Factors Associated with Development of Speech Production Skills in Children Implanted by Age Five

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Objective: **This study investigated speech production outcomes and the factors influencing the outcomes in children who had 4 to 6 yr of experience with a multichannel cochlear implant. Production variables examined included speech intelligibility, accuracy of consonant and vowel production, percentage of plosives and fricatives produced, duration of sentences, percentage of time involved in communication breakdowns during a communication sample, and responses to a speech usage questionnaire.**

Design: **181 children between the ages of 8 and 9 yr who received a multichannel cochlear implant before age 5 yr participated as subjects. Independent variables were the amount and type of educational intervention and intervening variables were distributed across child, family and implant characteristics. Multiple regression analyses provided a measure of the amount of variance associated with speech production skills accounted for by the intervening and independent variables.**

Results: **Performance for the key words in the speech intelligibility measured averaged 63.5% for the group of children. Accuracy of phoneme production was higher for consonants (68.0%) than for vowels (61.6%) for the group. More plosives were present for acoustic analyses (91.6%) than were fricatives (78.4%). Duration for the speech intelligibility sentences averaged 2572.3 msec. Communication breakdowns occurred on average 14.5% of the time involved in a language sample. Significant predictors of high levels of oral communication skills included higher nonverbal intelligence, gender, longer use of SPEAK processing strategy, a fully active electrode array, greater dynamic range, and greater growth of loudness. The primary rehabilitative factors contributing to high levels of oral communication were an emphasis on oral-aural communication and classrooms that emphasized dependence on speech and listening.**

Conclusions: **Speech production performance in children with cochlear implants is influenced by nonverbal intelligence, gender, implant characteristics including the length of time using the newest speech processing strategies, and educational programs emphasizing oral-aural communication. Factors previously thought to be major contributors to speech production performance, such as age of onset of deafness and age of implantation, did not appear to play significant roles in predicting levels of speech production performance.**

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Cochlear implants appear to aid the development of oral language skills in young children with profound hearing losses. Access to auditory information via cochlear implants appears to provide significant benefits in the development of a number of oral communication domains including sound repertoires (Blamey, Barry, & Jacq, 2001; Serry & Blamey, 1999; Tobey, Pancamo, Staller, Brimacombe, & Beiter, 1991), speech intelligibility (Miyamoto, Kirk, Robbins, Todd, & Riley, 1996; Mondain et al., 1997; Osberger, Maso, & Sam, 1993; Osberger, Robbins, & Todd, 1996; Robbins, Kirk, Osberger, & Ertmer, 1995; Tobey et al., 2000), and conversational abilities. Although it remains unclear precisely how perceptual processes guide the development of oral communication skills, it appears that auditory information from cochlear implants assists in developing both global and discrete oral communication skills.

Kent (1993) suggests several factors assist in determining whether a child will be a good or poor oral communicator. These factors include reliance on speech, appropriate social use of language, appropriate use of conversational repair strategies, and high levels of speech intelligibility. Positive interactions among these factors appear to produce good oral communicators. For example, individuals who rely on speech demonstrate high levels of speech intelligibility and are rarely poor oral communicators. Poor communicators, on the other hand, rely less on spoken speech, have lower levels of overall speech intelligibility and tend to need to implement communication repair strategies more frequently. When poor communicators fail to use appropriate oral communication and repair strategies, their success in the social use of language is diminished. Global and discrete components of oral communication may be at risk in young children with profound

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hearing losses and it appears perceptual information from an implant may diminish these risks.

