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Emergent literacy in kindergartners with cochlear implants

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Abstract

Problem—A key ingredient to academic success is being able to read. Deaf individuals have historically failed to develop literacy skills comparable to those of their normal-hearing peers, but early identification and cochlear implants have improved prospects that these children can learn to read at the levels of their peers. The goal of this study was to examine early, or emergent, literacy in these children.

Method—27 deaf children with cochlear implants (CIs) who had just completed kindergarten were tested on emergent literacy, as well as on cognitive and linguistic skills that support emergent literacy, specifically ones involving phonological awareness, executive functioning, and oral language. 17 kindergartners with normal hearing (NH) and 8 with hearing loss, but who used hearing aids (HAs) served as controls. Outcomes were compared for these three groups of children, regression analyses were performed to see if predictor variables for emergent literacy differed for children with NH and those with CIs, and factors related to the early treatment of hearing loss and prosthesis configuration were examined for children with CIs.

Results—Performance of children with CIs was roughly one or more standard deviations below the mean performance of children with NH on all tasks, except for syllable counting, reading fluency, and rapid serial naming. Oral language skills explained more variance in emergent literacy for children with CIs than for children with NH. Age of first implant explained moderate amounts of variance for several measures. Having one or two CIs had no effect, but children who had some amount of bimodal experience outperformed children who had none on several measures.

Conclusions—Even deaf children who have benefitted from early identification, intervention, and implantation are still at risk for problems with emergent literacy that could affect their academic success. This finding means that intensive language support needs to continue through at least the early elementary grades. Also a period of bimodal stimulation during the preschool years can help boost emergent literacy skills to some extent.

Keywords

deaf children; cochlear implants; reading; language

Statement of the Problem

There is perhaps no single skill more important to overall academic success than the ability to read. Once children reach roughly fourth grade, much of what they learn will be acquired through print, traditionally on paper but increasingly through electronic formats. Consequently it is essential that children acquire reading proficiency. This process proceeds

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smoothly for most children, but problems are encountered for five to ten percent of children who by all other indicators appear to be developing normally (Goswami 2011; Mogasale et al. 2011; Roongpraiwan et al. 2002). A major source of those problems has reliably been traced to difficulty recovering phonological (e.g., syllabic and phonemic) structure from the speech signal (Boada & Pennington 2006; Crain 1989; Liberman & Shankweiler 1985; Wagner & Torgesen 1987). Usually children display mature sensitivity to syllabic structure by 5 years of age and to phonemic structure by the time they reach seven or eight years of age (Liberman et al. 1974), at least in part due to reading instruction. Children with reading disabilities, however, fail to develop adequate sensitivity to such structure, in spite of instruction. Because these children display typical developmental patterns in all other respects, signs of reading problems are often missed until third or fourth grade, or even later. This situation makes it difficult to examine skills related to early, or emergent, literacy for these children.

Deaf children who receive cochlear implants may provide a way to examine emergent literacy in children who are not acquiring sensitivity to phonological structure on a typical timetable. Since roughly the turn of the 21st century, two factors have positively influenced spoken language outcomes for these children. First, programs in hospital nurseries that screen newborns have been able to identify congenital hearing loss at or near birth, rather than between three and six years of age, which was the norm just a couple decades ago (Commission on Education of the Deaf 1988). As a result, the opportunity exists to provide enhanced language experience as a way of promoting language development during those critical preschool years. Second, children with hearing loss too severe to be helped adequately by hearing aids now receive cochlear implants. These two practices have unequivocally led to better speech perception and production abilities in deaf children than what they previously attained (e.g., Geers & Brenner 2003; Svirsky et al. 2000). When it comes to reading, about half of deaf children who receive cochlear implants are demonstrating word reading and comprehension scores within one standard deviation of their normal-hearing peers (Geers 2003; Spencer et al. 2003); of course, that means that half of children with implants continue to perform more than one standard deviation below the mean of their normal-hearing peers. Further research is needed to understand the reading acquisition process for children with implants and the factors that explain their performance (e.g., Paul 2003).

One thing that is clear is that there are constraints on the kinds of signal properties conveyed by cochlear implants such that sensitivity to phonological structure is likely affected. These devices are not able to preserve all acoustic details available in natural speech signals. The processing strategy that has uniformly been adopted by manufacturers divides the speech spectrum into some number of channels, and recovers amplitude structure from each of those channels. Electrodes positioned close to the basilar membrane are then stimulated at levels specified by the recovered amplitude measurements. Primary among the limitations imposed by this processing strategy is the fact that spectral resolution is highly restricted in implants. In particular, formant transitions are poorly represented because changes in formant frequencies are coded only when those frequencies cross processing channels. Furthermore, the frequency-place match along the basilar membrane for implant users is not typical (Rosen et al.1999; Shannon 2002), so whatever spectral information implant users get is different from the norm. As a result of these limitations, perception of phonemic contrasts is restricted, even for adult implant users who lost their hearing long after acquiring language (Dorman et al. 2002; Lane et al. 2007; Munson & Nelson 2005). Consequently there is every reason to suspect that children who have been deaf since birth and receive cochlear implants will have severely constrained access to the acoustic structure that underlies phonological, specifically phonemic, structure. More global linguistic structure, such as that associated with syllables, can readily be recovered from the signals provided by implants because that kind of linguistic structure is well represented by amplitude structure. This all means that processing limitations can be expected to impact reading acquisition in a deleterious manner through their effect on children's abilities to recover phonemic structure.

Another line of investigation supports that prediction. Several investigators have provided evidence that difficulties in the processing of sensory information related to speech signals might underlie reading problems when they occur for children with normal hearing (Goswami et al. 2002; Hawker et al. 2008; Johnson et al. 2011; Ramirez & Mann 2005; Tallal 1980; Tallal & Piercy 1978; Wright et al. 1997). However, the conclusion is not universal (Hazan et al. 2009; Messaoud-Galusi et al. 2011), and the proposed nature of the perceptual deficit varies even among studies that report one. Nonetheless, there is some consensus that dyslexia might have its roots in how the speech signal is processed perceptually. Due to the constraints in signal processing for cochlear implants, children who use these devices could reasonably be expected to show similar deficits. For children with normal hearing who have dyslexia there is a suspected degradation in signal representation due to problems in the perceptual system. For children with implants there is a definite degradation in signal representation due to problems in the processing of the device. In both cases the net result is a deficient auditory representation of the speech signal. Because phonemic awareness deficits are predicted to arise from this signal degradation, it is reasonable to expect these deficits in children with implants. Therefore, the first hypothesis tested by the work reported here was that children with CIs would have poorer phonemic awareness than either children with normal hearing or children with hearing loss who have enough residual hearing to use hearing aids, and so retain some access to spectral structure in the speech signal.

Earlier Findings Regarding Literacy and Phonological Awareness in Deaf Children

Several studies have already investigated the acquisition of reading and related skills in children with cochlear implants, and Marschark et al. (2007) provide a particularly thorough review of that work. The goal of most such studies has been to measure the effects of cochlear implantation on language and literacy acquisition and identify independent factors that explain those effects. Geers and colleagues followed some of the first children to receive cochlear implants in the early 1990s through high school, measuring performance on a wide assortment of language-related tasks (e.g., Geers 2003, 2004; Geers & Hayes 2011). Results showed mean performance for these children to be near the 15th percentile of normal performance (−1 standard deviation) on all measures. Factors such as nonverbal intelligence and number of active electrodes explained significant portions of variance in outcomes on language and literacy measures. Age of implantation did not.

Other investigators have similarly tested the language and literacy skills of children with implants (Burkholder & Pisoni 2003; Geers 2004; Kyle & Harris 2010; Pisoni & Cleary 2003, 2004; Pisoni et al. 2010; Wauters et al. 2006). Because of similarity in focus, several of them are particularly relevant to the current study. For example, James et al. (2009) examined phonological awareness in 19 8-year-olds with cochlear implants, 19 reading-level matched peers, and 19 chronological age matched peers. They examined children's sensitivity to three kinds, or levels, of phonological structure: syllable, rhyme, and phoneme. The tasks were all visual with pictures representing target words; no acoustic stimuli were used. The children with cochlear implants performed as well as children in the two control groups on syllable awareness, but more poorly with rhyme and phonemic awareness. That finding would be predicted based on the idea that syllable structure at the linguistic level is discernible from amplitude structure at the acoustic level. Recognizing phonemic structure, on the other hand, requires access to spectral structure, precisely what is impoverished in cochlear implant processing strategies. Evidence of poorer access to phonemic structure was similarly reported by Ambrose, Fey, and Eisenberg (2012) for 24 preschool children with cochlear implants, compared to a control group of 23 age-matched peers with normal hearing.

