Phonological Awareness, Vocabulary, and Reading in Deaf Children With Cochlear Implants

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Purpose: To explore the phonological awareness skills of deaf children with cochlear implants (CIs) and relationships with vocabulary and reading development.
Method: Forty-three deaf children with implants who were between 5 and 15 years of age were tested; 21 had been implanted at around 2.5 years of age (Early CI group), and 22 had been implanted at around 5 years of age (Late CI group). Two control groups—a deaf hearing aided group (16 children) and a typically developing group of hearing children (19 children)—were also tested. All children received a battery of phonological processing tasks along with measures of reading, vocabulary, and speechreading. Analyses focus on deaf children within the normal IQ range ($n = 53$).
Results: Age at cochlear implantation had a significant effect on vocabulary and reading outcomes when quotient scores were calculated. Individual differences in age at implant, duration of fit, phonological development, vocabulary development, auditory memory, visual memory, and speech intelligibility were all strongly associated with progress in reading for the deaf implanted children. Patterns differed somewhat depending on whether quotient scores or standard scores were used.
Conclusions: Cochlear implantation is associated with development of the oral language, auditory memory, and phonological awareness skills necessary for developing efficient word recognition skills. There is a benefit of earlier implantation.

KEY WORDS: cochlear implant, reading, phonology

Cochlear implantation offers access to auditory information about speech that has been previously unavailable to profoundly deaf children. Cochlear implants (CIs) work by transmitting information about the amplitude envelope at a reduced number of frequency channels. Although this reduced information omits fine time structure cues to phonetic structure, deaf children can use these envelope cues to recognize speech quite effectively (e.g., Connor & Zwolan, 2004; Nicholas & Geers, 2006; O'Donoghue, Nikolopoulos, & Archbold, 2000). Recently, work with children with developmental dyslexia and with speech and language impairments has shown that amplitude envelope cues are very important to developing high-quality phonological representations of speech (e.g., Corriveau, Pasquini, & Goswami, 2007; Goswami et al., 2002; Richardson, Thomson, Scott, & Goswami, 2004). This raises the possibility that the information about the amplitude envelope delivered by CIs may enable deaf children to develop phonological representations that are effective in supporting the acquisition of reading. In hearing children, the relationship between individual differences in phonological representation and individual differences in reading attainment has been widely documented (e.g., Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001).

If cochlear implantation is able to support the development of high-quality phonological representations by deaf children, then this should have an impact on their reading development. The development of high-quality phonological representations in hearing children is usually measured by phonological awareness tasks, which assess the phonological aspects of children's lexical representations at the linguistic levels of the syllable, rhyme, and phoneme.

It is at least plausible to suggest that access to the amplitude envelope of speech is likely to have important educational implications for deaf children. In a seminal study, Conrad (1979) noted that the average achievement for the deaf child leaving school was a reading age of 9 years. This level does not represent functional literacy. In fact, Conrad noted, "… it is hard to believe that it will be dispelled even by the most radical improvements in teaching methods … conceivable within the framework of current theoretical and technical knowledge" (p. 69). CI technology, rather than radical improvements in teaching, does seem to offer this possibility. First, the speech perception information that CIs provide should aid the development of phonological representations; second, improved speech perception seems likely to enhance the development of language skills more generally, with additional consequent benefits for literacy. Indeed, a number of studies of implanted children have shown that both speech perception and language skills are enhanced by cochlear implantation (Geers, 1997; Houston, Pisoni, Kirk, Ying, & Miyamoto, 2003; Richter, Eissele, Laszig, & Loehle, 2002; Stacey, Fortnum, Barton, & Summerfield, 2006; Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000; Tyler et al., 1997). For example, regarding speech perception, Tyler et al. (1997) measured the performance of 50 children who had used their CI for 2 years. Tyler et al. reported that most children showed improvements in speech perception, although there were large individual differences. Stacey et al. (2006) found that implantation was associated with significant enhancement of auditory performance and speech perception in their cross-sectional questionnaire study of hearing impaired children in the United Kingdom. Hence, the benefits of cochlear implantation for speech perception are well-documented.

Studies of the language development of profoundly deaf children with CIs suggest that the rate of language development exceeds that of other deaf children (Nicholas & Geers, 2006; Svirsky et al., 2000; Tomblin, Spencer, & Gantz, 2000). For example, Svirsky et al. (2000) measured the language development of deaf children before and after cochlear implantation. They found that the implanted children exceeded the predicted rate of development compared with nonimplanted deaf children on the expressive language measures of the Reynell Developmental Language Scales (Reynell & Huntley, 1985). Geers (1997) compared implanted children with two groups of hearing aid users, those whose average hearing loss was between 90 and 100 dB, and those whose hearing loss was greater than 100 dB. She found that the implanted children performed at an equivalent level in assessments of speech perception, speech production, and vocabulary development to the less severely impaired aided children (those whose average hearing loss was between 90 and 100 dB). However, rates of language development in deaf implanted children are not equivalent to those of hearing peers (Ertmer, Strong, & Sadagopan, 2003; L. J. Spencer, Barker, & Tomblin, 2003; P. Spencer, 2004).

In addition to the general benefits demonstrated for cochlear implantation, growing numbers of studies suggest that early implantation carries additional benefits for speech perception, speech intelligibility, and language development (Geers, Nicholas, & Moog, 2007; Miyamoto, Kirk, Svirsky, & Sehgal, 1999; Nicholas & Geers, 2007, 2008; O'Donoghue et al., 2000; Svirsky, Chin, & Jester, 2007; Tomblin, Barker, Spencer, Zhang, & Gantz, 2005). For example, Nicholas and Geers (2008) reported on the spoken language skills of 76 deaf, orally educated children who had been implanted before the age of 38 months. They found a linear relationship between age at implantation and test scores on different preschool language measures, including auditory discrimination, receptive vocabulary, and expressive language. Geers et al. (2007) reported a similar significant effect of age at implantation in a different cohort of implanted children, using receptive vocabulary (Peabody Picture Vocabulary Test—Revised [PPVT–R]; Dunn & Dunn, 1997) as the main outcome measure. They noted that other predictors, notably preimplant aided hearing threshold and nonverbal IQ (NVIQ), also played important roles in the predictive relationships. There is some evidence that the benefits of implantation may level off after a certain chronological age, between 2 and 3 years (Baumgartner et al., 2002; Nicholas & Geers, 2007; Sharma, Dorman, & Kral, 2005). In general, recent studies support the view that implantation before 2 years is most desirable with respect to spoken language outcomes (Miyamoto, Hay-McCutcheon, Kirk, Houston, & Bergeson-Dana, 2008; Nicholas & Geers, 2007).

The potential benefits of implantation and in particular early implantation for reading development have received less attention. In a recent review, Marschark, Rhoten, and Fabich (2007) suggested that empirical results to date were highly variable and that even though earlier implantation should be associated with higher reading achievement, this had yet to be demonstrated consistently. They noted that many studies have failed to control for potentially critical variables, such as age of implantation and consistency of implant use. Connor and Zwolan (2004) studied a cohort of 91 deaf implanted children, and they reported that multiple factors affected the development of reading comprehension skills, including preimplant vocabulary and socioeconomic status. Nevertheless, age at implantation was found to have a large effect on reading outcome. Archbold et al. (2008) recently reported a significant negative correlation between age at implantation and net reading age as assessed by the Edinburgh Reading Test (University of Edinburgh, n.d.) in a cohort of 71 implanted children (those implanted earlier had higher net scores). Geers and colleagues have also carried out a number of studies, and they have reported that the number of deaf children achieving age-appropriate reading levels is improving (e.g., Geers, 2002, 2003; Geers et al., 2002). Geers (2003) studied a large group of implanted children and found that the variable most strongly associated with reading outcome was overall language competence. The second was speech intelligibility. She also reported that communication mode made no significant specific contribution to reading variance in the children in her study. Geers (2002) reported that NVIQ made a significant contribution to variance in reading in children with CIs. In fact, NVIQ showed a stronger relationship with reading than other family variables, such as socioeconomic status. In hearing children, the most important predictor of reading outcomes is phonological awareness, the child's ability to reflect on the sound structure of words. Most studies of deaf literacy have not included measures of phonological awareness; rather, they have included measures of phonological coding when reading. This is because written items have been used to assess the potential influence of phonology on deaf literacy.

Reports from prior research have differed in their conclusions regarding deaf children's use of phonological coding when reading (e.g., Campbell & Wright, 1988; Carter, Dillon, & Pisoni, 2002; Dyer, MacSweeney, Szczerbinski, Green, & Campbell, 2003; Geers, 2003; Marschark et al., 2007; Perfetti & Sandak, 2000; Transler, Leybaert, & Gombert, 1999; Waters & Doehring, 1990). For implanted deaf children, however, studies do show significant positive effects. For example, in the comprehensive study by Geers (2003), rhyme skills were measured by using four kinds of written items: similar spelling, no rhyme (*men/man*); dissimilar spelling, rhyme (*word/bird*); dissimilar spelling, no rhyme (*big/school*); and similar spelling, rhyme (*year/dear*). Geers reported that this rhyme task was significantly related to reading outcomes in her implanted group, as were her other measures of phonological coding (making lexical decisions about homophones, such as *werd/word,* and digit span tasks). James, Rajput, Brinton, and Goswami (2008) developed nonorthographic measures of phonological awareness for deaf implanted children, on the basis of pictures. They found that nonorthographic rhyme knowledge was significantly associated with reading development for the implanted children in their sample (n = 19), as was vocabulary development. Although the sample size was small, regression analysis showed that 76% of the variability in the deaf children's reading was explained by three predictors: NVIQ, rhyme awareness, and receptive vocabulary.