Speech intelligibility is one core, global oral communication skill that appears to improve after cochlear implantation. Gains in overall speech intelligibility after cochlear implantation are reported in several studies using rating scales or item identification tasks (Archbold, Nikolopoulos, Tait, O'Donoghue, Lutman, & Gregory, 2000; Miyamoto et al., 1996; Mondain et al., 1997; O'Donoghue, Nikolopoulos, Archbold, & Tait, 1999; Osberger et al., 1996; Tobey, Angelette, Murchison, Nicosia, Sprague, Staller, Brimacombe, & Beiter, 1991; Tobey et al., 2000; Vieu et al., 1998). Studies contrasting speech intelligibility before and at various times postimplantation routinely demonstrate significant increases in intelligibility. Significant increases in speech intelligibility are associated with increased experience with the implant (Allen, Nikolopoulos, & O'Donoghue, 1998). Speech intelligibility postimplantation is higher in children with cochlear implants than in children with hearing losses averaging 103 dB HL and approaches intelligibility levels reported for children with less severe hearing losses (mean pure tone averages of 93 dB HL). Improvements are found in speech intelligibility after cochlear implantation, regardless of whether intelligibility is measured with minimal pair words, key words in sentences, total words in sentences, or rating scales (Chin, Finnegan, & Chung, 2001).

Positive alterations in speech intelligibility also are associated with more appropriate language used for communication. Language skills in children with profound hearing losses appear to be positively influenced with increased experience using cochlear implants (Coerts & Mills, 1995; Svirsky, 2000; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000). Improvements in the use of verbs, pronouns, adjectives, nouns and determiners are observed 3 yr postimplantation (Vieu et al., 1998). Measures of standardized receptive and expressive language use demonstrate steady improvement of language skills with increased experience with cochlear implants, particularly in children who are implanted at early ages and who use the most current cochlear implant technology (Svirsky, 2000).

Social use of language also is evident in preverbal communicative behaviors of young children with profound hearing losses. Children who demonstrate a high reliance on auditory-vocal pragmatic behaviors preimplant demonstrate higher language performance postimplantation (Archbold et al., 2000; Lutman & Tait, 1995; Tait, 1993). In particular, measures of autonomy characterized by contributions or interactions of a child that do not directly follow an adult's contributions in a communication endeavor appear to account for 16 to 27% of the variance noted in later language assessments (Archbold et al., 2000; Lutman et al., 1995). Some studies examining the language performance of cochlear implanted children relative to normative data from hearing-impaired children observe ceiling effects in the cochlear implanted data, suggesting their language use may be more appropriately measured using normative data from normal-hearing children (Tomblin, Spencer, Flock, Tyler, & Gantz, 1999).

Interactions between speech intelligibility and language use are observable in communication situations involving familiar and unfamiliar partners. Speakers who are less intelligible are more frequently involved in communication breakdowns (Tye-Murray, 1992; Tye-Murray, Spencer, & Woodworth, 1995; Tye-Murray, Witt, & Schum, 1995). Communication breakdowns involve both the speaker and the receiver. Speakers who are less intelligible are usually less well understood by their listening partner. Listening partners who may have limited hearing, as in the cochlear implant situation, usually experience more difficulty in understanding the messages of speakers. During conversational situations, adult cochlear implant users tend to control conversational situations, particularly if the communication partner is unfamiliar to them (Tye-Murray, Witt, Schum, & Sobaski, 1994). Thus, familiarity effects are evident in decisions regarding speech intelligibility and conversational abilities.

In addition to these more global measures of communication skills, improvements in more discrete oral communication skills are noted in young children postimplantation. Several investigators observe increases in the accuracy of consonant and vowel production postimplantation (Blamey et al., 2001; Coerts & Mills, 1995; Geers & Tobey, 1992; Kirk, Diefendorf, Riley, & Osberger, 1995; Roland, Tobey, & Devous, 2001; Serry & Blamey, 1999; Tobey, Pancamo, Staller, Brimacombe, & Beiter, 1991). Phonetic accuracy appears to improve with increased experience with a cochlear implant. Decreases in the number of substitutions, omissions, and distortions of consonants appear postimplantation (Geers & Tobey, 1992). Improved accuracy in sound production is noted when stimuli are elicited from pictures, repeating words or sentences after an examiner, or when engaged in communication samples. Similarly, measurements of acoustic variables such as duration of words (Tye-Murray, Spencer, Bedia, & Woodworth, 1996), fundamental frequencies (Fourakis, Geers, & Tobey, 1993), and formant frequencies (Fourakis et al., 1993) also appear to move toward values associated with normal-hearing speakers postimplantation.