Another study (Colin et al. 2007) asked if sensitivity to phonemic structure explains significant portions of variance in word reading for children with implants and those with normal hearing. By performing regression analyses on scores from each group separately, the authors showed that significant amounts of variance in word reading were explained by sensitivity to phonemic structure for children with normal hearing and those with hearing loss alike. None of the other predictor variables, including degree of hearing loss, explained a significant amount of variance. That finding is commensurate with a single deficit model of reading disability, proposing that a phonological deficit alone is the cause (see Pennington 2006, for a discussion of single and multiple deficit models).

Finally, Spencer et al. (2003) examined the relationship between reading comprehension and language skills for 16 9-year-olds with cochlear implants and 16 age-matched peers, for each group separately. Results demonstrated that the relationship between reading comprehension and oral language abilities was stronger for children with implants than for the children with normal hearing: $r = .8$ *vs.* $r = .5$, respectively. A separate study by Connor and Zwolan (2004) replicated the general result. Taken together, those findings appear at odds with a single deficit model and suggest that because children with cochlear implants have diminished access to the acoustic structure underlying phonemic structure, any reading proficiency they manage to acquire may actually depend more on general language abilities, including vocabulary. Those language abilities might develop in a more typical manner because of the intensive early intervention most children with hearing loss receive. The second hypothesis tested by the current work was that more variance in emergent literacy will be explained by general language skills for children with cochlear implants than for children with normal hearing.

How the Current Study Extends Past Studies

Although the current study was motivated by earlier work, it extends those studies in several important ways. In particular, this study was designed to examine the relationships between measures of literacy and measures of other skills thought to underlie literacy acquisition: sensitivity to phonological structure, executive functioning, and general language abilities. Children were tested at a young age (kindergarten) in order to examine emergent literacy in particular. This methodological detail should provide valuable information even for investigators interested in dyslexia in the normal-hearing population: it can be hard to get data on emergent literacy because reading problems are generally not diagnosed until later ages.

Because of some recent changes in the treatment of pediatric hearing loss, the current work was also able to investigate outcomes for these new trends in treatment. Other studies have been able to examine the effects of having a cochlear implant on language and literacy development, but generally that has involved only a single implant. It has been quite recent that other options – such as bilateral implantation or bimodal stimulation – have become available. In the current study, the majority of children with implants had two of them, and roughly half of those children had some experience with bimodal stimulation earlier in life. This configuration consists of a cochlear implant in one ear and a hearing aid in the other ear. Many children who receive cochlear implants have some small amount of hearing remaining, even if only in the very low frequencies below 250 Hz. That residual hearing is usually not enough to support speech recognition on its own, but when combined with electric stimulation through an implant it seems to provide some benefit to early language acquisition (e.g., Nittrouer & Chapman 2009). Based on the current prosthesis trends, the third hypothesis tested by this work was that children with some bimodal experience would perform better on emergent literacy measures than those with none.

Bilateral CIs are given to children with severe-to-profound hearing loss to help with sound localization and spatial release from masking (e.g., Litovsky et al. 2006). These psychoacoustic abilities should be expected to enhance opportunities for learning language by helping children hear language in the environment more efficiently. However, bilateral implants would not be expected to improve access to the acoustic structure that underlies phonemic categories: It is the same signal processing being implemented in both devices. Thus, the prediction could be made that children with bilateral implants might have better oral language skills than children with one implant, but they would not be expected to have better phonemic awareness. The fourth and final hypothesis tested by this work was that children with bilateral implants would perform better than children with just one implant on measures of oral language and perhaps reading, as well.

Skills to be Measured

In addition to measuring literacy, the current study sought to collect measures of skills believed to underlie early literacy (e.g., Shanahan et al. 2008). These are described below.

Phonological awareness

This term, fitting in the larger category of phonological processing, refers to a set of abilities involving sensitivity to and/or manipulation of phonological units. These units can be words, syllables, or phonemes. Some tasks examining these abilities require only implicit sensitivity to phonological structure, such as non-word repetition (e.g., Dillon & Pisoni 2001), but others require direct access and/or manipulation of linguistic units, such as decisions requiring participants to decide if test items share a common unit (e.g., Colin et al. 2007). Typically developing children first acquire abilities to recognize larger phonological units, such as syllables, and gradually hone their sensitivity to the point where they can recognize and manipulate individual phonemic segments (Fox & Routh 1975; Liberman et al. 1974). The protracted developmental process of refining the units of linguistic analysis reflects the highly encoded nature of phonemic structure. Children continue to discover phonemic structure and refine their own phonemic categories through much of the first decade of life (e.g., Beckman & Edwards 2000; Hazan & Barrett 2000; Nittrouer 2006). There is some evidence that tasks involving overt access of phonological units – those termed *meta*-phonological – predict reading better than tasks requiring only implicit access (e.g., Ecalle & Magnan 2002). Findings regarding children with implants and phonological awareness were summarized above.

Executive functioning

This term refers to a set of functions generally controlled by the frontal cortex that regulate attention and coordinate actions (Duncan 1986). When it comes to reading, it is important that an individual be able to store fairly long sequences of sensory information in a short-term, or working, memory buffer in order to process whole sentences. In some models this skill is viewed as independent of language abilities (e.g., Baddeley & Hitch 1974; Doiseau & Isingrini 2005), but not always (e.g., Pisoni 2000). Research with poor readers has shown that it is specifically a child’s ability to store and retrieve strings of *linguistic* materials that explains reading ability, not the storage and retrieval of sensory information more generally. For example, Brady et al. (1983) reported that normal-hearing 8-year-olds with reading disorders scored more poorly than their normal-reading peers on recall of word strings, but scored equivalently when asked to recall strings of environmental sounds. That observed deficit in recall of word strings has been reported by others for children with reading problems, compared to their typically reading peers (Hall et al. 1983; Nittrouer & Miller 1999; Spring & Perry 1983). The explanation given for these results is that words are stored in a short-term memory buffer using a phonemic code, and problems are encountered storing those words when a child has poor access to phonemic structure. Where deaf children are concerned, Pisoni and colleagues have demonstrated that digit span (another task often used to index verbal short-term memory) in children with CIs is correlated with their language experiences, so may develop as a result of those experiences (e.g., Cleary et al. 2000; Pisoni & Cleary 2003, 2004; Pisoni & Geers 2000; Pisoni et al. 2011). That work was generally done with children older than those tested in this study.

Speed of processing, typically measured by naming speed, is another skill that correlates highly with reading abilities (Catts et al. 2002; Phan et al. 2011; Torgesen et al. 1997). Although the way this skill should be categorized in cognitive terms has been uncertain, at times it has been described as an executive functioning skill (Denckla & Cutting 1999), and will be described as such in this report.

In general, even when children are found to be at-risk for reading deficits, strong abilities in verbal short-term memory and/or rapid serial naming have been identified as having ameliorating effects (e.g., Scarborough 1998). When it comes to deaf children, Pisoni (2000) has suggested that executive functioning skills such as verbal short-term memory and naming speed might help to explain the variability observed in performance on all language measures for children with cochlear implants, so these skills were examined in this study.

Oral language skills

The broad heading of ‘oral language skills’ can encompass an assortment of abilities, all of which have been found to correlate with successful literacy achievement. On the receptive side, children must be able to understand the language they are hearing before they can understand what they read. A child must also have a reasonably sized vocabulary. In particular, the size of a child’s *expressive* vocabulary seems strongly related to word reading abilities. Empirical outcomes support the importance of these two skills (auditory comprehension and expressive vocabulary) to emergent literacy (Wise et al. 2007). Finally, children must appreciate how narratives are constructed to communicate ideas richer than those expressed in single utterances in order to comprehend the academic texts that will serve up the material to be consumed in school (Roth & Spekman 1986; Snyder & Downey 1991). As with skills fitting into the domain of executive functioning, these skills have been found to correlate strongly with reading abilities specifically for deaf children (Crosson & Geers 2001; Geers 2003).

