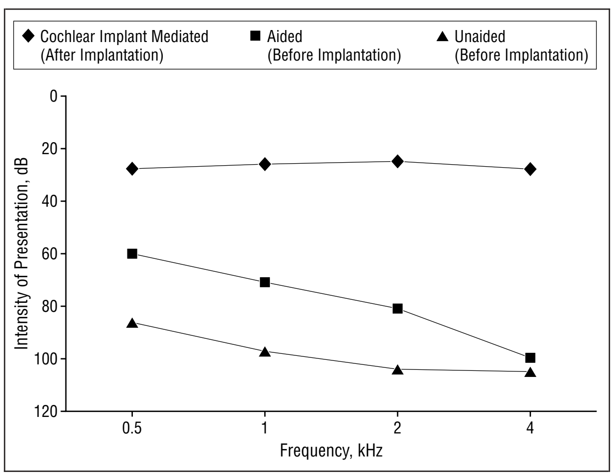
Audiological Evaluation

As shown in the **Figure**, substantial improvements were found in the mean frequency thresholds from both the unaided and aided preimplantation performance and that

Table 2. Demographic and Clinical Characteristics of 40 Subjects With Severe to Profound Hearing Impairments

	No. (%) of Subjects*
Sex, M/F	21/19 (52/48)
Onset of hearing impairment	
Prelingual (≤24 mo)	38 (95)
Postlingual (>24 mo)	2 (5)
Level of preimplantation hearing loss	
Severe (75-90 dB)	21 (53)
Profound (>90 dB)	19 (47)
Duration of deafness, mo	
<36	22 (55)
≥36	18 (45)
Cause	
Congenital†	32 (80)
Meningitis	8 (20)
Preimplantation communication method†	
Total communication	25 (63)
Sign language (exclusively)	3 (7)
Oral	12 (30)
Age at cochlear implant surgery, mo	
<48	22 (55)
≥48	18 (45)
Type of cochlear implant‡	
Clarion	26 (65)
Nucleus 22	9 (23)
Nucleus 24	5 (12)

*The percentages in this section have been rounded.
†Congenital includes cytomegalovirus, prenatal rubella, genetic, and unknown causes.
‡Clarion is manufactured by Advanced Bionics Corp, Sylmar, Calif; Nucleus 22 and Nucleus 24 are manufactured by Cochlear Corp, Englewood, Colo.



Significant improvements ($P<.001$) in mean pure-tone threshold were found 1 year after receiving the cochlear implant at each of the 4 frequencies measured, compared with preimplantation performance either with or without hearing aids.

with the cochlear implant. All 40 subjects showed improvement from preimplantation to postimplantation performance. Paired t test analysis found all the group differences to be significant ($P<.001$) for all 4 frequencies.

The pure-tone thresholds averaged across the 4 frequencies tested are given in **Table 3** both before and after implantation. A 2×2 repeated-measures ANOVA confirmed that the audiological improvement by the total sample after implantation was statistically significant ($P<.001$). Both age groups exhibited comparable audiological performance before the hearing aid trial and with the cochlear implants, but a 2×2 repeated-measures ANOVA found that the younger age group demonstrated significantly greater improvement from aided preimplantation to cochlear implant performance ($P<.01$). One-way ANOVA found no significant relationship between change in mean pure-tone threshold and level of preimplantation hearing loss (aided or unaided).

Table 3. Mean Pure-Tone Averages by Age at Cochlear Implantation*

Variable	Total Sample (N = 40)	Age at Implantation <48 mo (n = 22)	Age at Implantation ≥48 mo (n = 18)
Before implantation			
Unaided hearing	98.06 (8.65)	98.24 (7.77)	97.85 (9.85)
Range		80.00-113.75	75.00-107.50
Uses hearing aid	78.09 (12.75)	83.81 (9.71)	71.11 (12.75)
Range		62.50-97.50	40.00-88.75
After implantation			
Implant mediated	26.72 (6.25)	26.14 (5.92)	27.43 (6.73)
Range		16.25-37.50	17.50-38.75

*Data are given as mean (SD) of the pure-tone sensitivities at 500 Hz, 1 kHz, 2 kHz, and 4 kHz. Values are given in decibels.

