Examining Multiple Sources of Influence on the Reading Comprehension Skills of Children Who Use Cochlear Implants

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Children with profound deafness are at risk for serious reading difficulties. Multiple factors affect their development of reading skills, including use of cochlear implants. Further, multiple factors influence the overall success that children experience with their cochlear implants. These factors include the age at which they receive an implant, method of communication, vocabulary skills, preoperative residual hearing, and socioeconomic status. Ninety-one children with prelingual and profound hearing impairments who received cochlear implants at varying ages participated in the study. Structural equation modeling confirmed that multiple factors affected young cochlear implant users' reading comprehension skills and that there were significant associations between the predictors of reading comprehension. Pre-implant vocabulary had an indirect positive effect on reading through postimplant vocabulary, which had a direct positive effect on reading. Overall, children with stronger language skills demonstrated stronger reading outcomes. Age at implantation both directly and indirectly, through postimplant vocabulary, affected reading outcomes, and the total effect was large. Children who were younger when they received their implants tended to have higher reading comprehension scores. Socioeconomic status negatively affected reading. Children who used total communication prior to implantation tended to have stronger pre-implant vocabulary scores, but the total effect of pre-implant communication method on children's reading skills was negligible. Research and educational implications are discussed.

KEY WORDS: deafness, literacy, language development, communication, sign language, socioeconomic status (SES)

Children with profound hearing losses are at particular risk for serious reading difficulties. On average, these children graduate from high school with reading skills at a third-grade level (Allen, 1986; Holt, 1994). This gap in reading achievement between children with hearing impairment and children with normal hearing sensitivity widens as severity of hearing loss increases (Karchmer, Milone, & Wolk, 1979). In recent and separate studies, use of cochlear implants (L. Spencer, Tomblin, & Gantz, 1998; Svirsky, Stallings, Lento, Ying, & Leonard, 2002; Szagun, 2001; Tomblin, Spencer, Flock, Tyler, & Ganz, 1999) and early exposure to sign language (Padden & Ramsey, 1998, 2000) have been positively associated with vocabulary and literacy skills. Further, multiple factors affect the reading skills of children with cochlear
implants (Geers, 2002, 2003; Geers et al., 2002; Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001), just as multiple factors affect the reading skills of children with normal hearing sensitivity (Geers, 2002; Geers et al., 2002; Rayner et al., 2001).

Although there is research that has explored the multiples sources that affect reading skills among children with profound hearing losses, there is little research that has used multilevel modeling. The chief advantage of multilevel models is that they allow for examination of complex interactions among variables influencing children's reading. This study used structural equation modeling (SEM) to examine multiple factors that may affect reading comprehension skills among children with profound hearing losses. These factors include cochlear implant use, the age at which children receive implants, vocabulary skills, communication method, and other child and family variables.

Cochlear implants provide substantial useable hearing to children who derive no significant benefit from conventional amplification (National Institutes of Health, 1995). Accumulating evidence reveals that most children demonstrate significant improvement in their speech perception skills (Cheng, Grant, & Niparko, 1999; Meyer, Svirsky, Kirk, & Miyamoto, 1998), speech production abilities (Tye-Murray, Spencer, & Woodworth, 1995), and oral language development (Bollard, Chute, Popp, & Parisier, 1999; Miyamoto, Kirk, Svirsky, & Sehgal, 1999; Miyamoto, Svirsky, & Robbins, 1997) when they use cochlear implants.

Further, converging research indicates that multiple factors affect performance with the cochlear implant, including age at implantation (Connor, 1998; Connor, Hiebers, Arts, & Zwolan, 2000; Kileny, Zwolan, & Ashbaugh, 2001; Tyler et al., 2001), age at onset of deafness (Geers, 2002; Geers et al., 2002; Osberger, 1994), pre-implant residual hearing (Zwolan et al., 1997), length of cochlear implant use (Tye-Murray et al., 1995), family characteristics (Geers, 2002; Geers et al., 2002), type of device (Connor et al., 2000), and device functioning (Geers, 2002; Geers et al., 2002). Research on the effect of communication method has been equivocal (Ash, Hodges, Butts, Schloffman, & Balkany, 1997; Connor et al., 2000; Cullington, Hodges, Butts, Donal-Ash, & Balkany, 2001; Geers et al., 2001; Hodges, Dolan, Balkany, Schloffman, & Butts, 1999; Miyamoto et al., 1999; Ninio, 1983; Zimmerman-Phillips & Murad, 1997).

Only a few published empirical studies have specifically examined the variables affecting the reading skills of children who use cochlear implants. Recently, Geers and colleagues (Geers, 2002, 2003; Geers & Brenner, 2003; Geers et al., 2002) observed that multiple factors affect young cochlear implant users’ reading skills, including educational setting and communication method, family and child characteristics, and implant functioning. What is not clear is how these key variables interact and affect children’s reading through multiple pathways. Another study (Spencer et al., 1998) found that 54% of children who used cochlear implants and who were between Grades 4 and 12 were reading at or above a fourth grade level. The researchers then compared their results to the results of two similar studies that had examined the reading skills of children using conventional amplification (Furth, 1966; Krose, Lotz, Puffer, & Osberger, 1986). In these latter studies, only 8% and 14%, respectively, of the similarly aged children achieved reading skills at or above the fourth grade level.

Although the reading difficulties of children with hearing impairments present unique challenges, research on factors affecting the reading development of children with normal hearing sensitivity may be applicable to our study. The effects of children's vocabulary skills (Anderson & Freebody, 1981; Rayner et al., 2001) and socioeconomic status (SES; Jencks & Phillips, 1998) on their subsequent literacy development have been well established. Children with stronger vocabulary skills tend to achieve stronger reading skills than do children with weaker vocabulary skills (National Institute of Child Health and Human Development, 2000; Whitehurst & Lonigan, 2001). Children living in poverty tend to achieve weaker reading skills than do their more affluent peers. Other factors also appear to be crucial for reading development, such as phonological awareness and fluency (Rayner et al., 2001); however, examination of these variables is beyond the scope of this study.

The purpose of this study was to examine the effects of multiple variables on reading comprehension skills using multilevel modeling, specifically SEM. When using SEM, researchers first develop an a priori theoretical or conceptual model to test specific hypotheses (Kline, 1998). Based on current understanding of language and literacy development for children with normal hearing sensitivity, as well as extant research on variables affecting outcomes for children who use cochlear implants, we hypothesize that multiple variables will affect children's reading comprehension outcomes and present these relations in the conceptual model (see Figure 1). Although in studies using SEM the conceptual model is typically presented in the introduction (Hoyle, 1995), for illustrative purposes we discuss our hypotheses and the conceptual model more fully in the Method section. The following research questions were posed in this study:

1. What are the effects of the variables of interest on reading comprehension when key child and family variables are controlled?
2. How do these variables relate and interact with each other?
Figure 1. Conceptual model (SEM Model 1): Path diagram for testing the effects of low socioeconomic status (LSES), age implanted, communication method, and pre- and postimplant vocabulary on reading comprehension. This is the theoretically constructed model designed to test our hypotheses. All of the variables are observed as indicated by the rectangles surrounding the variable names. Latent and unobserved variables are indicated by circles. In this model, the disturbances or error are unobserved, as indicated by the circles. Unidirectional straight arrows indicate the predicted direction of the hypothesized effect. For example, in this model, we predict that LSES will directly affect pre-implant vocabulary and reading comprehension (Reading Comp). This is indicated by the arrows leading from LSES to Preimplant Vocabulary and to Reading Comp. Curved bidirectional arrows indicate a correlation. In this model, we predict that communication, speech detection threshold (SDT), and LSES will be correlated.