Several lines of research suggest that oral language skills would not necessarily be expected to depend heavily on an individual’s sensitivity to phonological structure. Generally speaking, these other skills are modeled as underlying reading comprehension, but independently from phonological awareness (Pennington & Bishop 2009). In particular, Snyder and Downey (1991) found that oral language skills and phonological awareness skills related differently to reading ability for children who read typically and those with disorders: Phonological awareness explained significant portions of variance in reading ability only for the typical readers. In addition, language deficits and reading problems are observed to occur independently of one another (Bishop & Snowling 2004; Catts et al. 2005). Finally, normal-hearing children can understand sentences vocoded to preserve only amplitude structure in as few as eight spectral bands with almost perfect accuracy by 5–7 years of age (Eisenberg et al. 2000). That kind of signal processing models the kind of acoustic structure available through cochlear implants. Because listeners can understand sentence length material with that structure, it must preserve adequate information for that purpose. All this evidence suggesting that oral language skills can develop somewhat independently of phonological awareness means children with implants might develop these skills in a typical manner on a close-to-typical timetable. If so, their role in literacy acquisition would not necessarily be constrained, and might even be enhanced due to children's poor sensitivity to relevant phonemic structure. That possibility was suggested by Spencer et al. (2003), and is further tested in this study.

Summary

In summary, the current study investigated early, or emergent, literacy skills in a group of children with hearing loss who use cochlear implants. Children with normal hearing and some with hearing loss who had enough residual hearing to benefit from hearing aids also participated. Based on previous findings, it was anticipated that children with implants would perform roughly one standard deviation below the mean performance of children with normal hearing on reading measures. The general goal of this work was to test that prediction and examine factors that explain literacy acquisition for deaf children with cochlear implants. Four specific hypotheses were tested:

1. Children with cochlear implants have poorer sensitivity to phonemic, but not necessarily syllable structure than children with normal hearing or those who wear hearing aids.
2. Oral language skills predict emergent literacy more strongly for children with cochlear implants than for children with normal hearing.
3. Some experience with bimodal stimulation facilitates better phonemic awareness and reading skills among children with cochlear implants.
4. Bilateral cochlear implants facilitate better oral language and reading skills.

Method

Participants

Fifty-two children who had just completed kindergarten came to The Ohio State University during the summer of 2010 to participate in this study. Of these, 35 had permanent sensorineural hearing loss with 3-frequency pure-tone averages greater than 50 dB HL in the better ear. Twenty-seven of those children had severe-to-profound hearing loss and wore one or two cochlear implants (CIs). Eight had moderate hearing loss and wore bilateral hearing aids (HAs). Another 17 children had normal hearing. Pure-tone audiometric measurements made at the time of testing confirmed these designations. All children with hearing loss received intervention services starting shortly after their hearing loss was identified at least once per week until they turned 36 months of age. Between 36 months of age and the start of kindergarten, all children with hearing loss attended preschool programs specifically designed for children with hearing loss for at least 16 hours per week. These programs all emphasized spoken language and provided pre-literacy experiences. All children participated in kindergarten curricula typical of mainstream educational programs during the year prior to testing.

Although their numbers were small, it was considered important to report outcomes for the children with HAs. All children with hearing loss, regardless of whether they wore CIs or HAs, had aided thresholds within the range of normal hearing, but children with HAs had access to the spectral structure that children with CIs lacked.

Sample sizes for children with NH or CIs were not particularly large either, but the advantages of using these particular samples outweighed possible disadvantages. With the exception of three children with NH, all children in the study had participated in a longitudinal study (Nittrouer 2010). Little attrition from the original sample of 205 children in the longitudinal study was encountered (only five families elected not to continue). Rather, the smaller samples in this experiment derived from the facts that: (1) only 40 of the original 87 children with NH were invited back; and (2) delays in refunding prevented testing of all children when they completed kindergarten. Having been in the longitudinal study meant that data had been collected from these children since they were 12 months of age, and no evidence was found for any child of risk factors for language or learning problems, other than hearing loss. Therefore, if differences were found in performance between children with NH and those with hearing loss, concern that they might be attributable to some undiagnosed difference between groups would be alleviated. In earlier work with these children, effect sizes of 1 or greater were found for language measures from children with NH and those with hearing loss. Assuming effects of those sizes continued to be found, the sample sizes of children with NH and CIs in the current study would provide at least 88% power to detect differences between these groups with alpha levels of .05.

Demographic measures—Table 1 presents demographic information for the three groups. Gender was well-balanced in all groups. Socio-economic status (SES) was indexed using a two-factor scale on which both the highest educational level and the occupational status of the primary income earner in the home is considered (Nittrouer & Burton 2005). Scores for each of these factors range from 1 to 8, with 8 being high. Values for the two factors are multiplied together resulting in a range of possible scores from 1 to 64. In general, a score of 30 represents a household in which the primary income earner has a four-year university degree and a job such as a mid-level manager or a teacher. Scores of 20 represent households in which the primary income earner has a high school diploma and works in a service industry, construction, or as a skilled craftsman. Although it appears children with HAs had lower SES scores than children in the other two groups, a one-way analysis of variance (ANOVA) failed to show a significant group effect.

Scores from three subtests of the Leiter International Performance Scale – Revised (Roid & Miller 2002) are provided as an index of three non-verbal cognitive abilities: matching, figure-ground recognition, and classification. The scores shown in Table 1 were obtained at 48 months of age for these children, excluding the three children with NH who were not part of the longitudinal study. Raw scores were recorded and used for statistical purposes, but here the scaled scores matching the mean raw scores are also shown. All children had non-verbal cognitive abilities within the normal range, and there were no group differences in mean scores.

The CID-22 word lists were presented via a loudspeaker at 0° azimuth. Each child heard one of the 50-word lists, and lists were randomized across children within each group. Children were videotaped as they repeated these words. At a later time, the videotapes were viewed and scored on a phoneme-by-phoneme basis. Consistent and obvious errors of articulation were not marked as wrong. All phonemes in a single word needed to be correct in order for that word to be scored as correct. Both phoneme and whole word scores were recorded. Significant group effects were found for the percentages of phonemes correct, $F(2,46) = 7.18$, $p = .002$, and of words correct, $F(2,46) = 10.80$, $p < .001$. In both cases, children with NH performed significantly better than children with HAs or those with CIs ($p < .01$), but there were no differences between children with HAs and those with CIs. Here and throughout this report, precise values from statistical tests are reported when $p < .10$; otherwise outcomes are reported as not significant (NS). Bonferroni corrections were used in computing p values for all multiple contrasts.

Audiometric measures—Table 2 shows means of audiometric measures for children with hearing loss. Regarding types of CIs, 11 of the 27 children with CIs had Cochlear Freedom, three had Cochlear System 5, 12 had Advanced Bionics HiRes/Harmony, and one had MedEl Tempo. Thirteen children with CIs had worn a HA on the ear contralateral to the CI for 12 months or more: The mean duration of bimodal experience was 29 months for these children. Seven of those children later received a second implant. Five of the other six children who had bimodal experience but did not receive a second implant had stopped wearing their hearing aids on the unimplanted ears. Eighteen children had bilateral CIs at the time of testing. Mean age at the time of the second implant is shown for them. Appendix A (Supplemental Digital Content 1) presents specific audiometric information for each child with a CI.

Equipment

All testing took place in sound-attenuated rooms. All stimuli used in testing were presented via a computer with a Creative Labs Soundblaster soundcard using a 44.1-kHz sampling rate with 16-bit digitization and a Roland MA-12C powered speaker for audio presentation. No live-voice stimuli were used, except in the auditory comprehension task. All stimuli, except those for the CID-22 word lists and the words for the verbal short-term memory task, were presented in audio-visual format using a 1500-kbps data rate and 24-bit digitization for video presentation. This allowed children to use visual cues for speech recognition. Presentation level was always 68 dB SPL.

All test sessions were video-recorded using a SONY HDR-XR550V video recorder so scoring could be done later. Children wore SONY FM transmitters in specially designed vests. The FM receivers provided direct line input to the video cameras to ensure good sound quality for all recordings.