Although improvements across both global and discrete features of oral communication are observed in children using cochlear implants, variability across children also is a key feature. No measure of oral speech communication skills seems to escape a wide range of performance levels. That is, many children demonstrate high levels of performance and other children demonstrate low levels of performance. Several variables have been suggested to play roles in the variability of speech production performance noted in children with cochlear implants. One of the most important variables suggested to play a key role is mode of communication (Geers et al., 2000; Geers & Moog, 1992). Modes of communication may incorporate signs or gestures, as well as listening and speaking. Systems of signing may incorporate full language structures as in American Sign Language, language structures similar to spoken English as in Signed English, or signs designed to highlight distinctive features of speech as in Cued Speech. However, it remains unclear precisely how mode of communication enhances or detracts from the development of oral communication skills. Oral communication skills in children using cochlear implants also are influenced by other critical variables including factors associated with the child and their family, device characteristics, school settings, and patterns of intervention. The purpose of this report is to examine sources of variance associated with cochlear implant children when engaging in oral communication. Our exploration will focus on both global and discrete measures of speech production including speech intelligibility, sound production, acoustic characteristics, and social use of communication.

METHODS

Subjects

As described earlier in this supplement (Geers & Brenner, 2003), 181 children between the ages of 8 and 9 yr participated in the study. Half of the children were male ($N = 90$) and half were female ($N = 91$). Unknown factors were attributed as the etiology of hearing impairment in 81 of the children. Meningitis and genetic factors were identified as the etiology of hearing impairment in 32 children, respectively. CMV was attributed as the etiology in 13 children. The remaining etiologies associated with the group included congenital deafness ($N = 9$), high fevers ($N = 6$), Mondini malformations ($N = 3$), prematurity ($N = 2$), birth complications ($N = 2$) and ototoxicity ($N = 1$).

Average age of the children at the time of testing was 8 yr 11 mo, with a range of 7 yr 11 mo to 9 yr 11 mo. Most children were implanted with a Nucleus 22 electrode array. Mean chronological age at the time of implantation for the group was 3 yr 5 mo, with a range of 1 yr 8 mo to 5 yr 4 mo. Average experience was 5 yr 6 mo for the group, with a range of 3 yr 9 mo to 7 yr 6 mo.

The average Performance Intelligence Quotient from the Wechsler Intelligence Scale for Children–Performance Scale (Wechlser, 1991) was 102.1 for the group of children. The group of children averaged 46.10% speech perception performance on the Lexical Neighborhood Test (Kirk, Pisoni, & Osberger, 1995) and 56.8% on the Bamford Kowal Bench Sentences (Bamford & Wilson, 1979). Additional demographic details regarding the population are found in Geers and Brenner (2003).

Communication mode was assessed through a parental rating scale inquiring how emphasis was placed on speech and auditory development in the classroom. A designation of auditory-oral was given to children who received rankings reflecting they participated in a cued speech program, an auditory-oral program, or a auditory-verbal program. A designation of total communication was given to children who received rankings reflecting they participated in a sign-only program, a speech and sign program, and in a sign program with a speech emphasis that included speech only being used some portion of the time. A rank between 4 and 6 was assigned to the auditory-oral programs and a rank between 1 and 3 was assigned to programs incorporating signs. Questionnaires were completed for five time frames: preimplant, the first 3 yr postimplant, and current participation. Rankings were averaged across all test periods. Ninety-two of the children primarily participated in auditory-oral programs and 89 of the children participated in programs incorporating signs. Further details regarding these assignments are available in Geers and Brenner in this supplement (2003).