In hearing children, phonological awareness follows a developmental sequence, with awareness of syllables developing first, then awareness of rhymes, and finally (partly via alphabetic learning) awareness of phonemes (Goswami & Bryant, 1990; Ziegler & Goswami, 2005). Studies investigating the development of phonological awareness in deaf children have revealed a similar developmental sequence. For example, Sterne and Goswami (2000) investigated the phonological awareness of deaf hearing aided children in a series of experiments exploring syllable, rhyme, and phoneme awareness. The deaf children were between 9 and 13 years of age and had a reading age of between 6 and 9 years. Their performance was compared with that of two groups of hearing children: one of similar chronological age (CA-matched group) and one of similar reading level (RL-matched group). The deaf children were above chance in the picture-based tasks used at all phonological levels tested, but they were only similar in absolute performance levels to the hearing children in their performance in the syllable task. However, when making judgments about syllables, they were as competent as both CA-matched children and younger RL-matched children. Phonological awareness at the syllable, rhyme, and phoneme levels in deaf children with CIs was studied by James et al. (2005). In their study, 8-year-old implanted deaf children performed at levels above chance in picture-based tests of syllable and rhyme awareness, but they were only above chance in a phoneme awareness test when spelling (orthography) supported the phonetic judgments required.

To date, speechreading skills have not been systematically assessed in children with CIs with respect to their literacy development. This is unfortunate. Bergeson, Pisoni, and Davis (2003) reported that speechreading skills prior to implantation were the strongest predictor of speech and language outcomes after 3 years of implant use, suggesting that speechreading is not an isolated perceptual skill but has important linguistic consequences. Charlier and Leybaert (2000) have suggested that when visual cues are used to supplement oral language learning by deaf children, good levels of phonological awareness can develop. They found that severe and profoundly deaf children who had experienced cued speech from infancy were able to identify and produce rhymed pairs of words (called "friends"). This suggests that providing a visual specification of phonological contrasts, as in cued speech, supports the development of accurate phonological representations. Interestingly, Charlier and Leybaert noted that the deaf children in their study were influenced by speechreading similarities between the rhyming word pairs. Harris and Moreno (2006) reported that the good deaf readers (7–8-year-old children) who they studied were all good at speechreading and that speechreading skills predicted the degree of reading lag in the whole deaf group. Kyle and Harris (2006) also found that speechreading skills were associated with reading in their sample of mainly hearing-aided deaf children, along with expressive vocabulary. No associations were found for phonological awareness.

Overall, prior research with deaf children suggests that even if cochlear implantation does improve the phonological awareness skills developed by deaf children, other factors, such as speechreading skills and general language skills, will continue to be important. Indeed, success in reading for deaf children seems likely to depend on the successful integration of a number of developmental components, of which the enhanced access to speech information provided by cochlear implantation is likely to be only one contributing factor. In the current study, we therefore set out to investigate the relationships between all these factors (phonological, linguistic, and visual) and literacy in deaf children fitted with CIs. Our main research questions were whether cochlear implantation influences the development of phonological awareness skills, vocabulary skills, and literacy skills in deaf children, and if so, whether age at implantation has any additional effect. To investigate these questions, we compared the performance of a profoundly deaf group of children with CIs with that of a severely deaf group using hearing aids and a hearing control group of reading-age-matched children using a wide range of phonological awareness measures. We also used a wide range of assessments of reading, a number of memory measures, and a test of speechreading abilities, as well as an assessment of speech intelligibility. A number of the phonological awareness tasks were novel and were created especially for this study and a parallel study of adult deaf reading (MacSweeney, Waters, Brammer, Woll, & Goswami, 2008).

Method

Participants

Seventy-eight children between 5 and 15 years of age took part in this study. Of these, 59 children were deaf, and 19 were hearing. The 59 deaf children were all prelingually deaf and spoke English as their first spoken language, although British sign language was the primary language for nine participants. Fifty of the deaf children attended units in mainstream schools with hearing support; the other nine deaf children attended residential schools. Only five children in the sample were in total communication educational settings where predominantly sign language was used in teaching.

Forty-three of the deaf children had received CIs between 19 and 109 months of age.[1] The CI children were between 62 and 178 months of age at the time of the current study. Twenty-one children formed an early implanted group (Early CI), defined on the basis of an age at time of implantation younger than 39 months. This was a convenience definition for partitioning the sample to give equal numbers in both groups. It is, however, theoretically interesting, as Sharma, Dorman, and Spahr (2002) demonstrated a sensitive period for central auditory development before 42 months. Twenty-two children formed a late implanted group (Late CI), defined on the basis of an age at time of implantation later than 43 months. The 21 children in the Early CI group comprised 14 boys and seven girls between 62 and 163 months of age. In the Late CI group, there were 12 boys and 10 girls between 82 and 178 months of age. Participant details for the whole sample of 43 CI children are given in Table 1. A t test confirmed that there was a statistically significant difference in age at implantation between the two groups, $t(1, 41) = 8.6$, $p < .0001$. Duration of fit was broadly similar in the two implanted groups. There was no significant difference between mean duration of fit, $t(1, 41) = 1.1$, $p = .30$.

Two control groups were recruited. The hearing aided deaf controls (HA controls; $n = 16$) had an average hearing loss of between 32 and 96 dB and attended units attached to mainstream schools. Average hearing loss was available for most children and was calculated from unaided hearing levels at 250, 500, 1000, 2000, and 4000 Hz. As shown in Table 1, the mean unaided hearing loss of the HA control group (71 dB) was less than that of the profoundly deaf CI groups (109 and 106 dB, respectively). Unaided hearing level ranged between 90 and 117 dB in the Early CI group and between 93 and 120 dB in the Late CI group. A one-way analysis of variance (ANOVA) confirmed that for unaided hearing, the HA controls' mean was significantly higher than the two implanted groups' means, $F(2, 40) = 32.3$, $p < .001$. The HA controls' ages ranged from 77 to 160 months, with an average age of 119 months, making the group slightly older than the Early CI group (111 months) but slightly younger than the Late CI group (132 months). Details of aided hearing levels were also collected when available. The CI groups' means were each 35 dB and 34 dB, respectively, and the HA controls' mean was 35 dB. Aided hearing levels were not different between the groups, $F(2, 41) = 0.17$, $p = .85$.

[1]Thirteen of these children had previously participated in the study reported by James et al. (2005). These children (eight in the Early CI group and five in the Late CI group) were at the upper end of the age range for the implanted groups, but preliminary analyses showed that they did not differ significantly from the other implanted children in the Early and Late CI groups in any of the standardized or experimental measures used in the current study, with one exception. For the British Ability Scales—II (Elliott, Smith, & McCulloch, 1996) single word reading measure, the quotient score was significantly lower for these 13 children compared with the newly recruited children (0.69 vs. 0.87).

Table 1. Participant details for the whole cohort of 78 children.

Variable	Early CI group	Late CI group	HA controls	RA controls
n	21	22	16	19
No. of boys	14	12	5	11
Chronological age (mean in months)	111	132	119	98
SD	29.3	27.1	25.2	8.3
Range	62–163	82–178	77–160	
Age at implant (mean in months)	31	62		
SD	5.7	15.5		
Range	19–39	43–109		
Duration of fit (mean in months)	79	71		
SD	26.9	24.8		
Range	43–125	36–123		
Unaided hearing level (dB)	109	106	71	Within normal range
SD	9.3	7.6	20.5	
NVIQ[a]	108	98	96	57.5[b]
SD	13.5	17.4	13.7	11
Range	79–137	68–129	83–126	
Speech intelligibility[c]	2.3	2.9	2.4	
SD	1.3	1.2	1.2	

Note. Early CI group = Early Cochlear Implant group (implanted at around 2.5 years of age); Late CI group = Late Cochlear Implant group (implanted at around 5 years of age); HA controls = hearing aided deaf controls; RA controls = reading age controls; NVIQ = nonverbal IQ.

[a]Leiter International Performance Scale—Revised (Leiter–R). [b]British Ability Scales—II (BAS–II) *t* score, standardized average score = 50. [c]Phonological Evaluation and Transcription of Audio-Visual Language (PETAL) scale ranging from 1 to 5.

The reading age controls (RA controls) were hearing children from three local schools between 82 and 117 months of age. Because we had a broad age range in the deaf groups, the RA controls were selected as being average readers for their age and were matched to the average reading age range of the deaf groups as assessed by the Neale Analysis of Reading Ability—Revised (NARA–R; Neale, 1997). The children composing the RA controls were selected to have a reading age within 1 *SD* of the mean given their age.

Participants Used for Main Analyses

As shown by the range information in Table 1, some of the deaf children were of low IQ. It was therefore decided to restrict the statistical analyses to children whose NVIQ was 80 or more. Participant details for these 53 deaf children by group are provided in Table 2. NVIQ was assessed for the deaf groups using the Leiter International Performance Scale—Revised (Leiter–R; Roid & Miller, 1997). This test was selected because the standardization included deaf and special needs groups and because the subtests can be carried out nonverbally. The composite score for the Leiter–R Brief IQ Screen was used. Fifty-three deaf children met the IQ criterion: 39 in

Table 2. Participant details for deaf children with NVIQ scores in the normal range.

Variable	Early CI group	Late CI group	HA controls
n	20	19	14
No. of boys	13	11	5
Chronological age (months)	111	131	120
SD	30.1	28.5	26.9
Range	62–163	82–178	77–160
Age at implant (months)	31	59	
SD	5.8	11.5	
Range	19–39	43–80	
Duration of fit (months)	79	73	
SD	27.5	24.5	
Range	43–125	36–123	
Unaided hearing level (dB)	108	107	80.5
SD	9.0	6.9	19.4
NVIQ	109	103	100
SD	12.3	14.3	10.0
Range	91–137	82–129	83–126
Speech intelligibility (5-point scale)	2.3	2.9	2.4
SD	1.3	1.2	1.2

the CI groups (20 in the Early CI group, 19 in the Late CI group) and 14 HA controls. The six deaf children with standard scores below 80 on the IQ screen also participated in the full range of tasks; their data are reported separately in the Results section. For the 53 deaf participants meeting the IQ criterion, a one-way ANOVA confirmed that there was no significant difference between the three deaf groups in NVIQ, $F(2, 52) = 2.5$, $p = .10$. Using t tests, we confirmed that age at implantation still differed significantly for the CI users, $t(1, 37) = 9.46$, $p < .001$. Duration of fit did not differ for the CI users, $t(1, 37) = 0.78$, $p = .44$. Seven of the CI users had British sign language as their primary language, and four CI users were being educated in total communication settings. For the hearing children, NVIQ was assessed using the Matrices subtest of the British Ability Scales—II (BAS–II; Elliott, Smith, & McCulloch, 1996). The mean Matrices t score for the RA controls was 58 (standardized $M = 50$, $SD = 10$), confirming that they were also an average-ability group.

