Phonological Awareness, Vocabulary, and Word Reading in Children Who Use Cochlear Implants: Does Age of Implantation Explain Individual Variability in Performance Outcomes and Growth?

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The phonological awareness (PA), vocabulary, and word reading abilities of 19 children with cochlear implants (CI) were assessed. Nine children had an implant early (between 2 and 3.6 years) and 10 had an implant later (between 5 and 7 years). Participants were tested twice over a 12-month period on syllable, rhyme, and phoneme awareness (see James et al., 2005). Performance of CI users was compared against younger hearing children matched for reading level. Two standardized assessments of vocabulary and single word reading were administered. As a group, the children fitted early had better performance outcomes on PA, vocabulary, and reading compared to hearing benchmark groups. The early group had significant growth on rhyme awareness, whereas the late group showed no significant gains in PA over time. There was wide individual variation in performance and growth in the CI users. Two participants with the best overall development were both fitted with an implant late in childhood.

There are some indications that the reading level of deaf[1] adolescents who use cochlear implants (CI) falls within the range expected of age-matched peers with no hearing difficulties (Geers, 2003; Spencer, Gantz, & Knutson, 2004) more often than that which has been reported with respect to deaf adolescents who did not use CI (Allen, 1986; Conrad, 1979; Marschark & Harris, 1996). This finding is consistent with the growing body of research which suggests that CI enhance the development of speech perception (Blamey et al., 2001) and the acquisition of spoken language (Dawson, Blamey, Dettman, Barker, & Clark, 1995; Miyamoto, Svirsky, & Robbins, 1997). Studies of reading and language in deaf children show that language, whether spoken or signed, is strongly associated with reading (Moores & Sweet, 1990; Strong & Prinz, 2000; Waters & Doehring, 1990). Enhanced language development afforded by CI should also mean improved literacy levels for CI users (Connor & Zwolan, 2004; Crosson & Geers, 2001; Spencer, Brittan, & Tomblin, 2003). One possibility is that a corollary of enhanced language development is enhanced phonological skills. For hearing children, the early stages of reading development depend on the ability to reflect on or manipulate speech sound units, a skill referred to as phonological awareness (PA; Bradley & Bryant, 1983). The difficulty that deaf children face in developing awareness of the phonology of spoken language (Campbell & Wright, 1988; Charlier & Leybaert, 2000; Harris & Beech, 1998) has been thought to be a contributory cause of the low reading attainment that was (and possibly continues to be) characteristic of school leavers who are deaf.

PA refers to the child's ability to reflect on the phonological structure of their language. There are a range of measures of PA for hearing children that explore children's ability to identify and recognize similarities between phonological representations and

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to segment and manipulate those representations (e.g., by adding or deleting sounds). It is generally accepted that children's ability to do PA tasks is a reflection of the underlying quality of their phonological representations in the lexicon (Swan & Goswami, 1997). Fowler (1991) suggested that these representations start out being holistic in nature and become increasingly segmentally organized over time. Ziegler and Goswami (2005) drew on a wide body of empirical evidence to support the argument that PA develops from larger to smaller units during childhood, with syllable and rhyme awareness developing prior to phoneme awareness. One plausible idea is that vocabulary growth drives the increase in phonemic representation of lexical entries (Metsala & Walley, 1998; Ziegler & Goswami, 2005). Prior to literacy instruction, hearing children demonstrate awareness of syllable and rhyme, but full phonemic awareness develops reciprocally with literacy once a child starts to read an alphabetic orthography (Johnston, Anderson, & Holligan, 1996; Kirtley, Bryant, MacLean, & Bradley, 1989).

The central position of vocabulary development in PA is consistent with Locke's (1997) wide-ranging neurolinguistic development theory of sensitive periods in language development. According to Locke, there is a critical mass in vocabulary development that triggers the segmental organization of lexical entries. If a sizeable increase in lexical development does not happen by about 24 months of age (with an upper boundary of 36 months), the neurolinguistic mechanism responsible for representational redescription (the analytical–computational mechanism) will not be "turned on." A failed mechanism would result in the inability to extract phonological similarities that occur in the ambient language. De Cara and Goswami (2002) suggested that in English the rime unit has a special status in terms of phonological similarity by virtue of the fact that there are many monosyllabic words that share a vowel and final consonant. Thus, evidence of rhyme awareness could be viewed as an important developmental milestone because it shows that the child has become sensitive to the regularities of the prominent patterns in the ambient spoken language. This is exactly the type of learning that Locke would propose is evidence of an intact analytic and computational mechanism. A strong interpretation of Locke's theory would lead to the prediction that children whose spoken language development is very delayed (up to the age of around 36 months) will not be able to demonstrate rhyme awareness.