Table 4. Preimplantation and Postimplantation Test Results for 40 Subjects With Severe to Profound Hearing Impairments*

Measure	Preimplantation (Aided) Result	Post-implantation Result	*P* Value, Paired *t* Test
Speech perception category score†	1.63 (1.43)	4.15 (1.94)	<.001
SB/BSID Nonverbal IQ	89.95 (14.03)	92.90 (12.35)	.10
Developmental Profile II			
Total DQ	82.43 (12.49)	90.65 (12.84)	<.001
Physical DQ	97.48 (13.47)	102.15 (11.15)	<.01
Self-help DQ	96.13 (12.56)	99.50 (13.06)	>.125
Socialization DQ	77.48 (15.60)	89.93 (16.36)	<.001
Academic DQ	81.03 (18.16)	87.33 (18.36)	.02
Communication DQ	60.68 (22.47)	69.50 (20.95)	<.002
CBCL total T score	48.35 (9.15)	47.45 (11.43)	.64

Abbreviations: BSID, Bayley Scales of Infant Development–Second Edition; CBCL, Child Behavior Checklist; DQ, developmental quotient; SB, Stanford-Binet Intelligence Scale–Fourth Edition.
*Data are given as mean (SD).
†Speech perception category score refers to the classification described by Geers and Moog.[4]

Speech Perception Evaluation

Mean speech perception scores for the sample both before implantation (aided) and at 1-year follow-up are given in **Table 4**; paired t test analysis found the postimplantation improvement to be statistically significant ($P<.001$). Speech perception scores improved at follow-up for 31 (78%) of 40 subjects and did not decline for any subject.

Table 5. Preimplantation and Postimplantation Test Results by Age at Surgery for 40 Subjects With Severe to Profound Hearing Impairment*

Measure	<48 mo (n = 22) Preimplantation Result	<48 mo (n = 22) Postimplantation Result	≥48 mo (n = 18) Preimplantation Result	≥48 mo (n = 18) Postimplantation Result
Developmental Profile II				
Total DQ	81.1 (11)	92.5 (11)	84.1 (14)	88.4 (14)
Physical DQ	96.5 (15)	102.9 (10)	98.7 (10)	101.2 (13)
Self-help DQ	94.6 (13)	99.3 (14)	97.8 (12)	99.7 (13)
Socialization DQ	74.9 (15)	92.4 (15)	80.5 (15)	86.9 (17)
Academic DQ	81.9 (17)	89.3 (20)	80.0 (19)	84.9 (16)
Communication DQ	60.6 (21)	74.4 (19)	60.8 (24)	63.5 (21)
SB/BSID Nonverbal IQ	88.6 (12)	93.6 (8)	91.7 (15)	91.3 (16)
CBCL total T-score	48.0 (7)	46.4 (11)	48.7 (11)	48.7 (12)

Abbreviations: BSID, Bayley Scales of Infant Development–Second Edition; CBCL, Child Behavior Checklist; DQ, developmental quotient; SB, Stanford-Binet Intelligence Scale–Fourth Edition.
*Data are given as mean (SD).

One-way ANOVA found that the change in speech perception was significantly related to level of preimplantation hearing loss ($P<.05$); greater improvement in speech perception was seen in subjects with initially less severe hearing impairment. The mean speech perception score increased by 3.1 for subjects with severe hearing loss, compared with a mean increase of only 1.8 for those with profound hearing loss. However, change in speech perception score was not significantly related to change in audiological performance.

Change in speech perception score was not significantly related to cause of hearing loss, preimplantation communication method, or type of cochlear implant device (1-way ANOVA). Change in speech perception was not significantly correlated to duration of hearing impairment, age at diagnosis, age at surgery, preimplantation nonverbal IQ, or time since surgery.