Tasks

Psychometric Tests

For deaf children, there are no standardized tests of reading or vocabulary in British English; consequently, the standardized tests for reading, vocabulary, and auditory memory were all tests standardized on hearing populations. Only the visual memory test used had been standardized on a deaf sample (Roid & Miller, 1997). The use of psychometric measures standardized on hearing children raises challenges in terms of administration to deaf children and interpretation of results (see Lollis & LaSasso, 2009; Prezbindowski & Lederberg, 2003). For example, deaf children may have difficulties in assimilating the information required to perform the task, there are risks of poor communication between child and examiner, and the iconicity of some signs may make it easier for the deaf child to guess the correct answer for some tasks (such as the PPVT–R). All assessments were administered by the first author, a speech and language therapist with 30 years of experience, who has specialized in working with deaf children. The participants' mothers or educational assistants were also present to assist in understanding the tasks if required.

Tests of reading. We used the NARA–R, which provides an accuracy score and a comprehension score using passages of text appropriate for children between 6 and 13 years of age. The calculation for rate (speed) of reading was not used. We also used the BAS–II single word reading subtest and the Wordchains test (Miller Guron, 1999). These tests provided standard scores normed on hearing children, which were useful for establishing the absolute level of reading ability of all the participants. However, raw scores on the reading tests also yielded an age-equivalent score, which was used to calculate reading quotient scores (Kirk, Miyamoto, Ying, Perdew, & Zuganelis, 2002). Quotient scores are obtained by dividing the reading age-equivalent scores by chronological age. A quotient less than 1 suggests delayed development. At all testing sessions, the child's support teacher (or mother) was present and was able to ensure that the child understood the task. Sign language was used when necessary to clarify instructions.

The NARA–R test comprises a series of short texts of increasing difficulty to be read aloud by the child followed by comprehension questions spoken and/or signed by the examiner. The text was available for reference when answering the questions. The BAS–II single word reading subtest was also used even though it has been dissatisfying in our previous work, as it had seemed less sensitive to deaf children's reading achievements. It was included here to provide comparability with our prior work (James et al., 2008, 2005). The Wordchains task was included, as it measures visual word form familiarity, which might be a strength for deaf children. In the Wordchains test, children were asked to draw a mark between a string of three or four words to indicate the separate words (e.g., *sandcoffeeblue*). There was a time limit of 3 min for the test. No speech was required for this task. Wordchains is therefore a test of orthographic knowledge. Standard scores were available for children 7–18 years of age on this test. It should be reiterated that none of these reading tests are standardized for deaf children; nevertheless, for comparisons between the deaf groups, this was not expected to exert any systematic effects on group differences.

Tests of vocabulary. Two vocabulary tests were used to assess vocabulary development. The British Picture Vocabulary Scale (BPVS; Dunn, Whetton, & Pintilie, 1997) is a receptive vocabulary test similar to the PPVT–R. Children were asked to look at the speaker, to listen to a spoken word, and then to select one of four black-and-white line drawings that corresponded with the spoken word. Because of the possibility of iconicity influencing the scores, no signing was used to present the target word. Prezbindowski and Lederberg (2003) commented that "receptive vocabulary tests such as the PPVT may underestimate deaf children's lexical knowledge because perceptual discriminability of the four choices for each word has not been controlled" (p. 394). Hence, the data should be treated with caution. To test expressive vocabulary, we used the Expressive One Word Picture Vocabulary Test (EOWPVT; Brownell, 2000). Children named colored pictures using a noun, verb, or category word. This is an American test, and thus one item was changed to reflect British vocabulary: *Raccoon* was changed to *Badger*. In addition, three pictures were changed: a *map* of America to a map of the British Isles, an American *windmill* to a British windmill, and the symbol for prescription (target word *pharmacy*).

Tests of visual and auditory memory. The memory screen from the Leiter–R was completed by the deaf groups, and the Digits Forward task from the BAS–II was completed by all groups. The Leiter–R Memory Screen assesses visual memory using two picture subtests: a picture association task and a spatial sequencing task. Instructions are provided nonverbally. The BAS–II Digits Forward task (digit span) assesses auditory memory. This test was carried out orally, and children were asked to repeat strings of spoken numbers of increasing length.

Experimental Phonological Awareness Tasks

The experimental phonological awareness tasks were picture-based to explore the children's own phonological representations of words in their mental lexicons. All items used are shown in Appendices A–C and were presented using a laptop computer. The picture pairs were sequenced in a random order within each task. Prior to the experiment, the pictures were shown to the child in a book. They were named and discussed with the experimenter. This was done to establish that the child used the intended label for each picture (e.g., *van, mouth*). Practice items were administered at the beginning of each task. In each experimental trial, children were encouraged to name the two pictures audibly and to make a quick judgment by pressing a "yes" (blue) button or a "no" (red) button on a button box. The naming check was intended to confirm that the participant was using the correct label when carrying out the judgment task. When a word was named incorrectly, the experimenter reminded the child of the correct word.

Rhyme task. In the rhyme task, children were asked to judge whether two pictures rhymed, for example, *walk/fork*. There were 48 picture pairs, of which 24 rhymed. Of these rhyme pairs, 12 were orthographically congruent (e.g., *leg/peg*), and 12 were orthographically incongruent (e.g., *walk/fork*). The words used were matched for frequency and familiarity, and they were controlled for orthographic similarity to prevent the children using orthographic images of the items as a basis for making their phonological judgments. Internal consistency as measured by Cronbach's alpha was good (α = .833).

Initial phoneme task. In the initial phoneme task, children were asked whether two pictures began with the same phoneme, for example, *swim/circus*. The initial phoneme task used 64 trials, 32 "yes" trials and 32 "no" trials. The trials were balanced so that half of the "yes" response items had matching initial phonemes and graphemes (e.g., *plate/pig*), whereas half shared the same phoneme but had different graphemes (e.g., *celery/skirt*). The "no" response pairs were also balanced for orthographic similarity. The words used were again matched for frequency and familiarity, and they were controlled for orthographic similarity. The rhyme and initial phoneme tasks were taken from an associated project with deaf adults (see MacSweeney et al., 2008). Internal consistency as measured by Cronbach's alpha was again good (α = .785).

Coda task. A coda task using the same forced choice response format was designed by the first author. Participants were asked to judge whether the final phoneme of two pictures was the same. The task used 48 picture pairs based on nouns that were matched for spoken familiarity and frequency. Twenty-four trials had the same coda, and 24 had a different coda. Speech production features of the words were considered. There was a balance of front and back vowels in the picture pairs, so that 19 pairs were front vowels (e.g., *wheel, leaf*), 17 pairs were back vowels (e.g., *horse, ball*), and 12 pairs were contrasted (e.g., *train, bone*). Seventeen of the pairs included diphthongs. Lip shape in the 19 front vowel pairs was spread, and in the 12 back vowel pairs, it was rounded. The other pairs had a mixed or moving lip shape. The number of letters in the words was considered. Words had between three and six letters, with 23 of the pairs having the same number, 18 differing by one, and six differing by two in number.

Tests of Speechreading

To explore the effect of visual speechreading skills on the development of phonological awareness, two sections of the Test of Adult Speechreading (TAS; Mohammed, MacSweeney, & Campbell, 2003) were used.

Single word speechreading. The single word speechreading task (TAS word) required participants to watch a silent video of a face speaking a single word on the computer screen. Participants were then shown a selection of six pictures and were asked to select the picture corresponding to the target word. There were 15 items in total, presented in random order.

Minimal pairs speechreading. This task was also taken from the TAS (TAS minimal pairs) and was presented on the computer in the same way as TAS word. Participants watched a silent video of a single word being spoken and were then given a choice of two pictures from which to identify the word. The names of the pictures differed by a single phoneme (e.g., *ball/bull, win-wing*). There were 30 items in this task, with three subgroups of 10 items each. The subgroups contrasted (a) final phoneme (e.g., *dog/doll*), (b) initial phoneme (e.g., *nail/sail*), and (c) medial phoneme (e.g., *heart/hot*).

Auditory Discrimination

This task was based on 32 pairs of spoken words, selected from two of the picture tasks: TAS word and coda. This was an auditory task presented using live voice but with no visual cues, and the children were asked to make a same/different judgment. Word pairs were controlled for front/back vowel production and for sonority. The different word pairs incorporated four phoneme-position changes: initial phoneme (*cake/snake*), medial vowel (*net/nut*), final phoneme (*bowl/bone*), and open ended versus closed (*cow/mouse*). Half of all the words used front vowels (*van/fan*), and half used back vowels (*suit/soup*).

Speech Intelligibility

This was based on the Phonological Evaluation and Transcription of Audio-Visual Language (PETAL; Parker, 1999), using speech samples of natural conversation captured on video during the testing sessions. The PETAL scale evaluates communication on a scale ranging from 1 to 5. A score of 1 was assigned when the child's speech was easily understood, and a score of 5 was assigned when oral speech was difficult to understand. Rating scores were assigned by the first author, who is a registered speech and language therapist.

Procedure

The children were seen either at school in a quiet room or in their home. Assessment was carried out in 1- or 2-day sessions, with breaks between tasks, for example, during a single school day. During the assessment sessions, the phonological tasks were interspersed among the standardized tests. The order in which the tasks were given was fixed: BPVS, rhyme task, TAS tasks, EOWPVT, coda task, BAS–II reading, auditory discrimination, initial phoneme task, digit span, NARA–R, and Wordchains.