Relating these theories of phonological development to deaf children yields the following prediction. Given the fact that CI fitting does enhance the development of spoken language, we might expect to find differences in PA in deaf children depending on the age at which the implant was fitted. Understanding more about the impact of the age of implantation has important clinical significance for parents, children, and professionals. Knowledge of the impact of age of implant fitting on functional attainment and the rate and trajectory of development is helpful for setting expectations and designing rehabilitation programs. We set out to examine whether age of implant affected the development of PA in deaf children, and given the important links with spoken vocabulary development and reading, we also investigated deaf children's development in these skills.

Age of Implant Effect on Vocabulary Development

Connor and colleagues (Connor, Hieber, Arts, & Zwolan, 2000) investigated the impact of communication mode on vocabulary development and speech production in CI users. As part of that study the impact of age of implantation was explored. Performance outcomes and growth rates in receptive vocabulary in children fitted before and after 5 years of age were compared. The results showed that children fitted before age 5 had higher performance outcomes at the 3-year postimplant period and higher growth rates over that period than children who received their implant after the age of 5. Children fitted before age 5 had an average growth rate of 0.63 per year in receptive vocabulary, children fitted after five years had average growth rates of 0.45 per year. In a more recent study designed to explore the impact of age of fitting, Connor and her colleagues (Connor, Craig, Raudenbush, Heavner, & Zwolan, 2006) recruited children who were very young at implantation (between 1 and 2.5 years) and compared their speech and vocabulary performance and growth rates with three other groups of children. One group had their implants between

2.6 and 3.5 years, a further group was fitted between the ages of 3.6 and 7 years, and the final group was fitted between the ages of 7.1 and 10 years. The growth rate of receptive vocabulary was compared over a 4-year postimplant-fit period. The children who were very young at the time of implantation had a significantly greater growth rate in receptive vocabulary over the first 3 years following cochlear implantation than the other three groups, but there was no significant difference in the growth rates between the four groups when the whole of the 4-year postimplant period was considered. El-Hakim and colleagues (El-Hakim et al., 2001) also examined the development of receptive and expressive vocabulary in a retrospective study of 72 children using CI over the 4-year postimplant period. In this study, the rate of vocabulary development was based on age equivalent scores from two vocabulary assessments. They found that there was an initial increase in age equivalent scores, however, the rate of vocabulary development slowed down in all the implant users in their study. However, it was more characteristic for children fitted after the age of 5 years to show a significant decrease in the rate of expressive vocabulary development than children fitted before the age of 5 years who did not tend to have a marked decrease in development. El-Hakim and colleagues reported that there was less variability in the rate of vocabulary growth in children fitted early and much wider degree of variability in children fitted after the age of 5 years. Szagun (2001) used a parental report measure to plot the growth in vocabulary development in a group of 22 children with implants over 3 years. The main focus of her study was on grammatical development and she compared the CI users with hearing children who were matched for language level at the start of the study. After 3 years of implant use, Szagun found that 10 CI users had equivalent grammatical development to hearing children, 6 implant users made slow progress compared to hearing children, and a further 6 implant users made very minimal progress. Age of implantation accounted for some variation in outcome, with earlier implantation related to greater grammatical development. However, results from a stepwise regression showed that quality of the maternal dialogue accounted for more variance in grammatical development than age of implantation.

The discussion of these studies shows that an effect of age of implant on vocabulary growth might be detectable in the first 2–3 years after implant fitting, but the differences between early and later fitting might be harder to detect over longer time period post-implantation. It is also germane to highlight that individual variation between implant users is commonplace, but it might be more characteristic of children fitted after the age of 5 years and there might be less variability in outcome when children receive an implant early. The effect of age of implantation may be attenuated depending on the other variables included in the analyses and one difficulty we have in critically evaluating the effect of age of implant is that not all studies use the same set of variables.

Methodological Considerations in Age of Implant Studies

Some of the variability in findings concerning age of implantation may be explained by a failure to take general cognitive ability into account. Given the links between language and nonverbal ability found in the normal population and in special populations (Viding et al., 2003) it is perhaps surprising that studies in the CI field have not tended to take general cognitive ability into account. Geers and her colleagues (Geers, 2002; Geers et al., 2002) showed that nonverbal IQ accounted for a significant proportion of the variance in speech perception, speech production, spoken language, and reading after other factors, including age of implant, were taken into account. In some CI research (including the studies by El-Hakim and colleagues and Connor and colleagues cited above), participants' nonverbal IQ levels were either not reported or not controlled in the analysis. Thus, the significance given to age of implantation in studies that predate the study by Geers et al. must be viewed in the light of the connection between nonverbal IQ, speech perception, and language. It is therefore crucial to consider potential interactions with nonverbal cognitive ability and to build this in to study design when testing children who use CI.