Production Measures

Speech Intelligibility • Thirty-six sentences comprised of three, five, and seven syllables formed the test materials (McGarr, 1983). The sentences contained key monosyllabic words selected from the corpus of words that predicted speech intelligibility in deaf children (Smith, 1975). Eighteen words were ranked the highest in intelligibility and 18 words were ranked the lowest in intelligibility. Children were shown a written version of the sentence and prompted with a verbal or sign elicitation to repeat the stimulus. Children's responses were recorded on a DAT recorder with the microphone placed approximately 12 inches in front of the children. Individual sentences were consequently computer edited and stored in wave files. Normal-hearing adult subjects served as judges of speech intelligibility. All judges were questioned to ensure they had limited exposure to the speech of individuals with hearing impairments. Judges were recruited from students at the University of Texas at Dallas, the University of Texas Southwestern Medical Center, and members of the Dallas-Ft. Worth Community. All judges signed consent forms approved by the University of Texas at Dallas Institutional Review Board.

To ensure that the judges did not become familiar with the test materials or a given child's speech, judges were allowed to hear a given sentence only once and to hear a given child only once. Judges were asked to write down as much of the sentence as they could understand. Three judges provided responses for each sentence, for each child. Responses across the three judges for the 36 key words were averaged to obtain a score of total key words correctly identified. Thus, speech intelligibility measures represent the average performance obtained from 108 judges (36 key words $\times$ 3 judges) per child.

Consonant and Vowel Production • Four speech-language pathologists transcribed the speech intelligibility sentences using narrow transcription. Transcribers were trained using 120 speech samples collected from another population of hearing-impaired speakers. Agreement across transcriber teams after the training sessions was 91% for broad transcriptions and 84% for narrow transcriptions, a finding similar to that previously reported by Shriberg and Lof (1991). Periodic calibration of transcribers occurred to reduce "transcriber drift." Reliability across transcribers for the current corpus of sentences was 93%. A computer software package, CASALA (Computer Aided Speech and Language Analysis) (Serry, Blamey, Spain, & James, 1997) was used to analyze phonetic transcriptions of the sentences from the speech intelligibility task. Reports from CASALA calculated the percentage correct consonants and vowels for each child.

Acoustic Analyses • Acoustic analyses were conducted on the 36 speech intelligibility sentences and 11 additional sentences described in greater detail in this supplement by Uchanski and Geers (2003). The 11 additional sentences were selected to contain words that facilitated measurement of nasal manner of /m/ and /n/, voice onset times of /t/ versus /d/, durations of vowels and words, second formant frequencies of /i/ versus /a/, and spectral moments of fricatives. As an initial step, the stimuli were inspected visually using a waveform display and listening to determine the percentage of plosives and fricatives present in the sentences (regardless of their accuracy). A percentage of plosives and fricatives were obtained.

Speech Usage Questionnaire • Parents were requested to complete a use of speech questionnaire inquiring how well their child was understood by familiar, less familiar and unfamiliar listeners. A 5-point scale ranging from completely understood to not understood at all was used. Items were designed to allow parents to use daily communication situations to make their judgments. Items in the familiar listener category described situations in which the child used speech with the parent, the teacher, and a close friend or sibling. The "less familiar listener" items described situations in which the child used speech with a normal-hearing classmate, a visiting relative, and a group of the parents' friends. The "unfamiliar listener" items described situations in which the child used speech with a waiter, an unfamiliar visitor at home, and to address a normal-hearing scout troop. A "Speech Usage" score was obtained by averaging the item scores.

Duration Measures • As mentioned earlier, the speech intelligibility corpus of sentences for each child were digitized and edited into individual files. These files were displayed as waveforms and a total duration of the sentence was calculated by locating the first and last zero crossing associated with sentence.

Communication Breakdown • Another global measure examined the components of a 10 minute video taped oral conversation between the child and an examiner who did not sign to determine how much of a conversation was spent repairing breakdowns when the examiner and the child failed to understand one another. During repeated passes through the videotape, a rater timed the duration of each conversational event using the DYALOG software developed by Erber and Weiner (1997). From this tape, the percent of examiner talk time, child talk time, time spent in silence, and time devoted to repairing communication breakdown were measured. For the analyses contained in this report, we focus only on the amount of time devoted to repairing communication breakdowns.