Results

Preliminary analyses were carried out to explore whether homogeneity of variance assumptions were met for all tasks. The reading and speechreading tasks all met homogeneity assumptions, and so one-way ANOVAs were performed to examine group differences. In the language and phonological awareness tasks, the assumptions of homogeneity of variance were not fully met, and so Kruskal–Wallis and Mann–Whitney U nonparametric tests were performed on the data. The RA controls' mean scores were much higher than the deaf group's mean scores. All data were examined for skewness and kurtosis. In the initial phoneme task, one high-scoring outlier from the Early CI group skewed the data. In this case, the outlier was not excluded as nonparametric analyses were performed. For each task, our aims were (a) to explore differences between the CI groups (Early vs. Late), (b) to compare all the deaf groups (Early CI and Late CI vs. HA controls), and (c) to compare the hearing and deaf children. An alpha level of .05 was set for all statistical tests.

Reading Performance

Reading performance for each group is shown in Table 3. A one-way ANOVA, taking Group as the between-subjects factor, was performed for each of the four reading tests. No significant effects of Group were found, indicating that there were no significant differences between the mean scores of the groups for reading accuracy, reading comprehension, or Wordchains (orthographic competence): NARA–R accuracy, $F(3, 68) = 0.28$, $p = .84$; BAS–II single word reading, $F(3, 68) = 0.93$, $p = .43$; NARA–R comprehension, $F(3, 68) = 0.66$, $p = .58$; Wordchains, $F(3, 60) = 2.18$, $p = .10$. Nevertheless, inspection of the reading age-equivalent scores shows that reading levels lagged chronological age by a considerable amount for the deaf groups. Mean discrepancies for NARA–R accuracy were 11 months for the Early CI group, 28 months for the Late CI group, and 24 months for the HA controls. This is suggestive of better progress in reading for the Early CI group. The children in the Early CI group are within the normal range for their age, and they have comparable reading age-equivalent scores compared with the children in the Late CI group, who are 21 months older (recall that duration of fit was equated between the Early and Late CI groups). The BAS–II single word reading test and the NARA–R reading comprehension measures showed a comparable pattern.

Following Kirk et al. (2002), we therefore calculated reading quotient scores for the two CI groups by dividing their reading age-equivalent scores by their chronological age. A quotient less than 1 suggests delayed development. When reading quotient scores were calculated, quotient scores were found to differ by age at implantation for NARA–R accuracy, $t(37) = 2.32$, $p = .026$; NARA–R comprehension, $t(37) = 2.42$, $p = .020$; and BAS–II single word reading, $t(37) = 2.05$, $p = .048$. In each case, the Early CI group's mean quotient was closer to 1 than the Late CI group's mean quotient, indicating a developmental trajectory closer to that attained by hearing children (NARA–R accuracy, 0.91 vs. 0.80; NARA–R comprehension, 0.88 vs. 0.74; BAS–II single word reading, 0.86 vs. 0.76). The mean quotients for the HA controls were 0.82 (NARA–R accuracy), 0.77 (NARA–R comprehension), and 0.79 (BAS–II single word reading), suggesting similar attainment to the Late CI group. Hence, there is a clear benefit of early implantation with respect to reading development. Seven of the CI children had reading quotient scores of 1.00 or greater (i.e., had reading ages equivalent to or greater than their chronological age). Six of these seven children were in the Early CI group, and all seven were being educated in an oral setting and used spoken English as their primary language.

Table 3. Mean standard scores, age-equivalent scores, and quotient scores for the normative IQ sample for the different reading measures.

Variable	Early CI group (*n* = 20)	Late CI group (*n* = 19)	HA controls (*n* = 14)	RA controls (*n* = 19)
Mean age in months	111	131	120	98
SD	30.1	28.5	26.9	8.3
NARA–R (accuracy)				
Reading age (age-equivalent score, months)	100	103	96	100
SD	29.5	25.6	18.4	14.8
Range	70–154	72–154	72–143	
Standard score	89	86	85	100
SD	13.4	10.1	8.6	8.2
Range	70–120	70–106	70–97	
Quotient	0.91	0.79	0.82	1.02
SD	0.17	0.15	0.10	0.13
NARA–R (comprehension)				
Reading age (age-equivalent score, months)	96	96	90	100
SD	30.0	25.1	16.7	16.9
Range	70–154	72–154	70–129	
Standard score	85	81	81	99
SD	15.4	11.4	8.6	8.8
Range	70–114	70–105	70–100	
Quotient	0.88	0.74	0.77	1.03
SD	0.20	0.17	0.12	0.13
BAS–II (single word)				
Reading age (age-equivalent score, months)	93	98	93	98
SD	21	16	18	12
Range	61–129	73–129	58–117	
Standard score	89	81	85	103
SD	14.4	13.5	10.7	10.1
Range	60–127	55–104	71–106	
Quotient	0.86	0.76	0.79	1.00
SD	0.16	0.13	0.12	0.09
Wordchains (standardized for age 7+ years)				
Reading age (age-equivalent score, months)	124	124	122	95
SD	40	42	35	19
Range	72–186	72–207	72–189	72–123
Standard score	100	94	98	95
SD	16.8	15.1	10.6	10.5
Range	77–131	70–122	83–114	

Note. NARA–R = Neale Analysis of Reading Ability—Revised.

In contrast, the standard scores achieved on the Wordchains test showed age-appropriate performance by all of the deaf children, even though the Wordchains test is also standardized on hearing children. The Wordchains test only gives a standardized score for children who are 7 years of age or older, and so some of the younger deaf children did not participate in this task (64 children over the age of 7 years participated, 45 deaf children participated, and 19 RA controls participated). The deaf groups achieved a mean standard score of between 94 and 100, thereby all showing performance levels within the normal range (standard score of 100). As there was no necessity for the participants to use a phonological code to carry out the Wordchains task successfully, this may explain the advantage shown by the deaf children in this task. However, it cannot be concluded that the deaf children did the Wordchains task in the same way as the hearing children.

Given that the deaf and hearing groups were matched for their absolute levels of decoding skills, reading comprehension, and orthographic knowledge, it is interesting to explore whether there are any group differences between the deaf and hearing groups in the language, memory, speechreading, and phonological awareness skills that are known to be important for the development of reading. We turn to these data next.

Vocabulary Development

For the receptive vocabulary task (BPVS), all three deaf groups scored below age-appropriate levels, as shown in Table 4. The BPVS is an auditory task, and therefore it was a difficult test for our deaf groups. Nevertheless, it is striking that the discrepancies in language age in months are much larger than the discrepancies in reading age in months for the deaf children. For example, whereas the children in the Early CI group were lagging on average by 11 months in reading attainment with respect to their chronological age, they were lagging on average by 29 months in vocabulary attainment. The Late CI group was lagging on average by 28 months in reading attainment but by 57 months in vocabulary attainment, whereas the HA controls were lagging on average by 24 months in reading attainment but by 52 months in vocabulary attainment. The RA controls scored at age-appropriate levels. However, the mean differences noted reflect a wide range of scores within the deaf groups. In the CI groups, a total of 11 children out of 39 children achieved scores within the average range on the BPVS—nine of them in the Early CI group. In the HA controls, there was one participant whose score was within the average range. Again, this is indicative of a beneficial effect of early implantation, and so language quotient scores were calculated for the two CI groups. The Early CI group had a mean quotient score closer to 1 than the Late CI group (means of 0.72 and 0.57, respectively). Homogeneity of variance assumptions were not met; hence, the Brown–Forsythe test was used to evaluate the group difference, which was significant (p = .045). Therefore, although receptive vocabulary skills were significantly delayed for all deaf groups, there was a vocabulary benefit associated with early implantation. The mean quotient score for the HA controls was 0.57, equivalent to the Late CI group.

For the expressive language measure (EOWPVT), performance was actually somewhat better for the children

Table 4. Mean standard scores, age equivalents, and quotient scores for memory and language measures.

Variable	Early CI group (n = 20)	Late CI group (n = 19)	HA controls (n = 14)	RA controls (n = 19)
BAS–II digit span (auditory memory *t* score, average = 50)	39	36	38	52
SD	11.3	8.1	8.44	5.2
Range	20–58	24–53	24–58	44–62
Quotient	0.72	0.59	0.66	1.10
SD	0.29	0.21	0.27	0.30
Leiter–R visual memory screen standard score	107	100	104	
SD	12.4	11.6	10.2	
Range	84–128	81–122	87–118	
BPVS receptive vocabulary				
Language age equivalent (months)	82	74	68	108
SD	46.0	24.0	19.3	23.5
Range	32–173	44–136	36–112	64–164
Standard score	82	67	68	106
SD	21.0	16.2	10.7	10.2
Range	50–118	40–102	52–87	87–123
Quotient	0.72	0.57	0.57	1.10
SD	0.28	0.15	0.11	0.18
EOWPVT expressive vocabulary				
Language age equivalent (months)	83	85	76	114
SD	48.0	31.40	27.3	17.9
Range	29–218	42–155	34–123	74–147
Standard score	80	76	74	108
SD	17.4	13.5	11.7	8.0
Range	55–115	55–107	55–96	93–125
Quotient	0.73	0.65	0.63	1.15
SD	0.28	0.19	0.16	0.12

Note. BPVS = British Picture Vocabulary Scale; EOWPVT = Expressive One Word Picture Vocabulary Test.

in the Late CI group and for HA controls compared with their performance with the receptive vocabulary test. Nevertheless, performance was still lagging far behind chronological age, with a discrepancy of 28 months for the Early CI group, 46 months for the Late CI group, and 44 months for the HA controls. The expressive language age of the hearing children was on average 16 months ahead of chronological age. For expressive vocabulary, language quotient scores did not differ by group. Although there was an advantage for the Early CI group, it was not significant, $t(37) = 1.05$, $p = .30$ (Early CI group's mean quotient = 0.73; Late CI group's mean quotient = 0.65). The mean quotient attained by the HA control group was 0.63. Therefore, expressive vocabulary skills were significantly delayed in the deaf groups compared with the hearing children, in contrast to their matched absolute levels of reading attainment.