A further complication in age of implant studies lies in the difficulty of creating groups of children who differ on age of implantation, but are matched on other variables that might also be predictors of outcome after implant fitting. For example, matching children for duration of CI use is important because, as we have already seen from the studies outlined above, growth rates vary after implantation. However, if duration of use is matched but age of implantation is varied, the children in the groups will always differ in chronological age at the point of data collection (children fitted later will be older than children fitted earlier). This could be particularly problematic for a study of PA and reading because, as previously stated, in hearing children phonemic awareness is reciprocally related to literacy instruction, and explicit instruction in the links between letters and sounds supports phonemic awareness which in turn promotes reading development (Hatcher, Hulme, & Ellis, 1994). Thus, older children (who have the benefit of longer exposure to print and more literacy instruction) might be expected to have better phonemic awareness and this could attenuate any age of implant effect. One way to take account of this potential confound is to compare CI users to hearing children matched for chronological age (who have the same length of exposure to print and literacy instruction) and hearing children matched for reading level (who have similar degrees of reading mastery). As well as evaluating performance outcomes relative to groups of hearing children, it is also important to consider the rate of development when evaluating the effect of age of CI. This can only be addressed in studies that adopt a degree of longitudinal assessment.

The Development of PA in CI Users

In James et al. (2005), we reported a short-term longitudinal study investigating the development of PA in a group of 19 pediatric CI users. We compared the performance of the CI users to that of profoundly and severely deaf children who used hearing aids. We found that PA in CI users developed over time, and followed the sequence predicted by theoretical models based on hearing children. Syllable and rhyme awareness (both larger phonological units) preceded phoneme awareness. In addition, we found that the benefit of CI use was most noticeable at the level of syllable awareness because it was at that level that the CI users' performance was equivalent to a group of severely deaf children. However, we noted that this facility with syllables could be a developmental effect, reflecting the sequence of skill acquisition, and that further benefits of CI (e.g., at the rhyme or phoneme levels) may be revealed as the children continued to develop.

A clear effect of orthographic knowledge on phonological development was found at the syllable and phoneme levels. Although the PA tasks were picture based, all the profoundly deaf children in the study (CI users and hearing aid users) found it easier to make judgments about shared phonological units when the spelling of the names of the pictures was congruent with the judgment to be made (e.g., when words with more syllables had longer spellings, or when words that had the same initial phoneme also had the same initial grapheme). This did not seem to be characteristic of the severely deaf children. The ability to make phonological judgments in the absence of support from orthographic knowledge is a valid indicator of sensitivity to the phonological structure of the ambient language.

The Current Study

In the current report, we explore the effect of age of implantation on PA, vocabulary, and reading in the same CI sample. Our group of CI users consisted of children who had been implanted relatively early in childhood (2–3.6 years, $n = 9$) and children who had been fitted later (between the ages of 5 and 7 years, $n = 10$). We compare performance outcomes using z-scores on the PA measures and standard scores on two standardized tests of vocabulary and word reading. We also evaluate the impact of age of CI by comparing rate of growth in children fitted early versus children fitted later on PA, vocabulary, and reading. At the outset of our study, we had expected to find differences in PA dependent on age of implantation. According to research on the plasticity of the central auditory system, there is a period of maximum plasticity that lasts for about 3.6 years (Sharma, Dorman, & Spahr, 2002). Thereafter, there is some plasticity of the central auditory system up to the age of 7 years. This finding is in accordance with the developmental phases outlined in Locke's theory. Based on these converging data, we predicted that there would be an advantage in PA for children who had received a CI earlier in development (i.e., before the age of 3.6) compared to children who had been fitted later (between the ages of 5 and 7 years). The quality of the child's phonological representations was measured by the novel battery of PA tests reported in James et al. (2005). In the current report, we examine the age of implant fitting by:

1. comparing PA in CI users (fitted early and late) relative to benchmark groups of hearing children matched for reading level and chronological age

    children fitted early should have performance that falls closer to the normal distribution of the benchmark groups than children fitted later