3. What are the combined direct and indirect effects of these variables on reading comprehension scores?

Method

Participants

Ninety-one children using cochlear implants (45 boys and 46 girls) participated in this study. Descriptive statistics for the groups of participants are presented in Table 1. All of the children participating in this study demonstrated cognitive abilities within normal limits. Cognitive ability was assessed by a licensed clinical psychologist at the medical center where the cochlear implant center was located. A number of different assessments were used, including the nonverbal portions of the Kaufman Assessment Battery for Children (Kaufman & Kaufman, 1983) and the Stanford-Binet Intelligence Scale (4th ed.; Thorndike, Hagen, & Sattler, 1986).

Preoperative unaided speech detection thresholds (SDTs) were greater than 80 dB HL for all participants. On average, children were 11 years old and had used their implant for more than 4 years at the time of their reading evaluation. Postoperatively, all children demonstrated SDTs between 15 and 30 dB HL when using their cochlear implants. Of the 91 children, 88 used the Nucleus 22 device and three children used the Nucleus 24 device. All of the children used the SPEAK processing strategy at the time of their reading evaluation. However, older children used MPEAK after activation until
Table 1. Descriptive statistics for participants by age at implantation (preschool ≤ 5 years; school age > 5 years) and by communication group.

<table>
<thead>
<tr>
<th></th>
<th>Total (n = 91)</th>
<th>Preschool age at implantation (n = 40)</th>
<th>School age at implantation (n = 51)</th>
<th>OC (n = 48)</th>
<th>TC (n = 43)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Age at reading evaluation (years)</td>
<td>10.98</td>
<td>2.67</td>
<td>9.45</td>
<td>1.63</td>
<td>12.03</td>
</tr>
<tr>
<td>Pre-implant aided SDT (dB HL)</td>
<td>53.37</td>
<td>14.01</td>
<td>57.50</td>
<td>16.53</td>
<td>50.72</td>
</tr>
<tr>
<td>Age at onset of deafness (years)</td>
<td>0.16</td>
<td>0.24</td>
<td>0.22</td>
<td>0.29</td>
<td>0.13</td>
</tr>
<tr>
<td>Age at implantation (years)</td>
<td>6.78</td>
<td>3.06</td>
<td>3.85</td>
<td>0.89</td>
<td>8.66</td>
</tr>
<tr>
<td>Length of implant use at reading evaluation (years)</td>
<td>4.24</td>
<td>2.15</td>
<td>5.63</td>
<td>1.56</td>
<td>3.36</td>
</tr>
<tr>
<td>Pre-implant vocabulary (SS)</td>
<td>59.73</td>
<td>16.53</td>
<td>62.63</td>
<td>21.16</td>
<td>58.08</td>
</tr>
<tr>
<td>Postimplant vocabulary (SS)</td>
<td>70.77</td>
<td>17.73</td>
<td>75.90</td>
<td>19.81</td>
<td>67.46</td>
</tr>
<tr>
<td>Reading comprehension (55)</td>
<td>69.78</td>
<td>13.40</td>
<td>76.42</td>
<td>13.50</td>
<td>65.02</td>
</tr>
</tbody>
</table>

Note. OC = oral communication; TC = total communication; SDT = speech detection threshold; SS = standard score with a mean of 100 and a standard deviation of 15 for children with normal hearing sensitivity.

The newer processing strategy was available. Length of time with SPEAK did not significantly predict reading comprehension skills and so was removed from the model.

Children received special education services soon after their hearing impairment was diagnosed. They attended public schools and were enrolled in oral or total communication educational programs. These programs emphasized use of spoken language and provided auditory training as well as speech and language therapy. Based on school visit observations, both the total and oral programs provided early intervention, self-contained classrooms, and opportunities for mainstreaming (with either oral or sign language interpreters, based on the child's communication method). Reading curricula varied among schools but, in general, included both meaning-based and code-based instruction (see Rayner et al., 2001, for a review). This instruction was implemented using commercially available programs, such as Milestones (Quigley & King, 1985), as well as school-designed activities.

Data Collection and Scoring

An audiological and speech and language evaluation was completed for each child prior to receiving a cochlear implant and approximately yearly thereafter. Speech-language pathologists and audiologists administered all of the tests and conducted school visits and parent interviews. The children's pre-implant and most recent evaluation results, which included a reading evaluation, were used for this study. Variables included in the statistical models are described below; descriptive statistics for these variables are displayed in Table 1.

Reading Comprehension

The Passage Comprehension subtest of the Woodcock Reading Mastery Test–Revised (WRMT; Woodcock, 1987) was used to assess reading comprehension. The testing was conducted in a quiet room according to standardized procedures, but with the following changes: (a) Children gave their answers using signed and/or spoken language according to their preference and (b) were permitted to read aloud using signed and/or spoken language if they wished. Raw scores were converted to standardized scores (M = 100, SD = 15) for statistical analyses. This conversion permitted us to compare the reading comprehension skills of children of varying ages and to compare their scores with the test standardization sample (i.e., children with normal hearing sensitivity).

The Passage Comprehension subtest is a modified cloze procedure. In a cloze task, the student is shown a brief passage of text and asked to report the missing word (e.g., The duck is swimming in the ___). The test is designed so that the child has to understand the entire passage, exercising decoding, vocabulary, and comprehension strategies to determine the correct response. Additionally, the cloze task implicitly requires an adequate grasp of the syntactic structure of English.