General Procedures

Four to six children were tested at each data camp over a two-day period with four test sessions on the first day and two on the second day. Each test session consisted of several tasks that required between 40 and 60 minutes to accomplish altogether. Children had a minimum of one hour between test sessions. The two tasks that involved responses being entered directly into the computer (i.e., verbal short-term memory and phonological awareness) were scored by the software at the time of testing. Otherwise, videotapes were viewed by experimenters later and scored then.

Stimuli and Task-Specific Procedures

Phonological awareness—Three tasks assessing phonological awareness were used to cover a range of developmental levels. All required meta-awareness of the structure being examined. Going into testing, syllable counting was considered the developmentally simplest because it assesses sensitivity to syllable structure within words. In this task, the child saw and heard a man on the computer monitor produce a word. The child needed to count the number of syllables in the word by tapping them on the table. This was the same task as that originally developed by Liberman et al. (1974), which has been used frequently since then (e.g., Nittrouer & Burton 2005).

In the Initial Consonant Same-Different task (henceforth the initial consonant task), the child saw and heard the same male speaker produce two words. The child needed to judge whether or not they started with the same sound. It requires sensitivity to phonemic rather than syllabic structure, so the ability to perform this task should be acquired later than syllable counting. The Final Consonant Choice task (henceforth the final consonant task) was considered the hardest because it measured the skill expected to be acquired latest. In this task the child saw and heard a target word, which needed to be repeated correctly. Then three more words were presented in similar fashion. The child's job was to select which of those three words ended in the same sound as the target word. This task was the most difficult both because it required children to recognize the final consonant, which is integral to the syllable rime, and because the child needed to store four words in a short-term memory buffer in order to compare each possible choice against the target. Both of these phonemic awareness tasks evolved from tasks originally published by Stanovich et al. (1984), and used subsequently by Nittrouer and Burton (2005), among others. Items for each task are shown in Appendices B through D (Supplemental Digital Content 1). The percentages of correct answers in each task served as the dependent measures.

Emergent literacy—The Qualitative Reading Inventory (QRI) – 4 (Leslie & Caldwell 2006) was used to assess word reading, reading comprehension, and fluency. This instrument has both narrative and expository passages written at various levels of reading ability. The child reads a passage and retells it in as much detail as possible. Next the examiner asks questions the child must answer. For this study, three passages were selected. One passage was a narrative written at one level below kindergarten (pre-primer), one was a narrative written at a primer (or kindergarten) level, and one was an expository written at the primer level. There are five questions associated with the pre-primer passage, and six with each of the primer passages. The number of correct answers to questions associated with the pre-primer passage was multiplied by two and four questions were added to each of the primer passage question sets to make a total of ten points possible per passage. The number of words read correctly was used as the dependent measure for word reading. The sum of correct answers to questions was the dependent measure for reading comprehension. Finally, the time required to read the passage was computed from the videotape, and the number of correct words read per minute was used as the metric of fluency.

Executive functioning—Both verbal short-term memory and rapid serial naming were examined. Although both digit span and recall of order for simple words have been used to evaluate verbal short-term memory, the latter task was selected for this study. Specifically, children were asked to recall the order of strings of monosyllabic words presented as auditory lists. This procedure has been used often to examine short-term memory (e.g., Brady et al. 1983; Spring & Perry 1983), and this particular task with these particular words has been shown to have good test-retest reliability (Nittrouer & Miller 1999). Words were presented over the speaker positioned at 0° azimuth, one meter in front of the child. Ten lists consisting of the same six words were presented, with the order of words varied across each list randomly by the program. Lists of six words were used because this length is roughly two words longer than typical digit spans reported for children 6 years of age (Gathercole & Pickering, 2000; Orsini et al., 1987). Lists of that length work well: If lists are close to a listener's digit span there is a risk that the listener will perform at ceiling. If lists are too long, floor effects may be found. Previous work (e.g., Nittrouer & Miller, 1999) has shown that lists the length of mean digit span plus two words generally provide scores in the middle of the performance range.

The six words used in the short-term memory task were *ball, coat, dog, ham, pack,* and *rake.* Words in each list were presented with an onset-to-onset rate of 1 sec. After all words were presented, pictures of each item in random order, but not matching that of the audio presentation order, appeared at the top of the computer touch screen. The child's task was to touch each picture in the order heard. As the child touched a picture, it moved down and into place to the right of the picture just previously touched. After all words were touched, the pictures were at the bottom of the screen, in order from left to right according to how the child recalled hearing them. The software recorded the child's responses and compared them to the order in which words were actually presented. It also recorded the time it took to respond. Before testing, the time it took for the child to touch the numerals *1* to *6* in left to right order was recorded by the program. The mean of five such trials was used as a control for computing response time to the task (i.e., response time to test trial – mean response time in control trials). Training prior to testing was done using the letters *F, H, Q, R, S,* and *Y.* After training on how to do the task with those letter stimuli, the test words were introduced by presenting them over the speaker one at a time and displaying the picture that matched on the computer monitor. All six pictures were then displayed simultaneously. Children had to label each word accurately by touching the correct picture in order to proceed to testing. After testing with the ten lists, this procedure was repeated. Data were eliminated from the analysis if the child could not label each picture with perfect accuracy. The percentage of items out of 60 (ten lists of six words each) for which order was accurately recalled was used as a dependent measure, along with mean corrected response time to the ten trials. Having the measure of response time served as a check on whether any differences that might be observed across groups could be traced to differences in response times. Longer response times could allow the memory trace to decay, thus diminishing recall accuracy.

For rapid serial naming, the color and object naming subtests of the Comprehensive Test of Phonological Processing (Wagner et al. 1999) were used. Each of these subtests consists of two pages, each with four rows of nine pictures. The child's task is to name the pictures in order as quickly as possible. The time required to name all 36 pictures was derived from the videotape of the test session and the sum across the two trials was used as the dependent measure. Both subtests were used so that skills on both simpler (color naming) and perceptually and articulatorily more difficult (object naming) tasks could be measured. It was considered possible that children with weaker speech and language abilities might perform typically on color naming, but not on object naming. Children needed to be able to name the pictures individually before testing in order to proceed to testing.

Oral language skills—Three aspects of oral language were examined. Children's abilities to comprehend spoken language were assessed using the auditory comprehension subtest of the Preschool Language Scales – 4 (Zimmerman et al. 2002). This task requires the child to demonstrate an understanding of spoken language by performing specific commands given by the examiner. Standard scores were used as dependent measures.

Expressive vocabulary was assessed with the Expressive One-Word Picture Vocabulary Test (Brownell 2000). This task requires the child to provide the words that label a series of pictured items shown one at a time on separate pages. Standard scores were used as dependent measures.

Finally, a 20-minute language sample was recorded from each child, consisting of several personal narratives. To elicit these narratives, the examiner entered the room with a bandage on one hand. She explained that she hurt her hand and had been to see a doctor. Using a framework of descriptions of how the injury will affect upcoming plans, the examiner elicited narratives related to five themes: (1) what happened at a doctor's visit the child recently had; (2) a fun birthday party the child has attended; (3) how to play a favorite sport or game; (4) the best vacation the child has taken; and (5) the best movie the child has seen. Because of the high level of subjectivity, these videos were then scored by three independent viewers. To be included as a narrative segment, a section of language production from the child had to consist of at least two consecutive utterances of at least two words each. All narrative segments were used to score the child's narrative abilities in the 12 assessment areas shown in Appendix E (Supplemental Digital Content 1). This assessment rubric was similar to many developed by other investigators for such purposes, and was primarily based on work by Heilmann et al. (2010). For each area, the observer gave the child between 0 and 3 points. Thus, the final narrative score could vary between 0 and 36. If scores provided by the independent observers for any child differed by three or more points, they jointly scored that narrative and that joint score was used. Otherwise, the mean score across the three observers served as the dependent measure. The mean reliability coefficient across every two-way combination of the three observers before rescoring was 99 percent.

Results

Scores on all dependent measures were screened to ensure they were normally distributed and there was homogeneity of variances across groups.

Group Differences across Measures

Phonological awareness—The first analysis looked at whether or not children with CIs had poorer phonological awareness than other children. Two children with CIs were unable to perform even the practice trials, so they were not tested on these tasks.