2. comparing rate of growth in the most sensitive measures of PA, trials that cannot be solved by relying on orthographic knowledge in children fitted early and late

    children fitted early should show higher performance on the orthographically incongruent trials and greater growth on these trials over time, although children with longer duration of CI use (over 4 years) may show attenuated growth rates between T1 and T2 based on prior research from children using CIs

3. investigating individual variation in performance and growth in children fitted early and late

    individual variation might be greater in children in the late group based on prior literature from the CI field

4. comparing standard scores on receptive vocabulary and single word reading in the early and late groups

    children fitted early should have performance that falls closer to the normal distribution of the standard norms than children fitted later

5. investigating individual growth over time on vocabulary and word reading in children fitted early and children fitted late

    children fitted early should show greater growth in vocabulary and reading over time, although children with longer duration of CI use (over 4 years) may show attenuated growth rates between T1 and T2 based on prior research from children using CIs, there might be more variation between children fitted late than between children fitted early

In addition to these comparisons, we provide detail on the factors that might contribute to individual variation among participants such as, preimplant hearing impairment, preimplant language level, implant factors (age of implant and duration of implant use), communication mode, and educational placement. These variables are not the central focus of our study, but they are reported in order to support the discussion regarding individual differences and to facilitate comparison with other data sets.

Method

Participants With CI

Participants were recruited from two CI centers in the United Kingdom. A set of criteria were applied to the whole population of children who had received an implant at Great Ormond Street Hospital (GOSH) and the Southampton Institute for Sound and Vibration Research (SOECIC). In total, 36 children met the criteria for the study. Written positive consent was given for 21 of these children. All the children were congenitally deaf with no history or suspicion of progressive hearing loss since birth. All the children had been fitted with an implant before the age of 7 years. We set out to investigate age of implant fitting at the start of our study and planned to investigate it as a between-subjects variable. Therefore, we adopted a categorical approach to recruitment in this regard. Children were recruited if they had been fitted with an implant between the ages of 2 and 3.6 years or if they had been fitted between the ages of 5 and 7 years. All the participants had been using their implant for at least 3 years. Rating of device use was established using the scale devised by Archbold, O'Donoghue, and Nikolopoulos (1998). All the participants were rated by their teacher of the deaf as being good users of their CI meaning that they used their device for most of the time. Children were only invited to take part in the study if their nonverbal cognitive

Table 1 Participants' hearing impairment and implant characteristics

Participant	CA (age; year)	Age at diagnosis	Aetiology	Age at hearing aids (age; year)	PTA[a]	Age at implant	Duration of CI
01 M	7.1	0.67	Unknown	0.9	—	2.17	4.11
02 M	7.9	0.25	Genetic[b] (AR)	0.3	120	2.42	5.4
03 M	7.6	0.83	Unknown	1.0	120	3.17	4.4
04 M	7.7	0.67	Unknown	1.0	125	2.92	4.8
05 F	9.11	0.50	Mondeni	0.7	115	2.92	4
06 F	7.6	0.92	Unknown	1.0	115	3.17	4.4
07 M	9.4	1.50	Unknown	1.8	100	3.25	6.1
08 F	5.9	0.58	Unknown	0.7	117.5	2.58	3.2
09 M	8.4	0.92	CMV	0.11	120	3.08	5.2
10 M	10.6	0.67	Genetic[b] (AR)	1.1	112.5	6.00	4.6
11 F	7.8	1.50	Unknown	2.4	117.5	4.92	2.9
12 F	9.3	0.42	Rubella	0.5	97.5	6.25	3
13 F	9.5	2.00	Unknown	2.0	122.5	6.00	3.5
14 F	7.8	0.67	Unknown	1.0	110.0	5.58	2.1
15 F	9.3	1.00	Unknown	1.1	117.5	6.42	2.10
16 F	10.5	0.33	Genetic[b]	0.4	117.5	7.00	3.5
17 M	8.7	1.50	Genetic[b] (AR)	1.8	102.5	5.92	2.8
18 M	9.6	0.25	Unknown	0.3	117.5	5.92	3.5
19 M	8.9	0.75	Genetic[b]	0.10	112.5	6.00	2.9

Note. AR, autosomal recessive; CMV, cytomegalovirus.

[a]PTA is the pure tone average calculated according to UK audiometric conventions across four frequencies (.5, 1, 2, and 4 kHz) in the better ear.