Pre- and Postimplant Vocabulary

Links between vocabulary and reading skill have been well documented for children with normal hearing sensitivity (Anderson & Freebody, 1981) and with profound hearing losses (Oakhill & Cain, 2000). Pre-implant vocabulary was evaluated using the Picture Vocabulary test of the Woodcock-Johnson Test of Cognitive Ability (Woodcock & Mather, 1989) and the Expressive One-Wo
Picture Vocabulary Test (EOWPVT; Gardner, 1990; n = 11). Postimplant, all children were assessed using the Woodcock-Johnson measure. Both tests incorporated picture identification tasks, in which the children were presented with a target picture and asked to name it. Standard administration procedures were followed except that both signed and spoken responses were accepted. Every effort was made to administer the tests to children who used signed and/or spoken language in an equivalent manner. Iconic gestures were not considered to be correct responses; only the exact spoken, signed, and/or finger-spelled target word was accepted as correct. Nevertheless, test scores for children with differing communication methods must be compared with caution because translation from sign language to spoken language may differ depending on the sign system used (e.g., Signed English, Signing Exact English [SEE]) and geographic region. The difficulties are similar to those encountered in cross-linguistic studies (Berman & Slobin, 1994; Tardif, 1996). Further, the tests were normed for children with normal hearing sensitivity, so comparing the scores of the children in this study with the standardized norms should be approached cautiously. Raw scores were converted to standard scores. There were no significant differences between pre-implant vocabulary scores of children tested using the EOWPVT and the Woodcock-Johnson measure (p > .05), so the test scores were combined into one variable, pre-implant vocabulary.

**Age at Implantation**

Age at implantation, in years, was calculated by subtracting each child's date of birth from the date that she or he received and used the external parts of their cochlear implant device. Forty children received implants at age 5 years or younger; of these, 10 children received their implants before age 3 years, and 14 children were implanted between ages 3 and 4 years. Fifty-one received their implants after age 5 years; of these, 32 received the implant before age 9 years, and 19 children were implanted between 11 and 14 years of age.

**Pre-Implantation Communication Method**

Children were assigned to one of two groups based on their primary method of communication (communication method) prior to receiving a cochlear implant. They were placed in the total communication (TC) group (n = 43) if they used sign language in combination with spoken language. Children in the TC group used sign systems based on English, including Signed English and SEE, which strive to replicate visually the structure of spoken English (Nevins & Chute, 1996; Ratner, 1997). Children were assigned to the oral communication (OC) group (n = 48) if they used only spoken language. Group placement decisions were based on pre-implant clinical observation as well as parent report. If the parent reported using sign language or that the child was in a TC educational program, or if the child used any formal sign language with the examiner (e.g., Signed English, SEE), then the child was placed in the TC group. If the parent reported using only spoken language with the child or reported that the child was in an OC educational program, then the child was placed in the OC group. If the parent reported using an oral approach, then the examiner did not use any form of sign language with the child.

Primary communication method and school placement were highly related for those children for whom examiners completed school observations. In general, children continued to use their pre-implant communication method after receiving an implant and none of the children in this sample had their educational placement changed for at least 3 years following implantation. Based on clinical observation, all of the children increased their use of spoken English postimplant and were using spoken English (either with or without sign language) at the time of the reading evaluation. In the model, the OC group was coded 0 and the TC group was coded 1 (Cohen & Cohen, 1983).

**Pre-Implant Aided SDTs**

Pre-implant binaural aided SDTs were included in our model to control for the varying levels of audiological information that the children were receiving from conventional amplification (i.e., hearing aids) before implantation. SDTs represent the softest speech sounds that children can detect. The binaural aided SDTs (reported in dB HL) were obtained using live-voice stimuli in a soundproof booth while children used appropriate amplification. Prior to receiving their implants, the children demonstrated mean binaural aided SDTs of 53 dB HL. Their unaided SDTs all were greater than 80 dB HL.

**Length of Use/Age**

Length of implant use (LOU) in years was calculated by subtracting the date at which children first received their cochlear implant (age at implantation) from the date of their reading evaluation. There is good evidence that LOU affects cochlear implant performance. Children demonstrate superior speech perception (Osberger, 1994), speech production (Tye-Murray et al., 1995), vocabulary (Connor et al., 2000; Connor, Raudenbush, & Craig, 2001), and reading comprehension skills (L. Spencer et al., 1998) after sustained cochlear implant use, and these skills continue to improve over time. It is important to note, however, that by including both LOU and age at implantation in the SEM,
the combined variable (LOU/age) represents the child's age at the time of the reading evaluation. Further, because we used standardized scores, the coefficient between LOU/age and the outcomes represents differences, by age, in the disparity in achievement between children with cochlear implants and their same age peers with normal hearing sensitivity. A positive effect would indicate that the achievement gap was less for older children than for younger children; a negative effect would indicate that the achievement gap was greater for older children than for younger children.

Age at Onset of Deafness

All of the children in this study demonstrated prelingual onset of deafness. This included children who were diagnosed with a profound sensorineural hearing loss prior to their first birthday. In our sample, 84% of the children were congenitally deaf. Research indicates that age at onset of deafness significantly predicts cochlear implant performance, including reading outcomes (Geers, 2002). However, using this sample, age at onset (in years) did not significantly predict reading comprehension and so was not included in the model.

Demographics: SES, Gender, Race/Ethnicity

Previous studies that have examined the effects of SES and the mother's educational level (a key indicator of SES) have revealed no significant effect on reading for children with cochlear implants (Geers, 2002; Hodges et al., 1999; L. Spencer et al., 1998; Tomblin & Spencer, 1997). However, Geers (2003) found that SES, using income as the marker, did uniquely explain reading variance. In studies of children with normal hearing sensitivity, SES is a consistent and robust predictor of reading skills (Jencks & Phillips, 1998; Snow, Burns, & Griffin, 1998) and, therefore, it was included in our analyses. The type of medical insurance coverage used by children's families was noted at the time of the pre-implant evaluation. Children who qualified for Medicaid and state-funded insurance were considered to be from low SES (LSES) families (n = 23). Children whose families had private insurance, with or without state funded insurance, were assigned to the middle SES (MSES) group (n = 68). This variable was coded as follows: 1 = LSES and 0 = MSES.

According to published research, there does not appear to be a gender gap on measures of achievement for children who are deaf (Slate & Fawcett, 1996) or for performance with their cochlear implant (Osberger, 1994). However, to rule out any gender effect, we included gender as a variable, where girls were coded 1 and boys were coded 0. The addition of the gender variable to our model during exploratory data analyses did not explain a significant amount of variance in standard scores on reading comprehension (critical ratio [CR] < 1.96). The gender variable, therefore, was not included in the final model.

With regard to racial/ethnic groups, our sample included only a small proportion of children from African American (n = 2) and other ethnic groups (n = 3). There is evidence that "deaf and hard of hearing children who are members of racial, linguistic or ethnic minorities [leave school] with fewer language skills than their White counterparts even when adjustments for other demographic differences are made" (Kluwin & Corbett, 1998, p. 426). However, adding minority as a coded variable (White = 0; minority = 1) to our model during exploratory data analyses did not explain a significant amount of variance in standard scores on reading comprehension (CR < 1.96). Therefore, this variable also was not included in the final models.