The 2 age-at-surgery groups were not significantly different in terms of level of preimplantation hearing loss, using χ^2 analysis—profound hearing loss was experienced by 9 (41%) of the 22 subjects in the younger group compared with 10 (56%) of the 18 subjects in the older group. However, the 2 groups did significantly differ ($\chi^2_{4,40}=12.2$, $P<.05$) in terms of preimplantation speech perception scores. All subjects in the younger age group received the lowest speech perception score of 1, whereas in the older age group, only 56% received a score of 1, and 2 subjects (11%) actually received the highest speech perception score of 6. In terms of postimplantation improvement in speech perception from closed-set (score, 1-4) to open-set (score, 5-6), χ^2 analysis found no significant difference between the 2 age groups.

Psychological Evaluation

As given in Table 4, the subjects generally demonstrated low-average to average nonverbal cognitive functioning (SB/BSID Nonverbal IQ) both before and after receiving the cochlear implant. Overall adaptive/developmental functioning (DP-II) was in the low-average range, with substantial delay in the communication and socialization areas, low-average academic score, and other specific areas within normal limits. No significant behavioral problems were reported, with the mean T-scores on all the Child Behavior Checklist subscales (not listed in Table 4) ranging from 44 to 55, within normal limits.

No significant change was found at follow-up in nonverbal cognitive functioning or behavior (paired *t* test analysis). However, significant improvements were seen in adaptive/developmental functioning. The mean DP-II total DQ was in the average range at follow-up, a statistically significant gain ($P<.001$), with particular improvements in communication ($P<.005$) and socialization ($P<.001$), together with modest but significant improvements in physical skills ($P<.05$) and academic skills ($P<.05$).

Psychological assessment results are summarized in **Table 5** for the 2 age-at-surgery groups. Before surgery, there was no significant difference between the age groups; however, 2×2 repeated-measures ANOVA revealed a significant age $\times$ skill interaction for overall adaptive/developmental functioning and for certain domains. On average, the younger group improved significantly more than the older age group in overall adaptive/developmental functioning ($P<.05$), communication ($P<.05$), and socialization ($P<.05$). No significant differences between age groups were seen for changes in the other DP-II domain scores (physical, self-help, or academic functioning). No age $\times$ skill interaction was found for nonverbal cognitive functioning or behavioral functioning.

The improvement in overall adaptive/developmental functioning was significantly and inversely correlated with duration of hearing impairment (Pearson $r=-0.445$, $P<.005$) and age at surgery ($r=-0.524$, $P<.001$), but not significantly correlated with age at initial diagnosis, preimplantation SB/BSID Nonverbal IQ, or time from surgery to postimplantation evaluation. One-way ANOVA found no significant relationship between change in overall adaptive/developmental functioning and level of preimplantation hearing loss, cause of hearing loss, preimplantation communication method, or type of cochlear implant device. No significant relationship was found, us-

What This Study Adds

Past studies of cochlear implantation in children who have severe to profound deafness have demonstrated improvements in behavioral and social functioning that were associated with improvements in cognitive skills. Such benefits could be related to either or both of the observed audiological or speech perception gains. However, there have been few studies of the development outcome of cochlear implantation and the factors influencing that outcome.

This prospective, longitudinal study of 40 consecutive patients who underwent cochlear implantation at age 1½ to 9 years found significant improvements in pure-tone hearing and speech perception as well as significant gains in developmental functioning, particularly in communication, socialization, and academic skills. However, no significant relationship was found between developmental improvements and either audiological or speech perception results. The greatest improvements in overall developmental, social, and communication skills are seen in the children who were youngest at surgery, particularly those receiving the cochlear implant before 4 years of age. We suggest a more proactive approach to cochlear implantation in children and propose that early implantation may help maximize the developmental outcomes of these children.

ing Pearson product moment correlation, between the change in adaptive/developmental functioning scores (either DP-II total or domain DQs) and the change in speech perception score.