[b]Participant has a deaf sibling.

development was considered to be within normal limits by the CI team. This was later validated by performance on a nonverbal reasoning test from the British Ability Scales (Elliott, 1996) children who had scores that fell below −1.5 *SD* on the matrices test of nonverbal reasoning were excluded from the study. No upper limit was set. One child was excluded from the study due to low performance on this test. A further child was excluded because he was too young to participate with formal testing. In total, 19 congenitally profoundly deaf children who had CI participated in this study.[2] One child withdrew from the study at Time 2. Further information about the sample selection and recruitment is provided in our previous report (James et al., 2005).

Nine participants had been fitted between the ages of 2 and 3.6 years, at the time of the study this was considered to be relatively early. Ten participants were fitted later, between the ages of 5 and 7 years. Eighteen of these children went through the preimplant assessment process at GOSH. There was no significant discrepancy between the time the referral was received by the implant team and the time of the decision to fit an implant between children who were younger at the time of fitting and those who were older at the time of fitting. The candidacy criteria during the period when these children were being considered did not change significantly at GOSH. The children fitted later appear to have been referred to the CI centers when they were older. The reasons for the relatively delayed referrals were related to local factors (e.g., family factors, local rehabilitative management, local National Health Service policy, etc.) rather than being an indication of change in policy regarding candidacy for a CI. All the participants had the Nucleus-22 CI with an ESPrit-22 speech processor and were using the same speech encoder strategy (SPEAK). A summary of the hearing impairment and CI characteristics for each participant is provided in Table 1 and a summary of pre-CI speech and language functioning, communication method at the start of the study, education placement, and nonverbal reasoning scores are in Table 2. Summary information for children fitted early and those fitted late is in Table 3.

The preimplant assessment of spoken receptive language was conducted by the specialist speech and

Table 2 Participants' preimplant language level, communication mode, education characteristics, and nonverbal reasoning at T1

Participant	Pre-CI receptive language age (months)	Communication method at T1	Speech perception at T1[a]	Education placement at T1	Matrices (nonverbal reasoning) at T1[b]
01	—	Oral	90	Unit[c]	39
02	18	Oral	100	Mainstream	76
03	18	Oral	67	Unit	48
04	9	TC[d]	80	Unit	66
05	9	Oral	80	Unit	47
06	9	Oral	90	Mainstream	70
07	9	TC	—	Unit	53
08	9	Oral	—	Mainstream	36
09	9	TC	77	Special school	50
10	18	TC	30	Special school	59
11	9	TC	76	Unit	80
12	18	Oral	90	Unit	38
13	18	TC	43	Unit	65
14	30	Oral	87	Unit	66
15	51	Oral	67	Mainstream	69
16	30	Oral	73	Unit	48
17	18	TC	76	Unit	62
18	18	Oral	90	Mainstream	48
19	9	TC	37	Unit	47

[a]Percentage correct on open set word list (Manchester Junior Word List) in an audio-only condition. This was administered at the CI centre at around the time of the start of the study.

[b]The standard score is cited here (50 represents the mean of the standardized population and 10 is the size of 1 *SD*).

[c]Units are specialist resourced centres placed within mainstream schools—the degree of integration into mainstream classroom is variable.

[d]TC, total communication.

language therapists in the CI centers as part of the preimplant candidacy assessment. A range of informal probes and published assessments were used to evaluate a child's level of spoken language comprehension and all these tests were administered with spoken language prior to cochlear implantation. Evaluating the significance of the impact of communication method on outcome following cochlear implantation is complicated. There is contradictory evidence regarding the impact on speech and language outcomes of adopting an oral communication method in favor of a sign-based method such as total communication (cf., Geers, 2002 with Connor et al., 2000). An empirical test of the impact of communication mode on outcome following CI fitting would require in-depth description of the child's individual preferences, performance, and potential as well as detailed developmental history with regard to oral and sign-based communication, analysis of the role of speech reading, and detailed description of communication practice in the child's social and learning environments including peer communication strategies. To our knowledge an empirical test such as this has not been carried out, but see Connor et al. (2000) for a detailed treatment of this issue. It is not our intention to explore the issue of