Table 3 displays mean percent correct responses for each group for each phonological awareness task. One striking result is that, contrary to predictions, mean scores for all three groups were more accurate for the initial consonant task rather than for the syllable counting task. This could be explained by differences in task difficulty: Apparently it is easier to judge if components of two stimuli are the same than it is to count components within a stimulus. Cohen's *d*s were computed on scores from children with NH and those with CIs and provided effect sizes. These are shown in the last column of Table 3 and indicate that children with CIs performed most similarly to children with NH on the syllable counting task, followed by the initial consonant task, and finally by the final consonant task. These results had been predicted: Children with CIs performed most like children with NH on the syllable counting task and least like them on the harder of the two phonemic awareness tasks.

A two-way repeated measures ANOVA performed on these phonological awareness data revealed significant main effects of task, $F(2,94) = 49.69$, $p < .001$, and group, $F(2,47) = 15.87$, $p < .001$. The Task x Group interaction was not significant, $F(4,94) = 2.16$, $p = .084$. Thus, scores differed across tasks such that children in all groups generally performed most accurately on the initial consonant task and most poorly on the final consonant task. The syllable counting task, which had been predicted to be the easiest for all children, was actually harder than the initial consonant task for these children, even those with NH.

One-way ANOVAs with group as the factor were also performed on data for each task separately. Syllable counting did not show a significant group effect, $F(2,47) = 2.76$, $p = .074$. Significant effects were found for the other two tasks: initial consonant, $F(2,47) = 10.15$, $p < .001$; and final consonant, $F(2,47) = 27.97$, $p < .001$. Post hoc comparisons were done to locate the source of significant group effects for these latter two tasks. For the initial consonant task, children with NH performed differently from children with HAs ($p = .036$) and children with CIs ($p < .001$). For the final consonant task, children with NH again performed differently from both groups of children with hearing loss: $p < .001$ for both groups. Children with HAs and those with CIs performed similarly on both of these tasks, suggesting that at least some of the difficulty children with CIs have in honing their sensitivity to phonemic structure might not be related to the signal they get through their devices, but rather an effect of the hearing loss itself. However, the small size of the sample of children with HAs may have constrained the possibility of finding a significant difference between these groups.

Emergent literacy—Table 4 shows results from the QRI. In addition to mean scores for each passage on each of the three measures, a composite score was computed for each of the three measures across the three passages. For the word reading and fluency measures, means across the three passages were computed for each child. For the reading comprehension measure, the sum of questions answered correctly across the three passages was computed. This metric was used rather than a mean across passages because absolute values were low.

Looking first at word reading scores, it appears that children in all groups read the most words correctly for the primer narrative. Both primer passages had more words available to read than the pre-primer, and apparently the words in the narrative were easier to read than those in the expository. It also appears that children with NH read better than children in the other two groups for all three passages. A two-way repeated measures ANOVA was performed on these data with passage as the within-subjects factor and group as the between-subjects factor, and the results are shown at the top of Table 5. The main effects of passage and group were both significant, but the interaction was not ($p > .10$). Post hoc *t*-tests were done to locate differences among groups. Only the NH *vs.* CI contrast was significant ($p = .032$). A one-way ANOVA performed on the composite reading score showed the same main effect of group, $F(2,49) = 3.54$, $p = .037$, and again only the post hoc contrast of NH *vs.* CI was significant ($p = .032$).

Looking next at reading comprehension scores, it again appears from Table 4 that there were differences across passages: Children in all groups were more likely to answer questions correctly for the pre-primer narrative, followed by the primer narrative, and lastly by the primer expository. It also appears that children with NH performed best, followed by children with HAs, and finally by children with CIs. Results of the ANOVA are shown in the middle of Table 5, and support the trends described: Both main effects were significant. In this case, the Passage x Group interaction was also significant: The difference among groups diminished as the material became harder. Turning to the post hoc contrasts, it was again found that the only significant contrast was that of NH *vs.* CI ($p < .001$). And again a one-way ANOVA performed on the composite comprehension score revealed the same significant group effect, $F(2,49) = 8.35$, $p = .001$, and significant post hoc contrast of NH *vs.* CI ($p < .001$).

Looking at results for the fluency metric at the bottom of Table 4, it is apparent that the numbers of correct words read per minute decreased with increasing text difficulty. However, variability among children was quite high for all groups, and children with NH did not necessarily read faster than the children with hearing loss, especially those with HAs. Results of the ANOVA are shown on Table 5. Only a significant main effect of passage was found, which suggests that measures of fluency do not reliably index reading skill for deaf children: These deaf children were as fluent as the children with NH, but did not read as accurately or comprehend as well. The composite fluency score similarly failed to show a significant group effect.

Executive functioning—In the serial recall task designed to examine verbal short-term memory, four children with CIs and one child with HAs were unable to recognize the words reliably in the pre-test labeling task, so they were not tested. Because their difficulties reflect problems in auditory recognition, the failure to do so does not mean that these children's short-term recall was necessarily impaired. With the rapid serial naming tasks, one child with CIs was not able to label either all of the colors or all of the objects, so he was not tested on these tasks. Video was inadvertently lost for three other children: one with CIs and two with HAs.

Table 6 displays means for these measures. The top two rows show results for the verbal short-term memory task. The bottom two rows show mean naming times for the color and object naming tasks. One-way ANOVAs performed on each of these four measures failed to reveal a significant group effect for any measure, although it was close for percent correct on serial recall, $F(2,44) = 2.75$, $p = .075$; for the other three measures, $p > .10$. The failure to find a significant group effect for percent correct on serial recall differed from results obtained by others who observed group effects when outcomes for only children with NH and those with CIs were compared, excluding children with HAs (e.g., Cleary et al., 2000; Pisoni & Cleary, 2003; Pisoni & Geers, 2000). For that reason, as well as because the group effect found here was close to significant, a simple *t* test comparing percent correct scores for children with NH and those with CIs was performed. That analysis revealed a significant difference between these two groups, $t(38) = 2.28$, $p = .029$. Consequently, there was some evidence of a deficit in verbal short-term memory for children with CIs, compared to children with NH.

Oral language skills—Table 7 shows mean scores for each group on the three measures of oral language abilities. One-way ANOVAs performed on data for each of these measures showed significant group effects for all: auditory comprehension, $F(2,49) = 10.09$, $p < .001$; expressive vocabulary, $F(2,49) = 8.98$, $p < .001$; and narrative skills, $F(2,49) = 12.58$, $p < .001$. Post hoc comparisons showed that children with CIs performed significantly differently from children with NH on all three measures ($p < .001$). Children with HAs performed similarly to children with NH on the auditory comprehension and expressive vocabulary measures, but differently on the measure of narrative skills ($p = .003$). The HA *vs.* CI contrast was not significant for any measure.

Summary—These inferential statistics indicate that children with CIs performed more poorly than children with NH on most measures of literacy and its underlying skills. The measures not showing significant effects were syllable counting, reading fluency and the measures of executive functioning. Word reading and comprehension scores of children with CIs were roughly one standard deviation below the mean of children with NH, as expected. The largest group effects were found for the measures of phonemic awareness: Cohen's *d*s show that children with CIs scored roughly 2 SDs below the means of children with NH. That outcome had been predicted because signal processing strategies for cochlear implants do not preserve the kinds of signal structure, mostly spectral, that underlies phonemic categorization. The finding that had not necessarily been predicted was that these particular children with CIs would perform more poorly than the children with NH on measures of oral language: Children with CIs scored roughly 1.5 SDs below the means of children with NH on these tasks. Thus, in spite of having been identified early in life with hearing loss and having received appropriate treatment for that hearing loss, these children with CIs were hindered in their general language development. Children with HAs performed better than children with CIs on many measures, although the differences usually did not reach statistical significance. In general, children with HAs performed intermediately between children with NH and those with CIs. Because intervention strategies were similar for the two groups of children with hearing loss and aided thresholds were within normal limits for all children, this trend may reflect the importance of having spectral structure to the learning of phonemic categories.

Explaining Variance in Emergent Literacy for Children with NH and those with CIs

The amount of variance explained in children's emergent literacy by measures from each construct (phonological awareness, executive functioning, and oral language) was explored next. The composite measures of word reading and comprehension were used as dependent variables in these analyses. The measure of reading fluency did not show differences among groups, so that was not used.