Analytic Strategy

Our analytic strategy incorporated path analysis using SEM to test our hypothesis that multiple factors influence children's reading comprehension. "Path analysis can be viewed as an extension of multiple regression" (Klem, 2000, p. 65), but where there is more than one variable. With SEM, using AMOS software (Arbuckle, 1994–1999), we statistically compared the covariances between the variables in the theory-based model (see Figure 1) with the actual relations between the variables in our data set. If the theory-based model fits the data well, then the covariances implied by the model should not differ significantly from the covariances in the observed data. Goodness-of-fit measures are used to test the fit (Hoyle, 1995). If the model fits the data well, it is considered plausible. This notion of plausibility is important because there may be alternative models that fit the data equally well (Klem, 2000). For example, if reading comprehension actually predicts postimplant vocabulary, then such a model might fit the data as well as a model hypothesizing that postimplant vocabulary predicts reading comprehension, or, as we hypothesize, that there is a reciprocal relation between the two. SEM can reveal which models are plausible, but not which ones are correct.

Although in this study we use SEM to test a path analysis (Klem, 2000), where all variables are observed, more elaborate models including latent variables may also be examined using SEM. However, larger samples of more than 100 are required for these models (Kline, 1998).

Cognizant that our sample size is small for SEM, we selected several measures of goodness of fit for our model, including an estimate of chi square, which is
sensitive to sample size. We also report the Tucker-Lewis fit index (TLI) and the comparative fit index (CFI). A nonsignificant chi square indicates a good model fit with the data (i.e., the theoretical model does not differ significantly from the data driven model). Higher TLI and CFI values also suggest a good fit. Additionally, we report the root mean square error of approximation (RMSEA), which is an absolute fit index and takes into account the complexity of the model. Values below .05 represent a good fit. Descriptive statistics are provided in Table 1 and the correlation matrix of the variables included in the SEM is provided in Table 2.

In addition to overall model fit, SEM can provide information regarding the significance of direct effects or path coefficients (e.g., age at implantation to reading comprehension in Figure 1). The direction of the arrow, usually left to right, implies the flow of the causal effect. Path coefficients, which may be unstandardized (each measure on its own scale) or standardized (all variables on the same scale falling between -1 and 1), are interpreted in the same way that multiple regression coefficients (unstandardized and standardized) are interpreted—"they control for correlations among multiple presumed causes of the endogenous variable" (Kline, 1998, p. 52). For example, the path coefficient between age at implantation and reading comprehension controls for the correlation of variables in the model—communication, SDT, vocabulary, LOU, and so on. Unstandardized path coefficients' CRs above 1.96 may be considered to differ significantly from zero at the .05 level (i.e., 95% confidence level). Standardized path coefficients of less than .10 are generally considered small, those around .30 are considered medium, and those above .50 are considered large (Kline, 1998). Indirect paths (communication to pre-implant vocabulary to postimplant vocabulary to reading comprehension) also are estimated in SEM, which will be discussed more completely in the Results section.

Also included in the models (see Figure 1) are the disturbances, or error. These are designated by a large D (i.e., D1, D2, etc.). In SEM path analysis, every endogenous variable has a disturbance, which is analogous to the residual in a multiple regression (Klem, 2000; Kline, 1998). Theoretically, a disturbance may be considered to represent the influence of all of the unmeasured variables that affect the variable. For example, many variables may influence the age at which children receive cochlear implants over and above their method of communication, SES, and pre-implant SDT. Such variables include the age at which the child is diagnosed and the availability of an implant center (or, historically, the implant itself). The disturbance can be seen as a composite variable that represents these unmeasured causes of age at implantation (Kline, 1998). Standardized disturbances represent the unexplained variance (1 – R²; Klem, 2000). R² values, also called the squared multiple correlations (SMCs), are the percentage of variance explained for each endogenous variable in the model, and these are reported in the standardized path diagram (see Figure 2).

### Rationale for the Conceptual Models

The path diagram for our conceptual model is presented in Figure 1. Note that the disturbances for LOU/age and age (implanted) are assumed to covary because, together, they represent a child’s age at the time of the reading evaluation. Further, the disturbances between pre-implant vocabulary and age at implantation are assumed to covary because we predict a negative relation between them. This is based on research that indicates the language skills of children using hearing aids grow at about half the rate of those of children with normal-hearing sensitivity (Miyamoto et al., 1997; Svirsksy, 2001). Thus, there is an achievement gap that increases over time. Communication method, LSES, and

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**Table 2. Correlation coefficients for variables in the model.**

<table>
<thead>
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<th>1</th>
<th>2</th>
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<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<td>2.</td>
<td>.125</td>
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<td>4.</td>
<td>.410**</td>
<td>.065</td>
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<td>.400**</td>
<td>-.23*</td>
<td>.016</td>
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<td>8.</td>
<td>.044</td>
<td>.062</td>
<td>-.28**</td>
<td>.334**</td>
<td>-.61**</td>
<td>-.116</td>
<td>.516**</td>
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<td>9.</td>
<td>-.146</td>
<td>.250*</td>
<td>-.133</td>
<td>-.058</td>
<td>-.066</td>
<td>.231*</td>
<td>-.271*</td>
<td>-.166</td>
</tr>
</tbody>
</table>

Note. LSES = low socioeconomic status.

- p < .10. * p < .05. ** p < .01.
preoperative SDT are unanalyzed (i.e., allowed to covary) because, in this model, whatever causes them is unknown (Kline, 1998). Also, a reciprocal relation between reading and vocabulary was hypothesized based on research with children with normal hearing (Anderson & Freebody, 1981). Because we predict this reciprocal relation and have correlated disturbances, this model is considered nonrecursive. In this kind of model, variables may be both a cause and an effect of each other (e.g., reading comprehension and postimplant vocabulary). Without the reciprocal relation, the model can be considered partially recursive (although the literature is not consistent in its designation of models with unidirectional effects and correlated disturbances; Kline, 1998). Only recursive models, where the effects are unidirectional, where there are no correlated disturbances, and which involve only observed variables, can be tested using multiple regression. SEM must be used for the nonrecursive model we present.

When using nonrecursive models, the researcher must attend to the identification of the model. "A model is said to be identified if it is theoretically possible to calculate a unique estimate of every one of its parameters" (Kline, 1998, p. 108). If not, then it is underidentified or unidentified. In this study, the model is identified because we use instrumental variables, which predict preimplant vocabulary but not reading comprehension (pre-implant vocabulary) and that predict reading comprehension but not postimplant vocabulary (LSES and LOU). If we did not have the instrumental variables, then it would be impossible to find one unique solution for our model (there could be an infinite number of solutions), which is not permissible (Klem, 2000).

We hypothesized that multiple descriptive variables, including family SES, age at onset of deafness, and gender may affect reading performance with the cochlear implant. Exploratory analyses revealed that
Table 3. Unstandardized path coefficients from structural equation modeling (SEM Model 1).