Table 3 Summary of children fitted early and children fitted late

Variable	Children fitted early (age, year)	Children fitted late (age, years)
Age at Time 1	7.6 (1.0)	9.1 (1.0)
Nonverbal reasoning	52.8 (15.5)	58.2 (12.7)
PTA pre-CI	116.6 (100–125)	112.8 (97.5–122.5)
Age at diagnosis	0.9 (0.4)	0.11 (0.7)
Age of hearing aids	0.10 (0.5)	1.1 (0.8)
Age at implant fit	2.10 (0.4)	6.0 (0.6)
Duration of CI use at T1	4.8 (0.10)	3.1 (0.7)

communication mode on outcome post-implantation. We report the communication mode for individual participants in order to aid the exploration of individual differences. The communication method reported in Table 2 reflects the method used in the educational placement that the child was in at the start of the study. The term "oral" is used as an overarching term to define any practice that emphasized the use of speech and audition to communicate. The term "total communication" is used as an overarching term to define practice that emphasized the use of signing to support the child's development of spoken language. None of the children in our study were in educational placements that followed a sign-bilingual approach to communication. Given the potentiality for over interpretation or misinterpretation of the data regarding communication, we feel it is important to state that we consider communication mode and educational placement to be dynamic components of the developmental space, which the child and family respond to and shape. These components were not static prior to the onset of the study. For example, children had changed educational placement without changing communication method (i.e., going from specialist nursery school provision with oral communication methods to a unit-based resource with oral communication methods) and some children had changed education placement and changed communication method (from placements where manual communication was used to placements with oral methods and vice versa). The information summarized in Table 3 shows that the two groups were reasonably well matched on nonverbal reasoning, although some of the individual standard scores were quite high (i.e., +3 *SD*s).

There are several potentially important differences between the groups that need discussion. First, the children fitted early were younger than the children fitted later. This means that the children in the late group were intellectually more advanced than children in the early group and this might have given them an advantage and have the effect of attenuating any effect of age of implantation. A related point is that five children in the late group had nonverbal IQ scores that were above +1 *SD* of the mean, whereas only three children in the early group had scores significantly above the mean. In addition, the sex ratio between boys and girls was not the same in the groups. Overall academic and linguistic performance might be lower in boys than in girls (Maccoby & Jacklin, 1975) and it is important to bear this in mind when evaluating the comparison between the early and late CI groups because there were more boys in the early group. These differences work against the predictions made about performance in the early group. Finally, the children fitted early had been using their implants for longer (mean 4.8 years) than the children fitted later (mean 3.1). In terms of performance outcomes, this difference is likely to proffer an advantage to the early group because performance tends to improve with CI use. However, in terms of rate of development, this difference probably works against our predications. The prior literature suggests that after 4 years of implant use, growth rates slow down in children using implants. If these findings are valid and reliable, then the children in the late group should show steeper growth rates than the children in the early group. In summary, most of the differences between the participants work against the theoretical predictions about the age of implantation because they put the early group at a potential disadvantage. The implications for the analytical strategy are discussed in more detail below.

Hearing Comparison Groups

Two groups of hearing children were recruited from a school in South East London, UK. The school was chosen on the basis of convenience for data collection. The teaching of literacy in the school followed the National Literacy Strategy (Department for Education and Employment [DfEE], 1998). A group of hearing children were matched to the early and late CI groups on the basis of chronological age (CA comparisons) and reading level (RL comparisons). The children in the RL comparison group were matched to the CI users on the basis of word reading ability using the Word Reading test from the British Ability Scales (Elliott, 1996). Each CI user had a yoked hearing control with a similar reading age. *Similar* was deemed to be an age equivalent score that was ±3 months. All the hearing children met the following criteria: (a) they had word reading skills within the normal range, standard scores were not more than 1 *SD* above or below

Table 4 CI groups' and their hearing comparison groups' performance on the standardized tests

Variable	CI early	Reading controls (CI early)	Age-matched controls (CI early)	CI late	Reading controls (CI late)	Age-matched controls (CI late)
Age at test (age, years)	7.6 (12 months)	6.8 (9 months)	7.8 (12 months)	9.1 (12 months)	6.10 (6 months)	9.0 (12 months)
Sex (M:F)	6:3	6:3	4:5	4:6	2:8	5:5
Matrices[a]	52.78 (15.49)	49.67 (8.06)	54.78 (15.16)	58.20 (12.72)	51.00 (11.02)	50.30 (8.35)
Vocabulary[b]	69.44 (15.69)	100.11 (10.11)	99.89 (16.78)	48.80 (10.81)	95.70 (15.65)	102.00 (12.97)
Word reading[b]	95.00 (12.81)	107.44 (16.36)	106.44 (15.92)	81.90 (9.09)	107.70 (10.34)	112.80 (9.34)

Note. All participants completed all the tests.

[a]*T* score with mean of 50 and normal *SD* of 10.

[b]Standard score with mean of 100 and normal *SD* of 15. Standard deviations are in brackets.

the mean on the word reading test, (b) they had no known history of special needs, and (c) they had no known history of hearing impairment. In line with school policy, parents and carers were informed in writing about the study via the school. Parents and carers were asked to inform the school if they did not wish their child to be included in the study. One parent did not wish her child to be included in the study for medical reasons associated with an early history of fluctuating hearing impairment.