Regression analyses—The first question addressed was whether general patterns of relationship between the skills thought to underlie emergent literacy and literacy itself were similar for children with NH and those with CIs. Separate linear regressions with one predictor variable were performed with each of the composite measures to obtain standardized beta coefficients. Predictor variables included all six measures collected in the domains of phonological awareness and oral language abilities. For executive functioning, percent correct on serial recall and time for rapid object naming were selected to index working memory and processing speed, respectively. Separate coefficients were computed for children with NH and those with CIs. Children with HAs were not included because there were so few of them.

Standardized beta coefficients obtained from these 32 regression analyses (2 dependent measures x 2 groups x 8 predictor variables) are shown in Table 8. Asterisks indicate which of these coefficients were significantly different from zero. Univariate ANOVAs were performed separately on scores from each of the two dependent variables to see if these coefficients were different for the two groups of children. This was done by using group (NH or CI) as a fixed factor and using each predictor variable as a covariate, and looking at whether the Group x Covariate interaction was significant. None was significant, suggesting that the general patterns of relationship among each of the skills that underlie emergent literacy and literacy itself are similar for children with NH and those with CIs. Nonetheless, it remained possible that the variables *most* predictive of reading acquisition across these two groups could be different. To answer that question it was necessary to enter all variables into regression analyses in aggregate to see which explained significant portions of unique variance in the reading measures, and this needed to be done for children with NH and those with CIs separately.

Stepwise linear regression—Four standard stepwise linear regressions were done next, separately for each dependent variable of reading acquisition (mean words read correctly and the composite comprehension score) and separately for children with NH and those with CIs. The same eight predictor variables used to compute standardized beta coefficients shown in Table 8 were used in these analyses, and variables were entered for $p < .05$. Table 9 presents statistics for the predictor variables found to explain significant portions of unique variance for the dependent variables, for each group. Looking first at the results for word reading, it can be seen that the most significant predictor for children with NH was the score on the initial consonant task. That outcome highlights the strong influence of phonemic awareness on typical emergent literacy. For children with CIs, the most significant predictors were syllable counting and narrative scores. These children had restricted access to phonemic structure due to the signal processing strategies of their implants. When literacy acquisition proceeds largely uninformed by typical phonemic awareness, other skills take on enhanced roles in the process (Snyder & Downey, 1991). Indeed, different phonological and oral language skills were found to be most predictive of word reading for children with NH and those with CIs. Outcomes of these stepwise regressions for children with NH and those with CIs were replicated using a backwards selection process.

Looking next at reading comprehension, it is again seen that different underlying skills are most predictive of success for these two groups of children. For children with NH, the only significant predictor was expressive vocabulary. For children with CIs, syllable counting and narrative scores were again the predictor variables found to explain most of the variance in outcomes. When a backwards selection process was used for these comprehension scores, the model obtained for children with NH using forward stepping was replicated again. For children with CIs, however, slightly different results were obtained. In this case, narrative scores were found to explain the largest portion of unique variance, but rapid serial naming and auditory comprehension scores were found to explain roughly equal amounts of additional variance, instead of syllable counting. Although there is no reason to select one or the other of the models derived for children with CIs as most representative of what supports acquisition of reading comprehension, both models differ from what was found for children with NH. Thus it may still be concluded that there were differences across groups in the contributions of the underlying skills to that acquisition. The variables that were found to be most predictive of reading success differed for the two groups.

Children with CIs

As a final step, outcomes for children with CIs were examined separately to see if factors related to their prosthesis configuration or history could explain variability in performance on either the measures of emergent literacy or on the skills that support literacy development. Again, the composite measures of word reading and comprehension were used as indicators of emergent literacy; measures of phonological awareness and oral language were considered as the skills that support emergent literacy. Measures of executive functioning were not used in these analyses because standardized beta coefficients (Table 8) were not significant for children with CIs or those with NH.

Demographic factors—Zero-order correlation coefficients were obtained between scores for each of eight measures (two of emergent literacy, three of phonological awareness, and three of oral language) and the demographic factors of SES, pre-implant better-ear PTAs, age of identification, age of first implant, age of second implant, and length of (first) implant experience. Of all these correlations, only a few had $p < .10$: SES *vs.* expressive vocabulary, $r = .45$, $p = .018$, age of first implant *vs.* initial consonant task, $r = -.54$, $p = .006$; age of first implant *vs.* auditory comprehension, $r = -.40$, $p = .038$; and length of implant experience *vs.* initial consonant task, $r = .58$, $p = .002$. Thus, being implanted earlier in life was associated with better phonemic awareness and abilities to comprehend spoken language. Length of implant experience, which is strongly related to age of implantation for these children, was associated with better phonemic awareness. Age of identification, pre-implant better-ear PTAs, and age of second implant failed to explain significant amounts of variance for any dependent measure.

Prosthesis effects—Any potential effects of having two implants, rather than one, and of having had or not had at least one year of bimodal experience were examined. Only one child was still wearing a HA with a CI at the time of testing. That child was not included in these analyses. All other children could be clearly categorized as having one or two CIs, with no HA at time of testing, and as having had a history of bimodal experience, or not. This one child did not fit these categories neatly.

Because SES and age of first implant were each found to explain significant amounts of variance on some measures, groups were checked to make sure they did not differ with respect to these demographic factors. Children with one and two CIs were well-matched on both SES and age of first (or only) implant: Mean SES for both groups was 33 (SD = 12). Mean age of first implant was 21 months (SD = 17 months) for children with one CI and 20 months (SD = 11 months) for children with two CIs. This difference was not significant.

Mean SES was 27 (SD = 10) for children with some bimodal experience and 38 (SD = 12) for children with no bimodal experience. This difference was significant, $t(24) = 2.53$, $p = .019$. Mean age of first implant was 19 months for both groups (SD = 12 months for children with some bimodal experience and SD = 8 months for children with no bimodal experience). Thus, there was one potentially relevant difference on these demographic factors as a function of whether children had some bimodal experience or not. It indicated that children with no bimodal experience might be expected to score better as a group on expressive vocabulary than children with some bimodal experience because SES is positively correlated with these vocabulary scores.

Table 10 shows means for the dependent measures that have been considered in other analyses. Here, children with CIs are categorized as a function of whether they had one or two CIs at the time of testing. From the results, it appears that children with one CI consistently scored better than children with two CIs on the measures of emergent literacy and oral language. Outcomes for measures of phonological awareness show no consistent advantage for one group over the other. In any event, a series of t tests performed on each measure separately for children with one and two CIs did not reveal any significant differences. Thus, no benefits were observed for having two implants instead of just one.

Table 11 shows means based on whether or not children had any bimodal experience. It appears that children with some bimodal experience performed better than children with no such experience on all measures except expressive vocabulary. Subsequent t tests revealed results with $p < .10$ for reading comprehension, $t(24) = 1.88$, $p = .072$, the initial consonant task, $t(22) = 2.26$, $p = .034$, the final consonant task, $t(22) = 2.27$, $p = .034$, and auditory comprehension, $t(24) = 1.83$, $p = .079$. Thus, even though the effect was not always statistically significant, a period of time with bimodal stimulation was found to facilitate the acquisition of early literacy and other skills that promote literacy. The measure that showed the smallest effect size was expressive vocabulary, the one measure that had a significant correlation with SES. Children with no bimodal experience had a higher mean SES than children with some bimodal experience. That seems only to have “leveled the playing field” for these groups.

Discussion

The purpose of this study was to examine emergent literacy and the skills underlying literacy acquisition, especially phonological awareness, in kindergarten children who use cochlear implants. These children were all identified with hearing loss very early in life and received appropriate treatment for that hearing loss, as well as intervention for spoken language stimulation. Nonetheless, these children had highly restricted access to the acoustic structure underlying phonemic categories due to the signal processing limitations of cochlear implants. This situation made this sample of children an appropriate model for examining what happens when that kind of structure is unavailable during pre- and early literacy acquisition. It has been proposed that the source of reading problems for children with NH who encounter difficulty likely rests with problems processing the speech signal. Although the crux of the problem for those children might rest with how signal structure is processed by their perceptual systems (Johnson et al. 2011; Ramirez & Mann 2005), and the problem for children with CIs is that not all kinds of signal structure are available to them, the net result should be the same: Without appropriate kinds of sensory information, it is extremely difficult to hone sensitivity to phonemic categories. This study looked at what happens when that situation exists, using children with CIs as participants. Whereas the locus and nature of processing deficits continues to be debated for children with NH, there is no question that the availability of some forms of acoustic structure is limited for children with CIs. Hypotheses tested in this study included the prediction that children with CIs would have poor sensitivity to phonemic structure, but near-normal sensitivity to syllable structure; acoustic structure supporting the latter is preserved by implant processing algorithms. As a result, literacy skills were predicted to be poorer for the children with CIs than for these children with NH, who had no risk factors for reading problems. In addition, general language abilities were predicted to explain more variance in literacy measures for the children with CIs than for the children with NH, whose scores were predicted to be explained most strongly by phonemic awareness.