<table>
<thead>
<tr>
<th>Variable paths</th>
<th>Estimate</th>
<th>SE</th>
<th>CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDT to LOU</td>
<td>0.045</td>
<td>0.016</td>
<td>2.825*</td>
</tr>
<tr>
<td>LSES to LOU</td>
<td>0.258</td>
<td>0.511</td>
<td>0.505</td>
</tr>
<tr>
<td>Communication method to LOU</td>
<td>-1.003</td>
<td>0.440</td>
<td>-2.279*</td>
</tr>
<tr>
<td>Communication method to age implanted</td>
<td>1.162</td>
<td>0.653</td>
<td>1.779</td>
</tr>
<tr>
<td>SDT to age implanted</td>
<td>-0.045</td>
<td>0.024</td>
<td>-1.916</td>
</tr>
<tr>
<td>LSES to age implanted</td>
<td>0.261</td>
<td>0.758</td>
<td>0.344</td>
</tr>
<tr>
<td>LSES to pre-implant vocabulary</td>
<td>-7.378</td>
<td>3.818</td>
<td>-1.932</td>
</tr>
<tr>
<td>SDT to pre-implant vocabulary</td>
<td>0.024</td>
<td>0.119</td>
<td>-0.201</td>
</tr>
<tr>
<td>Communication method to pre-implant vocabulary</td>
<td>14.073</td>
<td>3.294</td>
<td>4.272*</td>
</tr>
<tr>
<td>Pre-implant vocabulary to postimplant vocabulary</td>
<td>0.322</td>
<td>0.111</td>
<td>2.992*</td>
</tr>
<tr>
<td>Reading comprehension to postimplant vocabulary</td>
<td>0.210</td>
<td>0.240</td>
<td>0.874</td>
</tr>
<tr>
<td>Age implanted to postimplant vocabulary</td>
<td>-0.839</td>
<td>0.823</td>
<td>-1.021</td>
</tr>
<tr>
<td>LOU to reading comprehension</td>
<td>-3.298</td>
<td>0.405</td>
<td>-8.149*</td>
</tr>
<tr>
<td>LSES to reading comprehension</td>
<td>-5.234</td>
<td>1.685</td>
<td>-3.106*</td>
</tr>
<tr>
<td>Age implanted to reading comprehension</td>
<td>-3.573</td>
<td>0.303</td>
<td>-11.804*</td>
</tr>
<tr>
<td>Communication method to reading comprehension</td>
<td>1.109</td>
<td>1.513</td>
<td>0.733</td>
</tr>
<tr>
<td>Postimplant vocabulary to reading comprehension</td>
<td>0.177</td>
<td>0.061</td>
<td>2.880*</td>
</tr>
</tbody>
</table>

Note. Communication method: TC = 1, OC = 0. LOU = length of implant use.

*CR > 1.96.  p < .05.

Results

Structural Equation Modeling of Variables Affecting Reading Comprehension

Age at implantation, pre-implant vocabulary, post-implant vocabulary, communication method, pre-implant SDT, and LSES significantly affected children's reading comprehension. In turn, they significantly affected each other as well (see Table 3). This model fit the data well (see Table 4) for the small sample size. Small sample size increases the likelihood of finding a nonsignificant chi-square value, suggesting a good fit that does not exist. The opposite case exists for very large samples. With large samples, chi square can be significant although the model actually fits the data well. That is why several measures of goodness of fit are provided.

Frequently, SEM is used to test competing theories and researchers present alternative models (Kline, 1998). To test alternative theories (e.g., communication method has a direct versus an indirect effect on reading),

Table 4. Summary of structural equation model goodness of fit.

<table>
<thead>
<tr>
<th>Chi square (χ²)</th>
<th>TLI</th>
<th>CFI</th>
<th>RMSEA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEM Model 1</td>
<td>Measure of fit</td>
<td>df</td>
<td>p</td>
</tr>
<tr>
<td></td>
<td>10.752</td>
<td>6</td>
<td>.096</td>
</tr>
<tr>
<td>SEM Model 2</td>
<td>Measure of fit</td>
<td>df</td>
<td>p</td>
</tr>
<tr>
<td></td>
<td>12.348</td>
<td>10</td>
<td>.262</td>
</tr>
</tbody>
</table>

Note.  TLI = Tucker-Lewis fit index; CFI = comparative fit index.

χ² difference(4) = 1.596, p > .05.
the conceptual model was refined or trimmed (see Figure 2 and Table 4). We deleted only theoretically unimportant paths. For example, comparing Figures 1 and 2, we hypothesized that children from LSES families would have equal opportunity to receive and use their cochlear implants (we deleted LSES to LOU and LSES to age implanted paths from the conceptual model). LSES should affect vocabulary (Hart & Risley, 1995) and so the LSES to pre-implant vocabulary path was left in the final model, even though in the conceptual model the path coefficient was not significant (see Table 4). Because our alternative model was nested within the conceptual model, our alternative model could be tested by comparing the chi-square estimate of the conceptual model with the chi-square value of the more parsimonious model (Kline, 1998). A comparison of these models indicated that goodness of fit was maintained in the more parsimonious model; the $\chi^2$ difference ($\chi^2_1$ for Model 1 minus $\chi^2_2$ for Model 2) was not significant, $\chi^2_{difference}(4) = 1.596, p > .05$. Indeed, comparison of the absolute goodness-of-fit measure, RSMEA, which takes into account the complexity of the model, revealed a better fit with the data than was obtained with the conceptual model (see Table 5). The results of the final model are presented below (see Table 5 and Figure 2).

### Pre- and Postimplant Vocabulary

Children's vocabulary, both pre- and postimplant, had a significant effect on their reading comprehension scores. Children's vocabulary just prior to receiving their implants significantly predicted their vocabulary at the time of the reading evaluation (see Figure 2 and Table 5, total standardized effect = .105), suggesting some stability in vocabulary over time. Their postimplant vocabulary, in turn, significantly predicted their reading comprehension score (see Figure 2 and Table 5). Of the variables, only communication method contributed to pre-implant vocabulary. In addition to pre-implant vocabulary, age at implantation significantly negatively predicted postimplant vocabulary. Children who were younger when they received their implants tended to have higher postimplant vocabulary scores than did children who were older at implantation; for every year younger children were at implantation, their fitted postimplant vocabulary score was 1.37 points higher (standardized effect = -.241). Reading comprehension did not significantly predict postimplant vocabulary.

### Age at Implantation

Age at implantation directly and negatively affected reading comprehension (see Table 5 and Figure 2). The

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**Table 5.** Unstandardized path coefficients and disturbances from structural equation modeling (SEM Model 2).