The results of the standardized tests of nonverbal reasoning, vocabulary, and word reading for all six groups are in Table 4. All groups had nonverbal reasoning scores that fell within the normal range (the mean score is 50 and the *SD* is 10).

The Reading-Level-Matched Design

In this study, the critical comparison is between the CI users and their matched reading-level group of hearing children. A strong prediction based on the sensitive periods theory is that the performance of children in the late group will fall below their younger reading-level-matched group on PA, whereas by comparison the performance of the children fitted earlier will fall within the normal distribution of their reading-level-matched group. There are problems associated with the interpretation of findings from reading-level-matched design due to the differences in chronological age and intellectual maturity between the groups (see Goswami & Bryant, 1990). The reading-level-matched groups are by necessity younger than the children using CI. In our study, there is a greater discrepancy in chronological age between the children in the late group and their reading-matched group than between the early group and their reading-matched group. The children in the late group are quite a bit older than their reading-matched group meaning that they are intellectually more mature and have had longer exposure to print and literacy instruction. It is especially important to raise this because of the potentially significant influence that orthographic knowledge can have on the development of PA in deaf children (see Introduction). The comparison with the hearing age-matched children will be used to see how the CI users compare with hearing children who have had the same degree of exposure to print and literacy instruction. Given the potentially influential role of orthographic knowledge on PA, it might be the case that the CI users have equivalent scores to hearing age-matched peers on trials where orthography can be used to aid phonological judgments. Any score that falls within the performance levels of age-matched peers from the orthographically incongruent trials would be interpreted as a very positive outcome for the CI users (see definition of PA trial types below).

Procedure

In the majority of cases, testing took place in a quiet room at participants' schools. In a few cases, permission for a school visit was not provided, so testing was conducted at the child's home. Every child completed four test sessions in total over two consecutive days. Each child had two sessions in a single day. One session was conducted in the morning and one session was conducted in the afternoon. The duration of each session was between 30 and 40 min. The first session was used to administer the published assessments of reading, vocabulary knowledge, and nonverbal reasoning. The three PA tests of syllable, rhyme, and phoneme were completed in separate individual sessions. The order in which the tests of PA were administered was counterbalanced across children. This procedure was followed at Time 1 (T1) and again 12 months later at Time 2 (T2) for the CI users.

Tests

Three tests of PA were designed for this study: a syllable test, a rhyme test, and a phoneme test (see James et al., 2005 for further detail). All the tests required a similarity judgment to be made. For example, the participants were presented with four black and white line drawings and asked to decide, from a choice of three, which item had (a) the same number of syllables as a cue picture (the syllable test), (b) the same rhyme as the cue picture (the rhyme test), or (c) started with the same sound as the cue picture (the phoneme test). All three tests were designed to enable analysis of the extent to which orthographic (spelling) knowledge influenced phonological judgments. In the syllable test, we manipulated the orthographic word length of the items so that, for congruent items, the picture with more syllables was spelled with more letters (e.g., *dog* vs. *pillow*), whereas for incongruent items it was not (e.g., *shop* vs. *body*). In the rhyme test, we manipulated the spelling of the rime (i.e., the vowel and any final consonant), so that the spelling of the picture names was either *congruent* with the phonological decision (as in the pair *face/race*) or *incongruent* with the phonological decision (as in the pair *hair/pear*). In the phoneme test, we manipulated the spelling of the initial sounds of the words so that they were either congruent (as in *finger/fox*) or incongruent (as in *queen/cot*). The tasks were presented on a laptop computer. The child made a choice by pressing a color-coded key on a button box. More information on the design of the tests and the procedure used for administration is in Appendix A and B (but see James et al., 2005 for further information). The first named author of this manuscript completed all the testing.