Results

Table 1 indicates the means and standard deviations for the speech production variables examined: total key words correct, total vowels correctly produced, total consonants correctly produced, percentage of plosives present, percentage of fricatives present, average performance on speech use questionnaire, duration of sentences, and the percentage of time spend in communication breakdowns. Performance for the key words in the speech intelligibility measured averaged 63.5% for the group of children. Accuracy of phoneme production was higher for consonants (68.0%) than for vowels

TABLE 1. Speech production performance of cochlear implanted children ages 8 and 9 yr.

	Mean	SD	Minimum	Maximum
Total key word intelligibility (%)	63.5	31.5	0.0	98.1
Female	69.3	9.2	1.0	98.1
Male	57.6	32.9	0.0	96.3
Vowel production (%)	61.6	22.1	1.2	91.6
Female	62.1	21.7	4.8	89.5
Male	61.1	22.7	1.2	91.6
Consonant production (%)	68.0	22.0	2.8	94.9
Female	71.0	18.6	24.9	94.9
Male	65.0	24.7	2.8	94.4
Plosive production (%)	91.6	17.5	0.0	100.0
Female	94.6	11.1	44.4	100.0
Male	88.6	21.8	000.0	100.0
Fricative production (%)	78.4	29.3	000.0	100.0
Female	83.4	26.6	000.0	100.0
Male	73.4	31.1	000.0	100.0
Average speech use quotient	3.6	0.9	001.0	5.0
Female	3.8	0.7	1.6	5.0
Male	3.4	1.0	1.0	5.0
Sentence duration	2572.3	986.3	1301.0	7776.0
Female	2416.0	813.7	1301.0	4792.0
Male	2730.0	1116.9	1507.0	7776.0
Communication breakdown (%)	14.5	16.9	000.0	90.0
Female	10.5	13.0	000.0	70.0
Male	18.5	19.3	000.0	90.0

(61.6%) for the group. Plosives were present for acoustic analyses (91.6%) more often than were fricatives (78.4%). Duration for the speech intelligibility sentences averaged 2572.3 msec. Communication breakdowns occurred on average 14.5% of the time involved in a language sample.

Significant differences were observed in the average performance of female versus male subjects. A similar distribution of gender occurred across the communication mode groups (43 females and 46 males in the total communication group versus 48 females and 44 males in the auditory oral group). As indicated in Table 1, significantly higher speech intelligibility scores were found for female subjects (69.3%) than for male subjects (57.6%). Higher performance for female subjects than male subjects was evident on all measures involving consonant production. Female subjects produced more accurate consonant production (71.0%) than male subjects (65%) in the transcription analyses. Similarly, a higher percentage of plosives and fricatives were measurable in the acoustic analyses for females (94.6% and 83.4%, respectively) than males (88.6% and 73.4%). Sentence durations were longer for the male subjects (2730.0 msec) than female subjects (2416.0 msec). Communication breakdowns occupied a greater percentage of the language sample time for male subjects (18.5%) than female subjects (10.5%). No differences were noted between male and female subjects for correct vowel production, 61.1% and 62.1%, respectively. Male subjects were more variable as a group on speech production measures than female subjects as indicated by their higher standard deviations on all measures.

All of the speech production measures were related as indicated by the intercorrelation matrix shown in Table 2. Generally speaking, higher correlations are observed between the more global measures of oral communication associated with speech intelligibility (total key words), how well a child is understood by familiar and unfamiliar listeners (Average Speech Use), and the percentage of time spent in communication breakdowns. However, speech intelligibility also appears highly related to more discrete oral communication skills such as correct consonant production, sentence duration, and the percentage of fricatives produced. The percent time spent in communication breakdowns, another global measure, appears negatively correlated with consonant production, percentage of fricatives produced, durations, and intelligibility. These examples of the relatively high correlation coefficients across measures support the possibility that variability in speech production may be represented by a single summary score. As in the case of speech perception

TABLE 2. Correlation matrix of speech production measures.