Memory Development

Visual memory was a developmental strength for the deaf children in our study. All groups showed mean standard scores on the Leiter–R Memory Screen task at the typically developing hearing level (see Table 4), and there were no significant differences by deaf group, $F(2, 45) = 1.78$, $p = .180$. Hence, the visual memory skills in our sample were age appropriate. It is possible that these visual memory skills supported the development of orthographic knowledge (it will be recalled that performance on the Wordchains task was also age appropriate).

In contrast, auditory memory skills in the deaf sample were not age appropriate. The BAS–II Digits Forward test was carried out by all participants. Nonparametric comparisons were used. A Kruskal–Wallis test showed that there was a significant difference between the groups, $\chi^2(3, N = 72) = 18.31$, $p < .001$. Mann–Whitney U tests confirmed that the RA controls' scores were ranked significantly higher than the deaf group's scores (Early CI group, $U = 74.0$, $p = .001$; Late CI group, $U = 55.0$, $p < .001$; HA controls, $U = 43.0$, $p = .001$). No significant difference was found between the scores of the CI groups ($U = 164.0$, $p = .47$) or between the HA controls and the CI groups (Early CI group, $U = 117.5$, $p = .43$; Late CI group, $U = 128.0$, $p = .86$). The three deaf groups scored poorly on this auditory memory test, although this was not unexpected. As the BAS–II enables an age-equivalent score to be calculated for auditory memory, we also calculated auditory memory quotient scores for the two deaf CI groups. There was some indication of a benefit from early implantation (Early CI group, $M = 0.72$; Late CI group, $M = 0.59$); however, this was not significant, $t(37) = 1.73$, $p = .09$.

Speechreading

Performance in the two speechreading tasks, TAS word and TAS minimal pairs, is shown in Table 5.

Table 5. Percentage of correct scores for the experimental tasks by group.

Variable	Early CI group (*n* = 20)	Late CI group (*n* = 19)	HA controls (*n* = 14)	RA controls (*n* = 19)
Rhyme	69	64	63	80
SD	16.6	17.3	13.7	9.3
Range	44–92	44–92	42–81	65–98
Initial phoneme	57	58	57	73
SD	9.0	11.7	6.6	11.3
Range	47–88	36–84	47–69	50–89
Coda	63.5	68	61	79
SD	16	17.4	16.2	13.0
Range	44–94	44–100	38–94	56–96
TAS word speechreading	53	61	60	47
SD	16.4	21.8	19.6	15.5
Range	33–93	13–93	27–87	13–73
TAS minimal pairs speechreading	60	64	68	60
SD	9.8	9.9	5.5	10.9
Range	40–83	40–83	53–73	43–80
Auditory discrimination	74	76	71	93
SD	12.3	11.7	16.5	9.2
Range	44–94	47–91	44–94	69–100

Note. TAS = Test of Adult Speechreading.

Inspection of Table 5 suggests that the hearing children did less well on the single word speechreading task than the deaf children. However, a one-way ANOVA, taking total TAS word score as the dependent variable, showed that group differences were not statistically significant, $F(3, 68) = 2.3$, $p = .09$. Performance in the minimal pairs speechreading task was also compared using one-way ANOVA, taking the total correct percentage as the dependent variable. Again, there were no significant group differences, $F(3, 66) = 1.70$, $p = .18$. However, in this task, the position of the phonemes to be contrasted was varied. There were 10 trials each for initial position, medial position, and final position contrasts. For the 10 items contrasting initial phoneme position, mean scores were 5.0, 6.0, 6.4, and 6.2 for the Early CI group, the Late CI group, HA controls, and RA controls, respectively. Group differences approached statistical significance, $F(3, 66) = 2.67$, $p = .06$. The mean scores suggest that the children in the Early CI group were not as good at reading initial phonemes from visual cues as the other children. There were no group differences for medial phoneme position. Here, the mean scores were 6.6, 6.3, 6.7, and 6.2, respectively, $F(3, 66) = 0.45$, $p = .718$. When the final phoneme position was contrasted, the mean scores were 6.4, 6.9, 7.0, and 5.6, respectively. Here, there was a statistically significant difference between groups, $F(3, 66) = 3.28$, $p < .05$. Post hoc Tukey comparisons revealed that these differences were between the RA controls and the Late CI group ($p = .042$) and the HA controls ($p = .049$) but not the Early CI group ($p = .337$). This suggests that the Late CI group and the HA controls were better able to discriminate between final phonemes using lip and cheek cues than the hearing children. The Early CI group was in between. Hence, speechreading skills are significantly enhanced in deaf children compared with hearing children when information about phonemes must be read from the face, at least for phonemes in the final (coda) position. Better speechreading skills may support the development of phonological representations.

Auditory Discrimination and Speech Intelligibility

Inspection of Table 5 shows that the deaf children were impaired in auditory discrimination, as might be expected. A one-way ANOVA, taking total score as the dependent variable, showed that there was a significant difference between the deaf groups and the RA controls, $F(3, 67) = 11.73$, $p < .001$. Nevertheless, the deaf children were capable of identifying the auditory similarities and differences in pairs of words in over 70% of the stimuli. The PETAL rating scores for speech intelligibility are also shown in Table 5. Rating scores ranged between 1 and 5 in each of the deaf groups. A Kruskal–Wallis test was performed on these scale data. There were no statistically significant differences between intelligibility in the deaf groups, $\chi^2(2, N = 53) = 2.68$, $p = .26$. The highest rating of 1 (speech easy to understand) was given to seven children in the Early CI group, two children in the Late CI group, and four children among the HA controls.

Phonological Awareness

Percentages of correct scores for all experimental tasks are shown in Table 5. Performance levels that would be expected given the level of reading attainment are shown by the typically developing children (RA controls). Percentages are given to enable comparison between phonological awareness tasks. The RA controls achieved significantly higher scores than the deaf groups on all the phonological tasks, even though they were matched to the deaf children for their level of reading (NARA–R accuracy score). It should be noted that the deaf children tried very hard in the phonological tasks and provided considered responses.

A wide range of scores was shown for the rhyme task among the deaf groups, as can be seen from Table 5. A Kruskal–Wallis test indicated a significant difference between the deaf groups and the RA controls, $\chi^2(3, N = 72) = 12.67$, $p < .005$. However, the post hoc Mann–Whitney *U* test between the Early CI group and the RA controls did not reach significance ($U = 122.5$, $p = .057$). This indicates that rhyme awareness in the Early CI group did not differ from that attained by younger hearing children with the same word reading skills. The RA controls differed significantly from the other deaf groups (Late CI group, $U = 83.0$, $p < .01$; HA controls, $U = 42$, $p < .001$). No significant difference was found between the scores of the two CI groups ($U = 149.5$, $p = .25$) or between the HA controls and the CI groups (Early CI group, $U = 107.5$, $p = .26$; Late CI group, $U = 131.0$, $p = .94$).

To investigate whether performance in the rhyme task was above chance level for the deaf groups, the scores were converted to *z* scores using the binomial distribution. Performance significantly above chance was calculated to be 30/48 (64%) correct. Examination of the *z* scores showed that the means of both the Early CI group and the Late CI group were significantly above chance, with the HA controls just missing (mean group performance 63% correct). For individual children, 12 out of the 20 children in the Early CI group scored above chance level, compared with nine children in the Late CI group and seven HA controls. Hence, around half of the children in each of the latter groups had developed phonological awareness of rhyme. Group comparisons were also computed when only those children in each group scoring above chance levels were included in the analysis. Now there were no significant differences by group, $\chi^2(3, N = 47) = 2.44$, $p = .49$ (Early CI group = 81% correct; Late CI group = 79% correct; HA controls = 73% correct;

RA controls = 80% correct). Hence, deaf children who performed the task consistently were equivalent in their rhyming skills to the younger hearing controls, irrespective of age at implant or whether hearing was aided. This implies that late-implanted children can also develop rhyming skills that equal those of hearing children matched for reading age, with the appropriate support.

Deaf children's performance with initial phonemes at group level was also poorer than that of the RL controls. Nonparametric tests were again carried out to compare group mean scores (see Table 5). A Kruskal–Wallis test indicated a significant difference between groups, $\chi^2(3, N = 72) = 19.40$, $p < .001$. Post hoc Mann–Whitney U tests showed that the RA controls scored significantly above all the deaf groups (Early CI group, $U = 58.5$, $p < .001$; Late CI group, $U = 66.5$, $p < .001$; HA controls, $U = 34.5$, $p < .001$). No significant difference was found between the scores of the two CI groups ($U = 189.0$, $p = .98$) or between the HA controls and the CI groups (Early CI group, $U = 129.0$, $p = .70$; Late CI group, $U = 125.0$, $p = .77$). A binomial distribution calculation showed that to score significantly above chance level, scores greater than 40 were required (40/64 = 62.5%). Group means were below chance level for all the deaf groups. However, four children in the Early CI group, five children in the Late CI group, and four HA controls achieved above-chance level performance with initial phonemes. In the RA controls, 15 of the 19 children achieved scores above chance level. Group comparisons were again computed when only those children in each group scoring above chance levels were included in the analysis. There were no significant differences by group, $\chi^2(3, N = 28) = 7.69$, $p = .053$. The Early CI group's mean was 70% correct, the Late CI group's mean was 72% correct, the HA controls' mean was 66% correct, and the RA controls' mean was 77% correct.