<table>
<thead>
<tr>
<th>Variable paths</th>
<th>Estimate</th>
<th>SE</th>
<th>CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDT to LOU</td>
<td>0.043</td>
<td>0.016</td>
<td>2.775</td>
</tr>
<tr>
<td>Communication method to LOU</td>
<td>-0.971</td>
<td>0.436</td>
<td>-2.224</td>
</tr>
<tr>
<td>Communication method to age implanted</td>
<td>1.186</td>
<td>0.649</td>
<td>1.828</td>
</tr>
<tr>
<td>SDT to age implanted</td>
<td>-0.047</td>
<td>0.023</td>
<td>-2.000*</td>
</tr>
<tr>
<td>LSES to pre-implant vocabulary</td>
<td>-6.778</td>
<td>3.663</td>
<td>-1.850</td>
</tr>
<tr>
<td>SDT to pre-implant vocabulary</td>
<td>-0.021</td>
<td>0.119</td>
<td>-0.179</td>
</tr>
<tr>
<td>Communication method to pre-implant vocabulary</td>
<td>14.027</td>
<td>3.291</td>
<td>4.262*</td>
</tr>
<tr>
<td>Pre-implant vocabulary to postimplant vocabulary</td>
<td>0.383</td>
<td>0.107</td>
<td>3.573*</td>
</tr>
<tr>
<td>Age implanted to postimplant vocabulary</td>
<td>-1.373</td>
<td>0.558</td>
<td>-2.462*</td>
</tr>
<tr>
<td>LOU to reading comprehension</td>
<td>-3.291</td>
<td>0.397</td>
<td>-8.281*</td>
</tr>
<tr>
<td>LSES to reading comprehension</td>
<td>-4.757</td>
<td>1.664</td>
<td>-2.859*</td>
</tr>
<tr>
<td>Age implanted to reading comprehension</td>
<td>-14.84</td>
<td>0.282</td>
<td>-12.369*</td>
</tr>
<tr>
<td>Postimplant vocabulary to reading comprehension</td>
<td>0.219</td>
<td>0.043</td>
<td>5.135*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disturbances</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>4.026</td>
<td>0.614</td>
<td>6.559*</td>
</tr>
<tr>
<td>D2</td>
<td>43.894</td>
<td>6.801</td>
<td>6.454*</td>
</tr>
<tr>
<td>D3</td>
<td>216.932</td>
<td>33.908</td>
<td>6.398*</td>
</tr>
<tr>
<td>D4</td>
<td>9.053</td>
<td>1.353</td>
<td>6.689*</td>
</tr>
<tr>
<td>D5</td>
<td>249.931</td>
<td>38.252</td>
<td>6.534*</td>
</tr>
</tbody>
</table>

Note. Communication method: TC = 1, OC = 0.

*CR > 1.96, p < .05.
younger the age of the children when they received their implant, the higher were their predicted reading comprehension scores. The total unstandardized effect, including both direct and indirect paths, was \(-3.785\); for every year younger children were when they received their implant, the model predicted that their reading score increased more than 3½ points (total standardized effect = \(-.900\), which is large). Age at implantation significantly affected postimplant vocabulary. The younger the age of the children when they received their implants, the greater were their postimplant vocabulary scores. SDT significantly predicted age at implantation. Children with higher SDTs (i.e., more severe pre-implant hearing loss) tended to be younger when they received their implants. Communication method did not significantly predict age at implantation.

**Communication Method**

There was no significant direct path between communication method and reading comprehension (see Table 5 and Figure 2). Indeed, as discussed previously, removing the path from the model improved the goodness of fit. Thus, classification in the TC group was associated with higher pre-implant vocabulary, but the total direct and indirect effect of communication method on reading comprehension was negligible (total standardized effect = \(-.004\)). Hence, assignment to the TC group, per se, did not significantly predict stronger reading comprehension.

**LOU/Age**

The negative effect of LOU/age on reading comprehension (see Table 5 and Figure 2) appears to run counter to results suggesting that longer cochlear implant use is related to increasing scores over time. This effect actually reflects an achievement gap between children who use cochlear implants and children of the same age with normal hearing sensitivity. The negative effect of LOU/age indicates that, on average, older deaf children demonstrate a greater disparity between their scores and the scores of their age-matched peers with normal hearing sensitivity than do younger deaf children. The negative association does not suggest that the older children's reading raw scores were lower than younger children's; visual inspection of the data indicated that, on average, raw scores were higher for older children.

The achievement gap was moderated by other variables. For example, children with larger vocabularies who received their implants at a younger age exhibited a smaller achievement gap than did children with smaller vocabularies who were older when they received their implants. Further, the achievement gap was apparent before children received implants, as evidenced by the significantly negatively correlated disturbances for age at implantation and pre-implant vocabulary \((r = -0.26, \text{ covariance } = -11.519, CR = -2.591)\).

**LSES**

The LSES children in this study appeared to have equal opportunity to receive (path to age at implantation) and use (path to LOU) their cochlear implants, and the model fit improved when these paths were removed. Furthermore, LSES was not significantly associated with communication method (covariance = .025, SE = .024, CR = 1.031; \(r = .113\)). Nevertheless, on average, children from LSES families achieved significantly lower reading comprehension scores than did children from MSES families (see Figure 2 and Table 5), and this effect was direct. Although the trend was negative, LSES did not significantly predict pre-implant vocabulary. The total effect of LSES was \(-5.326\). This effect means that children from LSES families, on average, achieved reading comprehension scores more than five points lower than did children from MSES families, when all other variables were held constant (standardized total effect = \(-.180\)).

**Discussion**

Our findings demonstrate that children can follow multiple pathways to stronger reading comprehension skills, with paths that include vocabulary, age at implantation, communication method, and SES. Each path has implications for reading development for children who use cochlear implants. The results of this study underscore the interrelatedness of factors that affect cochlear implant performance, the importance of early implantation, the important role of vocabulary, and the complexity of comparing the reading skills of young cochlear implant users who use different methods of communication. Multilevel modeling techniques, such as SEM, help to elucidate these complex relations.

**Age at Implantation Effect**

The age at which children received their implants strongly affected their reading comprehension. Specifically, children who were younger when they received implants achieved higher reading comprehension scores and this effect was large. In addition to the direct effect of age at implantation on reading comprehension, children who were younger when they received their implants generally had stronger pre-implant vocabulary skills. This trend predicted stronger post-implant vocabulary, which in turn predicted reading comprehension. Further, age at implantation had a direct effect on postimplant vocabulary. Thus, there appeared to be a lasting effect of early implantation
that had an impact on both vocabulary growth and reading outcomes.

The direct effect of age at implantation on reading was important. Regardless of children's vocabulary or other factors, children who were younger when they received their implants achieved higher reading comprehension scores. The direct effect of age at implantation on reading is intriguing and opens several interesting lines of speculation. The cochlear implant, and the age at which children receive them, may provide a natural experiment. This experiment can be used to examine how the age at which children obtain auditory information has an impact on their developing auditory and language systems (i.e., age at implantation is considered a naturally occurring independent variable; Cook & Campbell, 1979). Clearly age at implantation is affecting important factors, which are not included in our model, that contribute to reading success. These factors include access to sound and access to spoken English.