	Speech Intelligibility	Vowel	Consonant	Plosive	Fricative	Speech Use	Duration	Breakdown
Speech intelligibility	1.00							
Vowel	0.52	1.00						
Consonant	0.87	0.73	1.00					
Plosive	0.59	0.44	0.64	1.00				
Fricative	0.79	0.53	0.78	0.49	1.00			
Average speech use	0.82	0.48	0.78	0.55	0.70	1.00		
Sentence duration	−0.72	−0.46	−0.72	−0.59	−0.65	−0.72	1.00	
Breakdown	−0.78	−0.55	−0.80	−0.59	−0.72	−0.75	0.77	1.00

TABLE 3. Principal component loadings for speech production measures.

Speech intelligibility	0.93
Vowels correct	0.67
Consonants correct	0.94
Plosive production	0.71
Fricative production	0.85
Use of speech questionnaire	0.87
Sentence duration	0.83
Communication breakdown	0.89
Percent of total variance explained	72.30

performance, the collapsing of speech production scores into a single metric assumes the collection of speech production measures are tapping oral communication skills. As shown in Table 3, the principal component loadings account for 72.3% of the total variance associated with the speech production measures. Principal component loadings are highest for consonant production and speech intelligibility and are lowest for vowel production. Thus, 72.3% of the original variable variance is accounted for by the collective production metric.

Table 4 details the multiple linear regression analyses used to predict the amount of variance in the speech production principal component score associated with educational factors after the variance in performance due to child, family, and implant characteristics is taken out. As in the speech perception study, seven variables associated with the child and family were examined. These variables included the chronological age of the child at the time of testing, the chronological age at implantation, the chronological age at onset of deafness, performance intelligence quotients, gender, family size, and socioeconomic status. As indicated in the upper portion of the table, characteristics of the child and family accounted for 22% of the speech production principal component score. Performance intelligence quotients, gender, family size, and socioeconomic status were significant independent predictors. As indicated in the data described above, female subjects typically demonstrated higher performance and were less variable across the speech production measures relative to male subjects. Children with higher performance intelligence quotients who came from smaller families demonstrated higher speech production scores. Similarly, children from higher socioeconomic status families achieved higher speech production scores.

Characteristics of the implant accounted for an additional 20% after the variance associated with the child and family were removed as shown in the middle panel of Table 4. The four variables examined included length of time using the SPEAK speech processing strategy, the number of electrodes

TABLE 4. Multiple linear regression results.

Source	Regression Coefficient	df	F-ratio	$p<$	% Variance
Child and family characteristics					
Age	−0.15	1	1.24		
Age at implant	−0.15	1	2.72		
Age at onset	0.01	1	0.50		
Performance IQ	0.02	1	13.77	0.0001	
Family size	−0.16	1	6.16	0.01	
SES	0.04	1	4.31	0.04	
Gender	−0.21	1	10.09	0.002	
Error		173			
Percent total variance					22%
Implant characteristics					
Duration SPEAK	0.15	1	16.35	0.0000	
Number of electrodes	0.05	1	5.80	0.02	
Dynamic range	0.01	1	12.03	0.0005	
Loudness growth	1.37	1	6.92	0.01	
Error		168			
Percent total variance					20%
Educational characteristics					
Therapy hours	0.00	1	2.66		
Clinician experience	−0.01	1	0.05		
Parent participation	−0.07	1	0.21		
Public/private	0.11	1	2.03		
Classroom placement	0.22	1	5.38	0.02	
Communication mode	0.16	1	12.60	0.0005	
Error		162			
Percent total variance					11%
Total explained variance					53%

implanted, the dynamic range, and loudness growth. Each of these implant variables were important and contributed independent variance to the speech production scores. Speech production scores were higher for children who had more experience with the newest speech processing strategy, more active electrodes, a greater dynamic range, and good loudness growth.

After controlling for the variables associated with the child, family and implant, we examined the influence of educational characteristics on speech production performance. As described elsewhere in this supplement (Geers & Brenner, 2003), six educational variables were used as predictors. These variables include the number of therapy hours, the experience of the clinician delivering therapy, the amount of parent participation in therapy, the type of schooling (public versus private), the type of classroom (mainstream versus special education), and the mode of classroom communication. Educational variables accounted for an additional 12% of the variance associated with the speech production principal component score. Two of the variables were associated independently with the speech production outcome. These variables were the type of classroom, mainstream versus special education, and mode of communication used in the classroom. Speech production scores were higher for children in mainstream classrooms who primarily communicated using auditory-oral modes.