Performance with codas (the final phonemes in syllables) was at a similar level to performance with initial phonemes and rhymes. A Kruskal–Wallis test indicated a significant difference between group mean scores, $\chi^2(3, N = 72) = 13.04$, $p < .005$. Mann–Whitney U post hoc tests showed that the RA controls scored significantly higher than all the deaf groups (Early CI group, $U = 81.5$, $p < .005$; Late CI group, $U = 107$, $p < .05$; HA controls, $U = 51.5$, $p < .01$). No significant difference was found between the scores of the two CI groups ($U = 156.0$, $p = .34$) or between the HA controls and the CI groups (Early CI group, $U = 125.0$, $p = .60$; Late CI group, $U = 98.5$, $p = .21$). Twenty-one deaf children (seven in the Early CI group, nine in the Late CI group, and five HA controls) and 15 of the hearing children scored above chance level (64% correct) on the coda task. These data show that performance with codas (final phonemes) is better for deaf children than performance with initial phonemes, in which only 13 children scored above chance levels. As speechreading skills for codas were significantly better for the deaf children, speechreading skills may contribute to the development of phonological representations for codas by deaf children. Group comparisons were again computed when only those children in each group scoring above chance levels were included in the analysis. There were no significant differences by group, $\chi^2(3, N = 36) = 0.86$, $p = .84$. The Early CI group's mean was 82% correct, the Late CI group's mean was 83% correct, the HA controls' mean was 80% correct, and the RA controls' mean was 85% correct. Hence, all deaf children who performed the task consistently were equivalent in their coda judgment skills to the younger hearing controls.

In general, therefore, all deaf groups lagged behind the hearing controls in phonological awareness. Intriguingly, this shows that at the group level, the deaf children's reading skills have developed to the same absolute level as that of the younger hearing controls, despite overall depressed phonological awareness and depressed vocabulary development. This suggests that other developmental factors are contributing to the levels of reading attained by the deaf children in our study. The data discussed earlier suggest that speechreading skills and visual memory skills may be such factors, at least for some of the deaf children. Nevertheless, some deaf children in each group had achieved reading-level appropriate scores. We return to these points in the correlational analyses.

Effects of Primary Language and Educational Setting

Eight of the 53 deaf participants with IQ in the normal range used British sign language as their primary language (three in the Early CI group, four in the Late CI group, and one HA control), and of these eight children, five were in a total communication educational setting (two in the Early CI group, two in the Late CI group, and one HA control). All other deaf participants were in oral language school settings. To see whether primary language had any effect on the reading and language outcomes, we used quotient scores. There was a significant effect of primary language for each quotient variable, with higher mean scores for the oral children: NARA–R accuracy (0.89 vs. 0.69), $t(37) = 3.89$, $p = .003$; NARA–R comprehension (0.86 vs. 0.63), $t(37) = 4.12$, $p = .001$; BAS–II single word reading (0.85 vs. 0.64), $t(37) = 4.29$, $p = .001$; receptive vocabulary (0.70 vs. 0.40), $t(37) = 7.05$, $p = .000$; expressive vocabulary (0.74 vs. 0.44), $t(37) = 4.64$, $p = .000$; digit span/auditory memory (0.69 vs. 0.48), $t(37) = 2.84$, $p = .013$. However, these differences should be interpreted with caution given the small number of signing children in our sample. To compare performance on the other experimental measures, we compared mean performance for the signing children and the oral children.

There were no significant differences for any of the measures apart from performance in the rhyme task, $t(37) = 3.57$, $p = .003$ (signing children = 53% correct, oral children = 70% correct). The group difference in the auditory discrimination task approached significance, $t(37) = 2.19$, $p = .06$. The data therefore suggest an effect of oral (phonological) experience on rhyming, reading attainment, and vocabulary development. We also recomputed all the analyses reported earlier using the oral deaf children only, excluding the eight children who used sign as their primary language. No differences were found. To compare whether educational setting had an effect on development, we computed the mean performance on all tasks for the two children in the Late CI group who were signers in a total communication setting compared with the two children in the Late CI group who were signers in an oral communication setting. There were no significant differences in any of the measures, with most tasks showing mean performance levels within 5 percentage points of each other.

Children Scoring <80 on the Leiter–R Brief IQ Screen

There were six deaf children who scored below a standard score of 80 for NVIQ on the Leiter–R Brief IQ Screen who were thus omitted from the analyses reported so far. These children comprised four implanted and two HA controls (Early CI group, $n = 1$, IQ = 79; Late CI group, $n = 3$, IQs = 68, 71, and 74, respectively; HA controls, $n = 2$, IQs = 70 and 71, respectively). Despite their low cognitive ability, half of these children—two in the Late CI group and one HA control—were reading within 1 *SD* of the expected level of attainment for their age. This implies that the pattern of relationships for reading, language, and phonological awareness reported above for deaf children with average cognitive ability may also apply to deaf children with lower cognitive ability. All the group analyses described above were repeated when all 78 children were included in the analyses. Exactly the same patterns of group differences as reported above were found.

Factors Associated With Reading Development in Deaf Children

The group comparisons reported so far have revealed a benefit of early cochlear implantation with respect to reading attainment (quotient scores), receptive vocabulary (quotient score), and rhyme awareness. To explore the relationships between all the different measures and reading development, correlational analyses were used. For these analyses, age at implant was treated as a continuous variable. As chronological age was highly correlated with age at implant ($r = .544$, $p = .000$), two sets of correlations were computed. In one set, the standard scores achieved for reading and language were used, controlling for age and NVIQ. The standard scores show the absolute levels of reading and language attainment reached by our deaf participants, and the factors correlate with these absolute levels of attainment once age and IQ are taken into account (see Table 6). In the second set of correlations, the quotient scores for reading, language, and auditory memory were used. As age was already adjusted in these analyses, only NVIQ was controlled (see Table 7). As chronological age and age at implantation are significantly related, age at implantation would only be expected to show effects in the quotient analyses. Partial correlations for the Early CI and Late CI groups are shown in Tables 6 (age and IQ controlled) and 7 (IQ controlled).

Table 6 shows that, as is usually found in studies of hearing children, absolute reading attainment was significantly correlated with the vocabulary and phonological awareness measures (rhyme, coda, and phoneme) and also with auditory memory (digit span). Speechreading skills at the word level and speech intelligibility also showed significant associations with the reading and vocabulary measures (the correlations with speech intelligibility are negative, as a low score on the PETAL corresponds to better performance). As might be expected, better speechreading skills at the word level and better speech intelligibility were also both significantly correlated with phonological awareness. Therefore, the associations between speechreading, speech intelligibility, and reading could be operating via phonological awareness. Visual memory was not correlated with word decoding skills but was significantly correlated with reading comprehension and orthographic knowledge (Wordchains task). Unexpectedly, auditory discrimination was not correlated with the reading, phonological, or vocabulary outcome measures. However, auditory memory was linked to phonological awareness, vocabulary, and speech intelligibility.

A second set of correlational analyses (not shown) explored analogous patterns for the HA controls. There were few significant correlations, which should in any case be interpreted with caution as this was a smaller group. Receptive vocabulary was significantly correlated with BAS–II single word reading for aided deaf children ($r = .557$, $p < .05$), and expressive vocabulary was significantly correlated with NARA–R reading comprehension ($r = .697$, $p < .01$). In addition, speechreading skills (TAS word) showed a significant correlation with reading comprehension ($r = .533$, $p < .05$) and orthographic knowledge (the Wordchains task; $r = .675$, $p < .05$). Auditory memory was significantly correlated with phonological awareness (rhyme and coda measures, *r*s = .662 and .577, respectively, *p*s < .05) and with receptive vocabulary ($r = .600$, $p < .05$).

Table 6. Partial correlations between reading and language standard scores and experimental measures—cochlear implant children (n = 39), controlling for age and NVIQ.

Task	NARA–R comprehension	BAS–II single word reading standard score	Wordchains	BPVS	EOWPVT	Rhyme	Initial phoneme	Coda	TAS word speech-reading	TAS minimal pairs speech-reading	Digit span auditory memory	Leiter–R visual memory	Auditory discrimination	Speech intelligibility (PETAL)	Age at implant	Duration of fit of cochlear implant
NARA–R accuracy	.873***	.898***	.772***	.721***	.745***	.564***	.392*	.574***	.393*	.009	.534**	.159	.020	−.492*	−.176	.141
NARA–R comprehension	—	.771***	.737***	.804***	.796***	.584***	.364*	.594***	.354*	−.092	.615***	.378*	.037	−.560***	−.215	.202
BAS–II single word reading standard score		—	.763***	.708***	.694***	.695***	.484**	.715***	.530**	.150	.577***	.160	.198	−.601***	−.091	.039
Wordchains			—	.470*	.425*	.532**	.088	.481*	.357	−.094	.518**	.600**	−.017	−.466*	−.017	−.014
BPVS				—	.862***	.695***	.371*	.535**	.339*	.116	.555***	.218	.099	−.756***	−.282	.230
EOWPVT					—	.615***	.421**	.515**	.383*	.028	.535**	.225	.072	−.664***	−.194	.162
Rhyme						—	.405*	.621***	.402*	.209	.647***	.277	.218	−.674***	−.218	.150
Initial phoneme							—	.387*	.521**	.328*	.328*	.253	.187	−.373*	−.104	.105
Coda								—	.416*	.010	.546***	.203	.308	−.554***	.055	−.080
TAS word speech-reading									—	.406**	.362*	.443*	.148	−.378*	.143	−.192
TAS minimal pairs speech-reading										—	.072	−.084	.167	−.065	.072	−.114
Digit span auditory memory											—	.437*	.193	−.588***	−.150	.129
Leiter–R visual memory												—	−.009	−.295	−.053	−.085
Auditory discrimination													—	−.329*	−.038	−.012
Speech intelligibility (PETAL)														—	.176	−.099
Age at implant															—	−.978***

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 7. Partial correlations between reading and language quotient measures and experimental measures—cochlear implant children (n = 39), controlling for NVIQ.