Access to sound may have affected other factors related to reading success, including children's interactions with caregivers (Sroufe, 1988), joint attention (P. E. Spencer, 2000), and their overall connection to the world around them (Neuman & Dickinson, 2001; Snow et al., 1998). Further, the salient auditory information provided by their implants may have supported the children's acquisition of phonological awareness, which is closely related to reading success (Bradley & Bryant, 1983; Perfetti, Beck, Bell, & Hughes, 1987; Rego, 1997). It should be easier for children to develop phonological awareness if they can hear and discriminate phonological information (e.g., Alegria, 1998). Furthermore, grasping the alphabetic principal relies on the understanding that letters in the alphabet are associated with a particular set of speech sounds (i.e., phonemes). Again, access to auditory phonemic information might be expected to facilitate children's grasp of the alphabetic principal and, hence, reading.

The implant provides greater access to spoken English and its complex phonological, prosodic, intonational, and morphosyntactic structure. Each of these factors independently and together may support reading development. There is emerging evidence for children with normal hearing sensitivity that the use of more typical intonation and prosody during oral reading is associated with stronger reading comprehension (Kuhn & Stahl, 2002). Morphosyntactic knowledge is also related to stronger reading comprehension (Neuman & Dickinson, 2001; Snow et al., 1998). The younger the children are when they receive their implants, the longer they have access to this information as they develop their literacy skills. Moreover, early exposure to language, regardless of modality, may be critical for typical language development (Bates, 1999; Connor et al., 2001; Connor, Raudenbush, Zwolan, Heavner, & Craig, 2004; Elman et al., 1996; Hart & Risley, 1995; Lenneberg, 1967; Locke, 1997). The effect of early implantation on growth in vocabulary (postimplant vocabulary controlling for pre-implant vocabulary) also supports early sensitive period theories. Early implantation provides access to spoken English during the important early language development phase, and the resulting stronger language skills would tend to support stronger reading skills.

Because the vast majority of reading research includes participants with full and ongoing access to sound, there may be other acoustic aspects of reading that remain undiscovered. Investigation of the reading skills of children who receive cochlear implants at different ages may help us to understand the complex links between acoustic aspects of speech, language, and literacy.

The average age at which the children in this study received their implants was 6.7 years and most of the children were implanted between 1991 and 1997 (5 received them between 1988 and 1990). These two factors have important implications for our findings. First, at the time these children were implanted, FDA guidelines stated that cochlear implants were appropriate for use in children 2 years of age or older. Recently, the FDA decreased the minimum age for implantation to 12 months. This change has resulted in an increase in the number of children receiving implants at younger ages. Because this change in policy was a fairly recent occurrence, reading comprehension data are not yet available for children who received implants prior to age 2 years. It is likely that future studies will demonstrate even stronger effects of age at implantation on reading comprehension than did our study.

Secondly, several recent technological advancements have been made with cochlear implant devices. Because the children in this study received their implants several years ago, the effects of these advancements are not reflected in this study. For example, all of the children utilized the SPEAK strategy at the time of their reading evaluation, but some spent substantial time using MPEAK before SPEAK was available. It is likely that future studies, which will include participants who have had years of experience using more technologically advanced devices, will demonstrate even stronger outcomes for children using cochlear implants.

**Family SES**

It is encouraging that children from LSES and MSES families appeared to have equal access to cochlear implant technology. However, because the average age of children in the MSES group was just over 2 years older, and the MSES group received implants between 1991 and 1997, the effects of age at implantation may be more pronounced in the MSES group. The reading age at implantation is considered a naturally occurring independent variable; Cook & Campbell, 1979). Clearly age at implantation is affecting important factors, which are not included in our model, that contribute to reading success. These factors include access to sound and access to spoken English.
implants and that SES was not related to communication method. Surprisingly, although the trend was negative, family SES did not significantly predict pre-implant vocabulary. A relation was expected based on prior research on children with normal hearing sensitivity (Hart & Risley, 1995). Nevertheless, the reading comprehension scores of LSES children were significantly lower when compared to children from MSES families. This result is a consistent finding in the literature for children with normal hearing sensitivity (Hart & Risley, 1995; Neuman & Dickinson, 2001; Snow et al., 1998) and with a recent finding for children with cochlear implants (Geers, 2003). Many factors appear to be associated with LSES. These factors can have a deleterious effect on children's reading outcomes; such factors include underachievement, reduced academic opportunity, unstable housing, family stress, health issues, and single parent households. Additionally, there may be factors unique to young cochlear implant users. For example, transportation problems that preclude regular appointments for implant programming have been negatively associated with reading success (Geers, 2002). Clearly, more research is needed to evaluate the effects of SES on children's performance with cochlear implants.

**Vocabulary and Communication Method**

SEM results indicated that a child's early vocabulary and ongoing vocabulary growth are important predictors of reading comprehension. These results support previous and recent findings for deaf children (Geers, 2003; Padden & Ramsey, 1998, 2000) and for children with normal hearing sensitivity (Anderson & Freebody, 1981; Loban, 1976; Snow et al., 1998) and underscore important but complex links between language and literacy. Children with stronger language skills tend to have stronger reading skills. Specific aspects of their language systems, including lexicon, syntax, morphology, metalinguistic awareness, and pragmatic use of language, are interrelated and are, in turn, related to reading comprehension (Connor, Morrison, & Petrella, in press; National Institute of Child Health and Human Development, 2000; Snow, 2001).

Because both pre-implant and current vocabulary were endogenous variables in our model, factors that were related to stronger vocabulary (e.g., communication method [see below] and early implantation [see above]) also were related to stronger reading outcomes. Supporting deaf children's language development may be a critical first step toward preventing later difficulties with reading. Early cochlear implantation, pre-implant exposure to visuospatial language, maximizing pre-implant residual hearing, and intensive language and auditory therapy to support language development are all methods to be considered. Further, these are not mutually exclusive endeavors. A combination of strategies might prove to be most effective; however, more research is needed, including experiments using random assignment to pre-implant language support treatments.

A child's communication method, whether OC or TC, did not directly affect his or her reading comprehension scores when other variables were controlled. Indeed, the total effect was negligible. In our model, communication method was associated with early vocabulary skills, which were associated with vocabulary growth, which, in turn, predicted reading comprehension. Children in the TC group tended to have stronger pre-implant vocabulary skills than did children in the OC group. This may have been an artifact of our vocabulary tests and the difficulties inherent in cross-linguistic studies (see Tardif, 1996). It may also be that using a visuospatial language prior to having access to auditory language information, via the cochlear implant, supported child language development, including vocabulary (Mayberry, Lock, & Kazmi, 2002). Neuropsychological studies of native sign-language users indicated that use and understanding of British Sign Language followed the localization patterns of spoken language (MacSweeney et al., 2002). Mayberry and colleagues (Mayberry, 1993; Mayberry et al., 2002) observed that late acquisition of a first language appeared to result in long-term deficits, whereas early acquisition of a first language facilitated the acquisition of a second language. Overall, early access to language, regardless of modality, appears to be important for ongoing language and literacy development (Hart & Risley, 1995; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991; Locke, 1997; Shonkoff & Phillips, 2000; Snow et al., 1998).