As in the case of speech perception, a mode of communication emphasizing listening and speaking appears to promote higher speech production performance. Figure 1 illustrates a plot of the residual scores for the speech production score and mode of communication rating. The residual scores reflect the mode score variance that is unrelated to the other predictor variables and the production score variance that is unrelated to the predictors. Thus, Figure 1 reflects the relationship between speech production and communication mode that is independent of the other variables in the regression. The scores have been re-scaled to have a mean of zero and the histograms on the axes display the distribution of the residual scores. The best fitting regression line is depicted, as is a one standard deviation ellipse demonstrating the direction and magnitude of the regression. The slope of the regression demonstrates the strong relationship of classroom communication mode when all other factors have been removed.

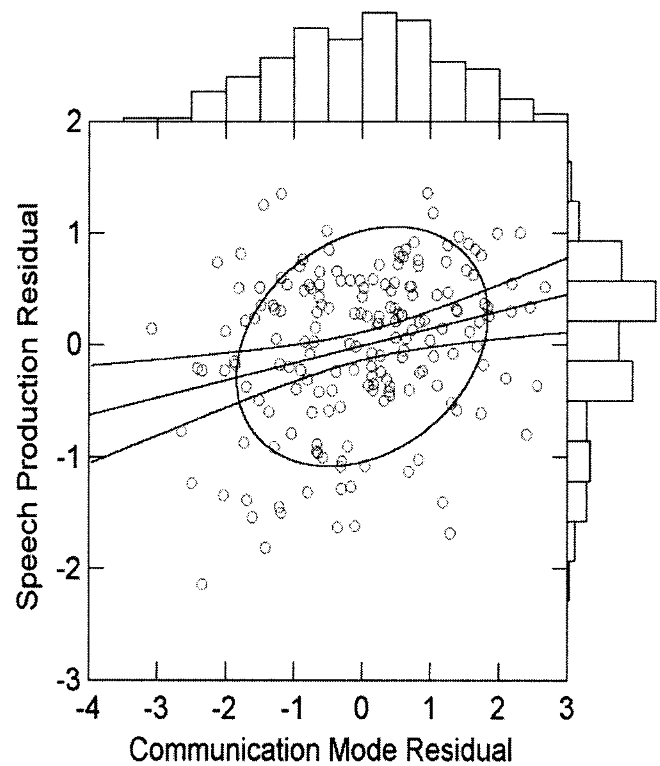

Figure 1. The abscissa displays the residual scores associated with mode of communication and the ordinate displays the residuals associated with speech production. The residual scores on the abscissa reflect the mode score variance that is unrelated to the other predictor variables. The residual scores on the ordinate represent the production score variance that is unrelated to the predictors. Thus, the plot indicates the relationship between speech production and communication mode that is independent of the other variables in the regression analyses. The scores have been re-scaled to have a mean of zero and the histograms on each of the axes display the distribution of the residual scores. The best fitting regression line is depicted, as is a one standard deviation ellipse demonstrating the direction and magnitude of the regression. The slope of the regression demonstrates the strong relationship of classroom communication mode when all other factors have been removed.

Discussion

Both global and discrete aspects of oral communication appear to be influenced by perceptual information provided by a multichannel cochlear implant. Speech intelligibility averages 63.5% and is considerably higher than previous reports of speech intelligibility scores of children with profound hearing losses averaging 17 to 21% (Smith, 1975). Relatively high levels of speech intelligibility appear to assist in overall communication abilities by reducing the amount of time taken in communication breakdowns. Consonant production also appears to be positively influenced as evidenced by the number of correct consonants produced (mean 68%) and the percentage of plosives and fricatives contributing to acoustic measures (mean 91.6% and 78.4%, respectively). Similarly, relatively high levels of accuracy are found for vowels (mean 61.6%). The relatively high levels of accuracy of sound production are in agreement with several previous reports examining sound production after implantation (Geers & Tobey, 1992; Kirk, Diefendorf, Riley, & Osberger, 1995; Mondain et al., 1997; Serry & Blamey, 1999; Tobey, Angelette, Murchison, Nicosia, Sprague, Staller, Brimacombe, & Beiter, 1991; Tobey, Pancamo, Staller, Brimacombe, & Beiter, 1991).