Task	NARA–R comprehension quotient score	BAS–II single word reading quotient score	Wordchains standard score	BPVS quotient score	EOWPVT quotient score	Rhyme	Initial phoneme	Coda	TAS word speech-reading	TAS minimal pairs speech-reading	Digit span auditory memory quotient score	Leiter–R visual memory	Auditory discrimination	Speech intelligibility (PETAL)	Age at implant	Duration of fit of cochlear implant
NARA–R accuracy quotient score	.948***	.850***	.647***	.753***	.667***	.455**	.310	.389*	.130	−.055	.643***	.434**	−.025	−.613***	−.365*	−.204
NARA–R comprehension quotient score	—	.801***	.603***	.731***	.606***	.331*	.249	.256	.021	−.167	.657***	.518***	−.070	−.612***	−.405*	−.245
BAS–II single word reading quotient score		—	.358*	.509***	.385*	.237	.146	.148	−.074	−.138	.491**	.340*	−.057	−.510***	−.418**	−.525***
Wordchains standard score			—	.623***	.529**	.627***	.281	.567***	.469***	−.013	.592***	.446**	.141	−.404*	−.017	.321
BPVS quotient score				—	.866***	.652***	.373*	.509***	.329*	.063	.589***	.295	.103	−.658***	−.187	.168
EOWPVT quotient score					—	.595***	.422**	.514**	.364*	.093	.491**	.225	.125	−.512***	−.070	.232
Rhyme						—	.473**	.677***	.505***	.277	.557***	.189	.298	−.537***	.007	.362*
Initial phoneme							—	.474**	.592***	.402**	.412**	.174	.275	−.288	.086	.335*
Coda								—	.560***	.158	.450**	.047	.403**	−.408**	.273	.341*
TAS word speech-reading									—	.516***	.183	.226	.295	−.209	.399**	.400**
TAS minimal pairs speech-reading										—	−.117	−.154	.248	−.033	.229	.243
Digit span auditory memory quotient score											—	.499**	.177	−.540***	−.251	.036
Leiter–R visual memory												—	−.082	−.297	−.180	−.217
Auditory discrimination													—	−.261	.126	.267
Speech intelligibility (PETAL)														—	.222	.085
Age at implant															—	.000

*p < .05. **p < .01. ***p < .001.

Table 7 shows that when quotient scores were used, age at implantation was significantly correlated with NARA–R word reading accuracy and reading comprehension, as well as with BAS–II single word reading. There was an advantage of early implantation for the reading measures (significant correlations were negative). Interestingly, with respect to speechreading, the Late CI group had better skills (significant positive correlation). Duration of fit was also significantly correlated with BAS–II single word reading, speechreading, and phonological awareness (rhyme, initial phoneme, and coda measures). Longer use of an implant was positively correlated with phonological outcomes but negatively correlated with the BAS–II single word reading measure. This suggests perhaps that the BAS–II is not a very sensitive measure of deaf children's reading attainment. In addition, as is usually found in studies of hearing children, NARA–R reading accuracy was significantly correlated with phonological awareness measures (rhyme and coda awareness) and also with auditory memory. Those deaf children with better phonological and auditory skills showed better reading performance. All reading measures were correlated with both receptive and expressive vocabulary abilities, and with both auditory and visual memory skills. Apart from the Wordchains measure, speechreading skills now did not show significant correlations with reading. Speech intelligibility was still correlated with all the reading, phonology, and vocabulary measures, with the exception of initial phoneme awareness.

Hence, there are some differences in the factors associated with reading for deaf CI children depending on whether standard scores or quotient scores are used. In particular, the phonological processing measures (rhyme, coda, initial phoneme) show stronger relations to the reading standard scores (the absolute level of attainment), whereas the age at implantation and duration of fit measures show stronger associations with the reading quotient scores (the relative level of attainment). Speechreading skills show stronger associations with reading standard scores. Vocabulary attainment and rhyme awareness show strong associations with reading for both quotient and standard scores, as do both auditory and visual memory and speech intelligibility. Therefore phonological, vocabulary, articulatory, aural, and visual skills all appear to support reading development in deaf children with CIs. Articulatory, speechreading, and visual memory skills support reading attainment in addition to the phonological and language skills that are associated with reading development in hearing samples.

A second set of correlational analyses again explored analogous patterns for the HA controls (not shown), controlling for NVIQ and using quotient scores for the reading, vocabulary, and auditory memory measures. This was a small sample, and there were few significant correlations. The different measures of reading showed significant correlations with each other, and NARA–R reading comprehension (quotient measure) was significantly correlated with auditory discrimination ($r = -.654$, $p = .021$) and with speech intelligibility ($r = .710$, $p = .007$). Phoneme awareness was significantly correlated with auditory memory ($r = -.604$, $p = .029$). Reading was not significantly correlated with either the vocabulary or phonology measures in this small sample.

Finally, to explore the relative strengths of the different associations indicated in the correlational analyses, multiple regression analyses were conducted for the CI cohort. In particular, we were interested in the relative contributions made by phonological awareness (rhyme awareness, the most consistent associate of deaf reading) and vocabulary (receptive vocabulary, which showed stronger associations) to deaf CI reading outcomes. Two series of three-step fixed entry multiple regression equations were computed that varied whether rhyme awareness was entered before receptive vocabulary or receptive vocabulary was entered before rhyme awareness. In each case, the dependent variables in each set of equations were the four reading measures, using the reading quotient scores for the NARA–R and BAS–II measures and the standard score for the Wordchains measure (in which deaf progress was age appropriate). The independent variables were entered in a fixed order as follows: Step 1, NVIQ; Step 2, either phonological awareness (rhyme) or vocabulary (BPVS quotient); and Step 3, the other experimental variables of theoretical interest. The unique variance accounted for in each case is shown in Tables 8 and 9.

When rhyme awareness was entered at Step 2 (see Table 8), it explained between 5% and 39% of unique variance in reading development, with a particularly strong contribution to the Wordchains measure—a putatively orthographic measure. Age at implantation still made a significant contribution to reading development for all three quotient measures, accounting for between 12% and 16% of unique variance. Duration of fit made an even larger unique contribution to the reading quotient measures, accounting for up to 40% of additional unique variance. Receptive vocabulary accounted for up to 38% of additional unique variance in each reading quotient measure, and speech intelligibility also exerted a notable effect, explaining up to 22% of additional unique variance. Therefore, speech intelligibility makes a contribution to deaf children's reading development that is independent of its association with phonological development, whereas speechreading does not. When receptive vocabulary was entered at Step 2 (see Table 9), vocabulary knowledge explained between 24% and 49% of significant unique variance in reading, for both quotient and standard measures (Wordchains). Once receptive vocabulary was

Table 8. R^2 changes for different predictors of reading when entered at Step 3 in multiple regression equations, controlling for NVIQ at Step 1 and rhyme awareness at Step 2.

Changes in R^2	NARA–R accuracy	NARA–R comprehension	BAS–II single word reading	Wordchains
Step 1: NVIQ	.128*	.162**	.062	.007
Step 2: Rhyme	.180**	.092*	.053	.390***
Step 3: Age at implant	.118**	.139**	.165**	.000
Step 3: Duration of fit	.137**	.128**	.403***	.010
Step 3: BPVS quotient score	.317***	.386***	.204**	.079*
Step 3: Initial phoneme	.010	.009	.001	.000
Step 3: Coda	.011	.002	.000	.037
Step 3: Speechreading	.011	.024	.047	.031
Step 3: EOWPVT quotient score	.212***	.216***	.087	.038
Step 3: Digit span	.192***	.271***	.175**	.085*
Step 3: Visual memory	.110*	.180**	.085	.111*
Step 3: Speech intelligibility	.166**	.222***	.193**	.006

Note. $n = 39$ for children with cochlear implants; dependent variables = NARA–R and BAS–II quotient scores and Wordchains standard score.

$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

controlled, phonological awareness or speech intelligibility no longer explained significant unique variance. Auditory and visual memory continued to add significant unique variance, explaining up to 11% of additional variance in reading outcomes. Expressive vocabulary did not make an additional unique contribution once receptive vocabulary was accounted for. Overall, the regression analyses suggest a special role for visual memory in the development of reading skills by deaf children and also for speech intelligibility. In addition, vocabulary development appears to exert a stronger effect than phonological development, which is the opposite pattern of that typically found for hearing children. Both speech intelligibility and phonological awareness of rhyme are strongly associated with vocabulary development, as neither accounted for significant unique variance in reading once receptive vocabulary was controlled in the regression analyses.

Discussion

This study was designed to see whether the speech perception benefits offered by cochlear implantation affect

Table 9. R^2 changes for different predictors of reading when entered at Step 3 in multiple regression equations, controlling for NVIQ at Step 1 and receptive vocabulary at Step 2.

Changes in R^2	NARA–R accuracy	NARA–R comprehension	BAS–II single word reading	Wordchains
Step 1: NVIQ	.128*	.162**	.062	.007
Step 2: BPVS quotient score	.495***	.448***	.243***	.385***
Step 3: Age at implant	.046*	.063**	.102*	.010
Step 3: Duration of fit	.098***	.117***	.360***	.048
Step 3: Rhyme	.002	.031	.015	.084*
Step 3: Initial phoneme	.001	.001	.002	.003
Step 3: Coda	.000	.015	.016	.084*
Step 3: Speechreading	.013	.045*	.061	.078*
Step 3: EOWPVT quotient score	.001	.003	.011	.000
Step 3: Digit span quotient score	.053*	.066**	.052	.077*
Step 3: Visual memory	.043*	.084**	.037	.075
Step 3: Speech intelligibility	.021	.025	.051	.000

Note. $n = 39$ for children with cochlear implants; dependent variables = NARA–R and BAS–II quotient scores and Wordchains standard score.