COMMENT

Results have been presented for audiological, speech perception, and developmental functioning in a sample of children with severe to profound hearing impairment just before and at 1 year subsequent to cochlear implantation. As expected, audiological and speech perception abilities significantly improved at follow-up evaluation, as did adaptive/developmental functioning, particularly in the language-related communication, social, and academic domains. Unexpectedly, there was also a modest but significant improvement in physical skills. No significant change was seen in nonverbal cognitive functioning, notwithstanding reports of improvement by others,[22] or in behavior, where no significant problems were reported either before or after surgery.

Generally, greater improvements in speech perception were found in subjects who had less severe initial hearing loss, despite audiological evidence that the cochlear implant was just as effective in conveying auditory sensation in those with initially greater hearing impairment. The difference might reflect more early speech-oriented development in the subjects with less profound hearing impairment; even with the same level of implant-mediated auditory sensation, subjects with greater initial impairment might require more experience with the cochlear implant to achieve comparable speech perception gains. In the present study, speech perception improvements were not found to be related to length of use of the implant, but study assessments were conducted in a rather narrow range about 1 year after surgery; others have found significant improvements in speech perception after 1 year, particularly in children who have prelingual impairment.

Contrary to hypothesis, no significant relationship was found between changes in speech perception and changes in adaptive/developmental functioning, although—as hypothesized—significant improvements were seen in both areas after implantation. This observation calls into question the model of Schum[8] and others that improvements in such areas as social functioning, communication, and academic skills are essentially a consequence of improved speech perception. The null result may be a consequence of the insensitivity of the speech perception score used in this study, which is a broad index based on a variety of measures. Another explanation could be that improvements in the perception of non–speech-related sounds, such as environmental cues, are also important to adaptive/developmental functioning.

Improvements in speech perception were not significantly related to age at implantation, age at initial diagnosis, duration of hearing impairment before receiving the cochlear implant, cause of implantation, or nonverbal cognitive functioning. The lack of a relationship to age at implantation is contrary to indications in the literature of better speech outcome with earlier intervention. However, such a relationship is not well established and, in any event, may only become evident at long-term follow-up (3-4 years after implantation), much longer than that of the present study.[27]

Children who were younger than 48 months at surgery did show better audiological improvement in this study, but this result most likely reflects the poorer outcome of the hearing aid trial for the younger children. Audiological results were comparable between the younger and older groups either without hearing aids or with cochlear implants.

Overall adaptive/developmental functioning and, in particular, communication and socialization skills improved significantly more in children who were younger than 48 months at surgery (preschool aged) than in older children. Consistent with this result, both younger age at surgery and shorter duration of hearing impairment were significantly correlated with greater improvements in overall adaptive/developmental score. These indications of the developmental benefits of earlier age at implantation and a shorter duration of hearing loss agree with our hypothesis and are in line with past research.[38]

Somewhat surprisingly, improvements in adaptive/developmental functioning were not significantly related to length of experience with the cochlear implant, age at initial diagnosis, or nonverbal cognitive functioning before surgery. As hypothesized, there was no significant relationship with the cause of hearing loss or the initial degree of hearing impairment. As with the results for speech perception, the lack of a significant relationship with time since surgery could simply reflect the limited range of follow-up intervals in the present study.

CONCLUSIONS

Our results suggest that cochlear implantation can be beneficial for children who have severe to profound hearing impairment, resulting in improvements in sound detection, speech perception, and adaptive/developmental functioning at 1 year follow-up. The greatest improvement in speech perception was for children who have the least initial impairment, whereas the greatest improvement in adaptive/developmental skills, particularly social and communication skills, was for children who were youngest when they received the cochlear implant. As others have pointed out, skills continue to develop for many years after cochlear implantation, and accurate assessment requires long-term follow-up. Future research will examine how the present results might change with time.

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