Close examination of the factors that appear to contribute to these relatively high levels of performance reveal two characteristics a cochlear implanted child contributes to the overall picture of learning oral communication skills. As in the case of speech perception performance, nonverbal intelligence is an important contributor. Children with higher nonverbal intelligence demonstrate higher oral communication scores than children with lower nonverbal intelligence scores. Gender also appears to play a role in oral communication abilities of 8- and 9-yr-old children with cochlear implants. Consistently higher speech production scores are found for female than for male children using cochlear implants. Gender differences in speech and language skills have been noted in many previous studies focusing on normal development or the performance of children with communication disorders. Normal-hearing girls score higher than boys on a variety of vocabulary and cognitive measures (Bornstein & Painter, 1999). Gender differences in communication profiles also are reported in older adults with hearing losses on the Communication Profile for Hearing Impairment (Garstecki & Erler, 1999). Gender differences were found on six scales including communication performance at work, communication environment, behavior of others, nonverbal communication strategies, personal adjustment to stress, personal adjustment with denial, differences at work. These data suggest that gender differences may play a role in communication situations throughout the lifespan. Variability in performance also appears to be gender related. Greater variability is found in male subjects than female subjects. As in the case of speech perception skills, once nonverbal intelligence and gender are accounted for, age of onset of deafness and age at implantation do not appear to contribute significantly to oral communication abilities when measured in children between the ages of 8 and 9 yr. The lack of an age of implant effect is probably due to the limited variance associated with this variable because all children were implanted within a limited time span. Family variables associated with parental education do not appear to contribute significantly to oral communication abilities.

Status of the implant device, itself, plays a critical role in oral communication abilities. The number of active electrodes and the characteristics of the map (i.e., optimal settings for dynamic range and loudness) all contribute to oral communication abilities. Children with a greater number of active electrodes and wide dynamic ranges have higher speech production scores than children with fewer active electrodes (under 10) and narrow dynamic ranges. Access and experience with the newest speech processing strategies also is important. Children who had the longest duration of use with the SPEAK strategy had the highest speech production scores and children whose implant was programmed with earlier processing strategies had lower speech production performance. The observation that experience with new technology is more important than length of implant use for oral communication skills is an important one. Changes in algorithms, chip design, and processing capacity are likely for the future and data from this study suggest that continual updating of the devices will be necessary to provide children with the equipment resources to maximize their speech production performance.

Oral communication performance also is influenced by two major variables: the mode of communication used educationally and the educational setting. Children who are in programs emphasizing listening and talking have higher speech production scores than children in programs that put less emphasis on these actions. Children who are in mainstream classrooms where they must rely on listening and talking also outperform children who are in special education classrooms where they may rely less on listening and talking. Data from this study suggest oral communication skills in children with cochlear implants are best achieved by emphasizing a communication environment that: a) relies on speech as the primary mode of communication, b) focuses on speech intelligibility, c) encourages appropriate use of consonants and vowels, and d) reinforces appropriate use of conversational repair strategies. As suggested by Kent (1993), proper attention to these important communication variables promotes good oral communication skills in children with cochlear implants.

In summary, speech production performance in children with cochlear implants is influenced by nonverbal intelligence, gender, family size, socioeconomic status, implant characteristics including the length of time using the newest speech processing strategies, and educational programs emphasizing oral-aural communication. Factors previously thought to be major contributors to speech production performance, such as age of onset of deafness and age of implantation, do not appear to play significant roles in predicting levels of speech production performance. Good speech production skills are promoted by communication environments emphasizing a reliance on speech for communication.

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