Because the effect of communication method on reading comprehension was indirect and a function of pre-implant vocabulary, our results suggest that if parents decide to use sign language with their young children, then they should learn sign language well, use it consistently, and use it as soon as possible to build children's language skills (Moeller, 2002). Assignment to the OC or TC group was based on the child's pre-implant communication system. Our results, therefore, may allow us to generalize about the effects of teaching children sign language before they receive an implant. These results, however, do not suggest the extent to which an educational program's emphasis on a particular communication mode benefits or detracts from the overall postimplant effect. Almost all of the children increased their use of spoken English postimplant. Furthermore, given that all of the TC group children in this study used sign and spoken language together, these
results may not generalize to children who use ASL to communicate.

Consider also that, according to our model, children in the OC group with stronger vocabulary skills would be expected to achieve stronger reading comprehension skills than would children in the TC group with weaker vocabulary skills. Overall, then, children's vocabulary, and by proxy, their language skills, appear to be stronger predictors of their reading comprehension skills than are the methods of communication. Parents who decide to use OC with their child should be cognizant of their child's early vocabulary development. Programs that focus on language stimulation (e.g., auditory–verbal methods) including vocabulary have demonstrated strong outcomes (Goldberg & Flaxer, 2001).

In this study, vocabulary, age at implantation, and family SES were significant predictors of reading, whereas communication method was not. In this regard, these results differed from Geers and colleagues (Geers, 2002, 2003; Geers, Nicholas, & Sedey, 2003). In their studies, communication method significantly predicted reading but age at implantation did not (Geers 2002, 2003). There were, however, important differences between our study and theirs in the covariates included, the sample child characteristics, and in the analytic strategies used. Communication method was defined and coded differently in the two studies. Studies by Geers and colleagues (e.g., Geers, 2002; Geers & Brenner, 2003; Geers et al., 2003) defined communication method based on the child's educational program. They coded communication method using a noninterval ranking from 1 to 6 and included children who used a variety of communication methods, such as auditory–verbal (rank = 6), primarily sign language (rank = 1), and cued speech (rank = 4). This study used two groups, OC and TC; none of the children used cued speech. The two studies used different markers for SES, which may have contributed to different results. Participants in the studies by Geers and colleagues (Geers, 2002; Geers & Brenner, 2003; Geers et al., 2003) tended to be more affluent than ours. Furthermore, it is not clear whether SES and communication method were related in the Geers et al. studies. If SES and communication method were related to each other, then the relation between communication method and reading outcomes may have been biased (i.e., the results related to the SES effect rather than to communication method effects). Additionally, some children in the Geers et al. (Geers, 2002; Geers & Brenner, 2003; Geers et al., 2003) studies had IQs falling below 85, which was not the case in this study. All of the children in this study had cognitive abilities within normal limits. No measure of pre-implant hearing levels was included in the Geers et al. (Geers, 2002; Geers & Brenner, 2003; Geers et al., 2003) studies, which may be important because pre-implant residual hearing has been positively associated with postimplant speech perception (Zwolan et al., 1997). Moreover, the Geers et al. (Geers, 2002; Geers & Brenner, 2003; Geers et al., 2003) studies included covariates that we did not include (e.g., hours of therapy, parent participation in therapy, and therapist experience). Finally, the two studies used different analytic strategies. Geers et al. (Geers, 2002; Geers & Brenner, 2003; Geers et al., 2003) relied on regression and we used SEM. Both strategies are useful, but for different kinds of research questions. All of these differences could contribute to the different results in our study and in Geers et al. (Geers, 2002; Geers & Brenner, 2003; Geers et al., 2003).

The different effects for age at implantation are probably due to the different participant criteria used in the studies. Only children who received their implant by age 5 years were included in the Geers et al. study (Geers & Brenner, 2003), whereas children who received their implants by age 14 years were included in our investigation. The difference in the age ranges, 3 versus 11 years, could lead to different results. Additionally, age at implantation effects have been found for other outcomes in other studies (Connor et al., 2000; Kileny et al., 2001; Kirk et al., 2002; Sharma, Dorman, & Spahr, 2002; Tyler et al., 2001). Importantly, these studies all shared the common finding that stronger language skills (vocabulary or syntax) are associated with stronger reading skills (Geers, 2003; Geers et al., 2003).

Implications

Overall, the children in this study were not reading as well as their peers with normal hearing sensitivity. In our model, the achievement gap between children with implants and children with normal hearing sensitivity was evident for both vocabulary and reading comprehension. Nevertheless, the cochlear implant does appear to support reading development, especially if received early. There is evidence that children who use cochlear implants attain higher reading comprehension scores and that these scores grow more rapidly over time when compared to their peers who use conventional amplification (L. Spencer et al., 1998). Furthermore, strong early vocabulary skills, strong vocabulary growth, and early implantation appear to lessen the achievement gap. Nevertheless, the difficulties that these deaf children experience in learning to read remain important and perplexing. In recent years, we have learned more about important factors that contribute to children's reading success (see Rayner et al., 2001), including phonological awareness (Bryant, Maclean, & Bradley, 1990), early intervention (S. W. Barnett, 1995), and parent involvement (Neuman & Dickinson, 2001). Programs based on this research may prove effective.
Educational recommendations should not be made on the basis of this study alone. Further research is clearly needed. Many factors, such as the quality of a child's educational program, early identification of hearing loss and early intervention, parental support, the student's motivation, and his or her speed of auditory processing and working memory, may all contribute to reading performance (Alderman, 1999; W. S. Barnett, Frede, Mobasher, & Mohr, 1987; Bus & van Ijzendoorn, 1995; Calderon, Bargones, & Sidman, 1998; Catts, 1997; Pisoni & Geers, 2002). We do suggest that all schools serving children with cochlear implants provide well-designed and implemented auditory training, speech and language development programs, and strong literacy instruction. Reading curricula should include specific focus on phonological awareness, decoding, fluency, reading comprehension, and writing (Adams, 1990; Neuman & Dickinson, 2001; Snow et al., 1998). Recommendations provided to parents should be made thoughtfully, based on the extant research, and with careful focus on the best interest and needs of the individual child within the context of the family, school, and community (Bronfenbrenner, 1986). Additionally, educational, clinical, and medical professionals should discuss the documented benefits of early cochlear implantation with parents and advise them accordingly. This open discussion will be especially important as universal newborn hearing screening promotes very early intervention for more deaf children.

Studies of children who use cochlear implants are complex, and converging evidence reveals that multiple child, family, device, and educational factors contribute to successful outcomes. The results of this study underscore and expand these findings while illustrating the usefulness of multilevel statistical modeling techniques to examine the multifaceted relations between variables that influence a child's performance with a cochlear implant.

Acknowledgments

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