Only eight children with HAs contributed data to this report, but including their data was useful. Although unaided auditory thresholds were better for the children with HAs than for those with CIs, aided thresholds were within normal limits for all children. The primary difference regarding sensory input for these two groups of children with hearing loss was that those with HAs were able to perceive spectral structure through their devices, whereas that structure is severely restricted for children with CIs.

Several components in the design of this study differed from earlier studies examining similar questions. This study was conducted with a group of participants who were all identified early and received intervention early. All children were close in age and in the same grade at the time of testing. Some children with CIs had two implants and some had just one. Some children had experience using a HA in combination with a CI (i.e., bimodal experience), and some did not. These additional factors led to the third and fourth hypotheses tested in this study: If access to some spectral structure in the sensory input is required for phonemic awareness, and by extension for literacy acquisition, it was predicted that children with some bimodal experience would show better outcomes than those with no such experience at all. Regarding bilateral implants, it was predicted that they would lead to better oral language skills and by extension better reading abilities for children with two, rather than just one implant.

Group Differences

Children with CIs showed poorer performance on almost every skill evaluated, compared to children with NH, and on some measures, even in comparison to children with HAs. In this study, the performance of children with HAs fell intermediate to that of children with NH and those with CIs for most measures. Group differences involving the HA group did not always reach statistical significance, but that could partly be due to the small size of that sample. By contrast, almost all differences between children with CIs and those with NH reached statistical significance. The only skill on which children with CIs performed similarly to children with NH was rapid serial naming.

Regarding phonological awareness, children with CIs performed more poorly than children with NH on the tasks measuring awareness of phonemic structure. These tasks showed the greatest differences between these groups of all constructs measured. This finding had been predicted because cochlear implants preclude access to some of the acoustic structure in the speech signal that supports phonemic categorization. At the same time, awareness of syllable structure was not found to differ significantly across groups. That outcome had also been predicted because processing strategies for cochlear implants preserve acoustic structure associated with syllable structure. Thus the first hypothesis was supported.

When it comes to measures of emergent literacy, children with CIs showed poorer skills on two of the three tasks compared to children with NH. Both their word reading and reading comprehension were roughly one standard deviation below the mean of children with NH. Only the measure of reading fluency failed to show group effects, suggesting that this metric is not sensitive enough to detect reading problems when they exist for deaf children. This outcome has important clinical implications because often fluency measures are the only ones used by educators to evaluate reading abilities in children.

When it comes to oral language skills, children with CIs performed more poorly than children with NH on all three tasks: auditory comprehension, expressive vocabulary, and narrative skills. Going into this study, the possibility was suggested that these children who were identified and received intervention at very young ages might be acquiring oral language skills on a typical time table. However, it is clear that even with early intervention, children with severe-to-profound hearing loss are not necessarily acquiring language skills at the same ages as their peers with NH.

Explaining Variance

An interesting outcome of the current study concerned the underlying skills that were most responsible for emergent literacy for children with NH and those with CIs. For children with NH, phonemic awareness, as measured by the initial consonant task, explained the most variance in word reading. The size of children's expressive vocabularies explained the most variance in their reading comprehension. For children with CIs, sensitivity to syllabic structure and broad narrative abilities explained most of the variance in both word reading and reading comprehension. Thus the second hypothesis was supported. Generally speaking, children with CIs lagged behind children with NH in their literacy acquisition. Within the limited range of literacy abilities demonstrated by these children, however, different underlying skills accounted for their success than those accounting for success by children with NH. In all likelihood, some sensitivity to phonemic structure is required to move to the level of reading proficiency in which the children with NH were generally operating. That kind of sensitivity eludes many children with CIs because of the limitations of their cochlear implants.

Prosthesis Effects

The current study was also able to examine factors related to the early treatment of hearing loss that may have affected emergent literacy and related skills for children with CIs. This exploration included age of identification of hearing loss, pre-implant audiometric thresholds, age at which children got their first and second implants, and length of (first) implant experience. The effects of bilateral implants and bimodal experience were also considered.

Regarding early treatment effects, the primary factor found to have an effect on any of the dependent measures was the age at which the child received a first implant. Moderately strong correlations were observed for this factor and phonemic awareness and auditory comprehension. A similarly strong association was found between length of implant experience and phonemic awareness. However, length of implant experience and age of first implant are such closely related factors that these effects can not be viewed as independent.

Turning to prosthesis configuration effects, no differences in outcomes were observed for children with one versus two implants, even though they were well matched on audiometric variables. However, children who had some bimodal experience showed generally better scores on the dependent measures, although the effect did not always reach statistical significance. This finding suggests that having access to the spectral structure of the speech signal available only with acoustic hearing may help deaf children with CIs, even if they have only limited access to acoustic hearing and only for a brief time. The finding highlights the more general point that reading acquisition really is dependent on being able to hear and process the acoustic signal of speech well enough to develop sensitivity to phonemic structure. The third hypothesis tested by this study was supported; the fourth was not.

Conclusions

This study investigated emergent literacy in children with hearing loss who wore cochlear implants. Because of the processing limitations of these devices, patterns of performance for these children could provide insight into what happens when literacy acquisition proceeds without the availability of the acoustic structure that underlies phonological, especially phonemic, structure. What we learn from these children is that phonemic awareness is critical, but other language skills play important roles, as well. For children who encounter challenges in discovering phonemic structure in the speech signal, awareness of syllable structure and other language skills take on enhanced importance. This was observed for deaf children in this study, but is presumably true for children with NH who have phonological awareness deficits, as well (Snyder & Downey 1991).

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Means and Standard Deviations (SDs) for demographic variables for the three groups of listeners. Leiter scores are from testing at 48 months of age. Socio-economic status is a two-factor index based on occupation and education of the primary income earner in the household.

	Group					
	NH		**HA**		**CI**	
	17		**8**		**27**	
	M	**(SD)**	**M**	**(SD)**	**M**	**(SD)**
Age at time of testing (months)	79	(3)	78	(4)	81	(5)
Proportion of males	.47	---	.50	---	.48	---
Socio-economic status	37	(14)	25	(11)	33	(12)
Leiter Matching Raw Score	27.4	(3.7)	28.0	(1.6)	26.0	(4.9)
Leiter Matching Scaled Score	*11*	---	*12*	---	*10*	---
Leiter Figure-Ground Raw Score	12.3	(3.7)	11.6	(3.9)	11.4	(3.4)
Leiter Figure-Ground Scaled Score	*12*	---	*12*	---	*12*	---
Leiter Classification Raw Score	14.3	(2.2)	12.6	(3.5)	13.6	(4.5)
Leiter Classification Scaled Score	*10*	---	*10*	---	*10*	---
CID-22 percent phonemes correct	96.0	(4.2)	76.4	(28.2)	75.5	(16.8)
CID-22 percent words correct	90.3	(8.3)	60.0	(34.9)	56.4	(23.2)

Table 2

Means and SDs for audiometric measures related to deaf children. Pure-tone averages (PTAs) are given in dB HL and are for the three speech frequencies of 500, 1,000, and 2,000 Hz. PTAs shown here are for the better ear. Eighteen children received a second implant.

	Group			
	CI		**HA**	
	27		**8**	
	M	**(SD)**	**M**	**(SD)**
Age at identification (months)	8	(8)	9	(11)
Pre-implant PTA (CIs)/Current PTA (HAs)	99	(18)	65	(11)
Age at first implant (months)	21	(13)	---	---
Age at second implant (months)	35	(14)	---	---
Mean length of implant use (months)	61	(13)	---	---

Table 3

Means and SDs for percent correct scores for measures of phonological awareness. In the last column, Cohen's *d*s provide estimates of effect sizes between scores of children with NH and those with CIs.