$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

the development of phonological awareness by deaf children and consequently support their reading development. The potentially beneficial effects of early implantation for reading and phonological skills were also of interest. Profoundly deaf children with CIs (mean unaided hearing levels of 109 [Early CI group] and 106 [Late CI group]) were found to have developed comparable levels of phonological awareness with severely deaf children (mean unaided hearing level of 80 dB for children with IQs >80), suggesting some evidence for benefit. Furthermore, there was a clear additional benefit of early cochlear implantation on reading development for the implanted children and also on receptive vocabulary and rhyme awareness. Children who were implanted before the age of 3 years had rhyming skills equivalent to those of reading-level matched hearing children. They also had reading skills that were close to being age appropriate (quotient scores between 0.91 and 0.86) and that were significantly greater than the quotient scores of the late-implanted children. The Early CI group also had a significantly higher receptive vocabulary quotient than the Late CI group (0.72 vs. 0.57). However, implantation helped reading and vocabulary development in the Late CI group as well, as their reading and receptive language quotient scores were equivalent to those of children who were less deaf than they were (the HA controls). The children in the Late CI group were also better at speechreading than the children in the Early CI group.

The benefit of early implantation for reading development is consistent with two recent studies showing an effect of early implantation on deaf literacy (Archbold et al., 2008; Connor & Zwolan, 2004), whereas the benefit of early implantation for receptive vocabulary supports a number of prior studies (e.g., Geers et al., 2007; Nicholas & Geers, 2008). A benefit of early implantation has also been suggested for speech intelligibility (Svirsky et al., 2007). Interestingly, when the factors that affected reading development in the implanted children were studied using correlational analyses and standard scores, speech intelligibility and speechreading skills both showed a significant relationship to reading. Standard scores provide an absolute measure of a deaf child's attainment compared with a hearing population norm. Speech intelligibility and speechreading were also correlated with phonological awareness for the implanted children, suggesting that both articulatory skills and the ability to derive phonological information from lip and cheek cues help in the development of well-specified phonological representations by deaf children. When reading quotient scores were considered, which measure the relative attainment of deaf children compared with hearing children, these factors were no longer important. Instead, age at implantation, duration of fit, and visual memory skills were now revealed to be important.

For both measures (reading standard and reading quotient scores), reading development in the CI children was significantly associated with phonological awareness, auditory memory skills, and vocabulary development. Phonological awareness and auditory memory are strong predictors of reading development in hearing samples (Goswami & Bryant, 1990), suggesting that the developmental trajectory of deaf children who have received CIs is similar to that of hearing children (see also James et al., 2005). Nevertheless, the deaf CI children had attained similar absolute levels of word recognition and reading comprehension to the (younger) hearing controls, despite having significantly poorer phonological awareness and auditory memory skills. This suggested that factors in addition to phonology and auditory memory were supporting reading development for the CI group. These were found to be speechreading skills, speech intelligibility, and visual memory. A role for speechreading in deaf literacy was also reported by Harris and Moreno (2006) and by Kyle and Harris (2006). As suggested by Charlier and Leybaert (2000), the visual specification of phonological contrasts appears to aid the development of phonological representations.

Similarly, speech intelligibility may be an indirect measure of articulatory skills, which may help in the development of phonological representations. A functional imaging study of the phonological system in the deaf brain (MacSweeney et al., 2008) has shown that signing deaf adults differ from hearing controls in showing greater activation of left inferior frontal gyrus (Broca's area) during the same rhyme task used here with deaf children. This suggests an increased reliance on the articulatory component of speech when making phonological judgments, which is also found for dyslexic children (Temple et al., 2003). This raises the possibility that the speech intelligibility measure used with deaf children is actually an indirect measure of the quality of the children's articulatory phonological codes. Indeed, apart from the articulatory differences, signing congenitally deaf adults activated the same neural systems as hearing controls during the rhyme task (MacSweeney et al., 2008). This suggests that phonological processing is supported by a supramodal phonological system even when language input differs (speech vs. sign; for detailed discussion, see MacSweeney et al., 2008). Finally, the deaf children's visual memory skills are most probably helping the development of the orthographic lexicon. Significant unique variance in reading comprehension and in the orthographic Wordchains task was still explained by visual memory skills in the multiple regression analyses, even after controlling for receptive vocabulary.

Receptive vocabulary development was also found to be important for reading development in deaf children, consistent with the results of many prior studies (e.g., Connor & Zwolan, 2004; Geers, 2003; LaSasso & Davey, 1987; Moores & Sweet, 1990). Overall, therefore, the data reported here complement the findings of Geers (2003) in showing a role for both overall language competence and speech intelligibility in reading development for deaf implanted children. The data reported here additionally show that early cochlear implantation benefits the development of reading, for both decoding and comprehension, as shown for decoding by Archbold et al. (2008) and for reading comprehension by Connor and Zwolan (2004). The data suggest that cochlear implantation enhances the phonological awareness and auditory memory skills that contribute to both reading accuracy and reading comprehension. In addition, articulatory phonology may play an important role in supporting reading development in deaf children, whereas speechreading skills may contribute to the development of well-specified phonological representations.

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Appendix A. Rhyme task (MacSweeney et al., 2008).

Rhyme/nonrhyme type	First word	Corresponding word
Rhyme same orthography	Leg	Peg
	Mouse	House
	Dog	Log
	Hook	Book
	Van	Fan
	Hop	Mop
	Bat	Cat
	Cap	Tap
	Nail	Tail
	Coat	Goat
	Rock	Sock
	Rug	Mug
Rhyme different orthography	Jail	Whale
	Wool	Bull
	Mum	Thumb
	Neck	Cheque
	Girl	Pearl
	Deaf	Chef
	Sheet	Meat
	Walk	Fork
	Goal	Bowl
	Cart	Heart
	Bowl	Hole
	Light	Kite
Nonrhyme, shared onset–vowel	Map	Match
	Dog	Doll
	Mouse	Mouth
	Cheek	Cheese
	Whale	Wave
	Book	Bull
	Coat	Cone
	Wall	Walk
	Goal	Goat
	Rope	Rose
	Bat	Bag
	Sheep	Sheet
Nonrhyme, shared vowel	Mouth	House
	Hop	Doll
	Bird	Pearl
	Wave	Chain
	Leg	Shell
	Match	Van
	Bag	Cap
	Cat	Tap
	Card	Heart
	Cot	Sock
	Hole	Bone
	Meat	Sheep

Appendix B. Initial phoneme task (MacSweeney et al., 2008).

Onset/orthography type	First word	Corresponding word	Onset/orthography type	First word	Corresponding word
Cluster onset, different orthography	Queen	Kite	Nonshared onset	Plan	Book
	Skirt	Celery		Skirt	Tail
	Climb	Key		Spoon	Ladder
	Queue	Coat		Blue	Mouse
	Swim	Circus		Green	Queue
	Cloud	King		Drink	Lake
	Frog	Photo		Frog	Van
	Sledge	Ceiling		Train	Dog
Cluster onset, same orthography	Plate	Pig	Nonshared onset, same orthography	Climb	Circus
	Three	Thumb		Glass	Giant
	Spoon	Suit		Green	Giraffe
	Blue	Baby		Three	Tail
	Glass	Goal		Plate	Phone
	Drink	Doll		Shred	Sock
	Shred	Ship		Sledge	Ship
	Train	Tiger		Cloud	Cheese
Phoneme onset, different orthography	Knife	Nail	Nonshared onset	Jug	Neck
	Knee	Neck		Nail	Light
	Cone	Key		Leg	Dog
	Circle	Suit		Vase	Fan
	Giraffe	Jelly		Book	Map
	Write	Red		Coat	Girl
	Fan	Phone		Baby	Pig
	Ceiling	Sock		Soap	Tiger
Phoneme onset, shared orthography	Cheese	Chain	Nonshared onset, same orthography	Celery	Cat
	Ladder	Light		Write	Wall
	Mouse	Map		Thumb	Tap
	Cat	Cake		Cone	Circle
	Vase	Van		Knee	Kite
	Jelly	Jug		Photo	Pig
	Red	Rose		Knife	King
	Lake	Leg		Chain	Cake

Appendix C. Coda task.

Coda type/practice items	Same orthography	/IPA/	Different orthography	/IPA/
Same coda				
Same onset	man moon	/m{n mu:n/	crane crown	/kreIn kraUn/
Different vowel	net nut	/net nVt/	phone fan	/f@Un f{n/
	pig peg	/pIg peg/	slide sword	/slaId sO:d/
	bird bed	/b3:d bed/	kite cat	/kaIt k{t/
Different onset	farm worm	/fAm w3m/	dice bus	/daIs bVs/
Different vowel	wall hill	/wOl hIl/	clock bike	/klQk baIk/
	dog jug	/dQg dZVg/	swing tongue	/swIN tVN/
	cup tap	/kVp t{p/	train bone	/treIn b@Un/
Different onset	ring king	/rIN kIN/	soap rope	/s@Up r@Up/
Same vowel	pen hen	/pen hen/	socks fox	/sQks fQks/
	cake snake	/keIk sneIk/	whale snail	/weIl sneIl/
	coat boat	/k@Ut b@Ut/	toast ghost	/t@Ust g@Ust/
Different coda				
Same onset–vowel	bat bag	/b{t b{g/	witch whip	/wItS wIp/
	hand hat	/h{nd h{t/	suit soup	/sut sup/
	shed shell	/Sed Sel/	rain rake	/reIn reIk/
	cheek cheese	/tSik tSi:z/	book bush	/bUk bUS/
Different onset	sun thumb	/sVn TVm/	wheel leaf	/wi5 lif/
Same vowel	plug duck	/plVg dVk/	spade paint	/speId peInt/
	leg bell	/leg bel/	horse ball	/hOs bO:5/
	zip fish	/zIp fIS/	shirt purse	/S3t p3s/
Different onset	snow bowl	/sn@U b@U5/	fly knife	/flaI naIf/
Same vowel	star shark	/stA: SAk/	shoe goose	/Su: gus/
	knee queen	/ni: kwi:n/	door fork	/dO: fOk/
	bee sweet	/bi: swit/	cow mouse	/kaU maUs/
Practice items				
C–	bin bath		house heart	
C+	pan plane		comb drum	