	Group						
	NH		**HA**		**CI**		**NH *vs.* CI**
	17		**8**		**25**		
	M	**(SD)**	**M**	**(SD)**	**M**	**(SD)**	***d***
Syllable Counting	69.1	(35.8)	59.6	(23.4)	46.2	(30.3)	0.69
Initial Consonant Task	93.1	(10.0)	70.1	(32.9)	64.4	(21.1)	1.74
Final Consonant Task	59.2	(23.4)	23.7	(24.3)	13.7	(14.6)	2.33

Table 4

Means and SDs for reading measures from the Qualitative Reading Inventory (QRI). Numbers of children in each group are shown under the group headings. Cohen's *d*s for measures with significant group effects are shown in the right column for children with NH *vs.* CIs.

	Group						
	NH		**HA**		**CI**		**NH *vs.* CI**
	17		**8**		**27**		
	M	**(SD)**	**M**	**(SD)**	**M**	**(SD)**	***d***
Word reading (words correct)							
Pre-primer Narrative	54.9	(8.4)	41.8	(24.2)	39.0	(23.1)	
Primer Narrative	85.9	(27.3)	74.4	(38.9)	56.3	(45.8)	
Primer Expository	43.7	(19.3)	35.9	(25.4)	24.0	(26.0)	
Mean words correct	*61.5*	*(17.3)*	*50.7*	*(28.9)*	*39.8*	*(30.2)*	*0.88*
Comprehension (answers correct)							
Pre-primer Narrative	8.7	(1.6)	6.0	(4.3)	4.4	(3.9)	
Primer Narrative	5.6	(2.4)	3.5	(3.3)	2.3	(2.7)	
Primer Expository	3.0	(1.7)	1.8	(2.4)	1.3	(1.7)	
Sum answered correctly	*17.3*	*(5.0)*	*11.3*	*(9.3)*	*8.1*	*(7.8)*	*1.40*
Fluency (correct words per minute)							
Pre-primer Narrative	51.5	(42.8)	58.3	(52.9)	39.5	(50.4)	
Primer Narrative	43.7	(43.3)	49.8	(47.8)	31.9	(46.4)	
Primer Expository	35.3	(33.8)	39.1	(35.7)	23.0	(32.7)	
Mean words correct per minute	*43.5*	*(39.3)*	*49.0*	*(45.0)*	*31.5*	*(42.9)*	*0.29*

Table 5

Statistical outcomes of two-way ANOVAs performed on measures from the QRI.

	F	*df*	*p*	Partial η^2
Word reading				
Passage	70.74	2,98	< .001	.591
Group	3.54	2,49	.037	.126
Passage x Group	1.64	4,98	NS	.036
Comprehension				
Passage	84.37	2,98	< .001	.633
Group	8.35	2,49	.001	.254
Passage x Group	3.88	4,98	.006	.137
Fluency				
Passage	24.70	2,98	< .001	.335
Group	0.747	2,49	NS	.030
Passage x Group	0.058	4,98	NS	.002

Table 6

Means and SDs for measures of executive functioning. Numbers of participants providing data for both sorts of tasks are provided at the top of the relevant columns. All times are in seconds. Cohen's *d*s for measures with significant group effects are shown in the right column for children with NH *vs.* CIs.

	Group						**NH *vs.* CI**
	NH		**HA**		**CI**		
	M	**(SD)**	**M**	**(SD)**	**M**	**(SD)**	***d***
Verbal short term memory	**17**		**7**		**23**		
Percent correct on serial recall	31	(12)	28	(10)	23	(10)	0.72
Corrected time for serial recall	3.7	(1.4)	2.7	(1.4)	3.7	(2.2)	0.0
Rapid serial naming	**17**		**6**		**25**		
Time for color naming	96	(34)	112	(18)	117	(56)	−0.45
Time for object naming	96	(28)	109	(23)	128	(60)	−0.68

Table 7

Means and SDs for measures of oral language skills. Standard scores are shown for Auditory Comprehension and Expressive Vocabulary. Narrative scores are points obtained out of the 36 points available on the scoring rubric. Cohen’s *d*s for measures with significant group effects are shown in the right column for children with NH *vs.* CIs.

	Group						
	NH		**HA**		**CI**		**NH *vs.* CI**
	17		**8**		**27**		
	M	**(SD)**	**M**	**(SD)**	**M**	**(SD)**	***d***
Auditory Comprehension	102	(11)	91	(23)	77	(20)	1.55
Expressive Vocabulary	110	(11)	96	(20)	89	(18)	1.41
Narrative Score	24.0	(3.1)	13.6	(6.1)	13.7	(8.7)	1.58

Table 8

Standardized beta coefficients for each predictor variable and the dependent variables of word reading and comprehension. Coefficients are shown separately for children with NH and those with CIs. Asterisks indicate coefficients that are different from zero.

	Phonological Awareness			Executive Functioning		Oral Language		
	Syllable Counting	**Initial Consonant**	**Final Consonant**	**Serial Recall**	**Rapid Naming**	**Aud. Comp.**	**Exp. Vocab.**	**Narrative Score**
Word Reading								
NH	.59	.68[*]	.47	.17	−.00	.61[*]	.58	.17
CI	.54[*]	.38	.43	.40	−.42	.63[**]	.53[*]	.63[**]
Comprehension								
NH	.68[*]	.61[*]	.43	.40	−.11	.52	.74[**]	.39
CI	.45	.35	.41	.33	−.38	.67[**]	.62[**]	.70[**]

[*] $p < .01$

[**] $p < .001$

Table 9

Outcomes of stepwise linear regression analysis for children with CIs and NH. Predictor variables shown are those that explained significant amounts of variance in the dependent variables of word reading or comprehension.

Predictor Variables	Standardized β	*t*	*p*	R^2 *for model*
Word Reading				
Children with NH				
Initial Consonant Task	.68	3.56	.003	.457
Children with CIs				
Syllable Counting	.57	3.91	.001	.607
Narrative Score	.44	3.02	.007	
Comprehension				
Children with NH				
Expressive Vocabulary	.72	4.00	.001	.515
Children with CIs				
Syllable Counting	.42	2.99	.008	.641
Narrative Score	.62	4.42	<.001	

Table 10

Means and SDs for measures of emergent literacy, phonological awareness, and oral language abilities for children with one or two implants at the time of testing. Cohen's *d*s provide estimates of effect sizes between scores of children with one and two CIs.

	Number of Implants				
	One CI		**Two CIs**		
	8		**18**		
	M	**(SD)**	**M**	**(SD)**	***d***
Emergent Literacy					
Word Reading	49	(32)	36	(30)	0.42
Comprehension	11.1	(7.0)	6.9	(8.2)	0.55
Phonological Awareness					
Syllable Counting	57.0	(25.6)	42.2	(32.3)	0.51
Initial Consonant Task	66.4	(20.8)	67.1	(16.6)	−0.04
Final Consonant Task	8.3	(9.6)	17.2	(16.1)	−0.67
Oral Language					
Aud. Comprehension	85	(17)	75	(21)	0.52
Expressive Vocab.	93	(15)	88	(20)	0.28
Narrative Score	16.6	(6.5)	12.7	(9.6)	0.48

Table 11

Means and SDs for measures of emergent literacy, phonological awareness, and oral language abilities for children with some bimodal experience or no bimodal experience. Cohen's *d*s provide estimates of effect sizes between scores for children with some bimodal experience and no bimodal experience.

	Bimodal Experience				
	Some		**None**		
	12		**14**		
	M	**(SD)**	**M**	**(SD)**	***d***
Emergent Literacy					
Word Reading	50	(34)	31	(26)	0.63
Comprehension	11.3	(8.8)	5.6	(6.4)	0.74
Phonological Awareness					
Syllable Counting	51.7	(36.7)	43.3	(25.1)	0.27
Initial Consonant Task	75.0	(16.7)	60.0	(15.9)	0.92
Final Consonant Task	21.0	(15.0)	8.5	(12.1)	0.92
Oral Language					
Aud. Comprehension	85	(21)	72	(17)	0.68
Expressive Vocab.	90	(17)	89	(20)	0.05
Narrative Score	16.6	(8.9)	11.6	(8.4)	0.58