Two published tests that have standardized norms based on U.K. hearing children were used to assess vocabulary and reading. The British Picture Vocabulary Scale (BPVS) (Dunn, Dunn, & Whetton, 1982) was used to assess knowledge of spoken vocabulary. This test of receptive vocabulary asks the child to select a target from four pictures and requires no verbal output by the child. The Test of Word Reading from the British Ability Scale was used to assess word reading (Elliott, 1996). In this test, the child reads single words aloud. In the case of deaf children, where the participant used total communication in the educational setting, test instructions were also signed for all the assessments. The items on the vocabulary test were presented with speech alone and were not signed. The results therefore reflect the child's ability to understand spoken words. Apart from this deviation from the published procedures, the procedure for test administration and scoring was followed for the BPVS. Published guidelines for the word reading test were followed, but the criteria for scoring was altered so that mispronunciations by the deaf children were not counted as errors. In a few cases, it was difficult to understand the child's pronunciation. When this occurred, the child was asked to sign the word or explain its meaning. For example, one item on the test is "babies." It was sometimes difficult to hear whether the plural had been marked in the child's speech. When this was the case, the child was asked to sign the item. If the sign did not indicate plurality, then the item was scored as incorrect. This method of scoring is subject to error. In order to gain a degree of validation for our results, the word reading age equivalent score was discussed with the class teacher. In all cases, the age equivalent scores from our test were within 6 months of the teachers' results.

Analytical Approach

In this manuscript, we set out to evaluate the impact of early cochlear implantation by comparing the performance of children fitted early with children fitted late relative to two groups of hearing children; children matched for reading level and children matched for chronological age. The null hypothesis is that there is no added value of early cochlear implantation on the PA, vocabulary, and reading outcomes of deaf children. The alternative hypothesis is that there is added

Table 5 CI groups' and their hearing comparison groups' mean performance on the PA tests (% correct score)

Test	CI early	Reading controls (CI early)	Age-matched controls (CI early)	CI late	Reading controls (CI late)	Age-matched controls (CI late)
Syllable test						
Congruent	69.11 (31.77)	61.67 (31.69)	72.78 (33.07)	77.60 (24.13)	75.40 (25.13)	92.70 (7.85)
Incongruent	61.67 (37.02)	54.11 (30.32)	65.44 (25.92)	67.90 (26.50)	56.60 (25.57)	83.40 (21.67)
Rhyme test						
Congruent	61.11 (31.91)	86.11 (22.89)	96.33 (8.43)	49.90 (27.73)	92.50 (9.24)	95.00 (8.99)
Incongruent	62.11 (26.85)	83.22 (23.34)	96.33 (6.08)	51.80 (27.34)	95.00 (11.19)	96.80 (4.13)
Phoneme test						
Congruent	57.22 (26.79)	83.33 (18.66)	89.00 (23.56)	63.30 (23.15)	93.70 (6.13)	96.80 (5.41)
Incongruent	38.00 (18.99)	85.67 (12.56)	79.44 (21.88)	34.90 (22.20)	86.50 (12.93)	90.00 (11.88)

Note. All participants completed all the experimental tests. Standard deviations are provided in brackets. Congruent trials are those where orthographic knowledge can be used to aid judgment (e.g., knowing *cat* and *fat* rhyme); incongruent trials are those where orthographic knowledge cannot be used to aid judgment (e.g., knowing *knee* and *night* have the same initial phoneme).

value of cochlear implantation on PA, vocabulary, and reading. The small numbers of children in the early and late CI groups means that a direct comparison of performance between the early and late groups should not be made given the possibility of a Type II error which would result in a decision not to reject the null hypothesis when it is false. This might lead to the conclusion that there is no added value of early implant fitting when in fact there is. Therefore, our analytical strategy is to describe the outcomes of the deaf children relative to hearing comparisons, plot the development over time in the two CI groups, and explore individual differences between CI users. The hearing group data act as a benchmark against which the early and late groups' performance is compared. The analysis of performance outcomes is on *z*-score comparisons, comparing the early and late groups on their *z*-scores relative to normative data derived from either the seen hearing comparison groups (PA tests) or standardized normative data (published assessments of vocabulary and reading). The *z*-score is an indication of the probability of obtaining a score within a standard normal population. The degree of variability within the standard population affects *z*-scores. In statistical terms, the distribution of the standard normal population is characterized by the mean and standard deviation. If the distribution of scores from the standard normal population is normally distributed with equal scores above and below the mean, then 95% of the population lie within ±1.96 *SD*s from mean. A *z*-score of 0 means that 50% of the standard population would have scores above the observed score and 50% of the standard population would have scores below the observed score. *z*-scores that are at or below −2 indicate that only 2.3% of the scores from the standard population would fall below the observed score and therefore for our analysis *z*-scores that fall below −2 are categorized as falling outside of the normal distribution of the standard population.

Results

The means and standard deviations for the early and late groups and their corresponding hearing matched groups (reading-level comparisons and chronological age-matched comparisons) on the PA tests (congruent and incongruent trials) are in Table 5. The prediction was that if there is an effect of age of implant fitting more children fitted early will have *z*-scores that fall within +2 and −2 *z*-scores relative to hearing children matched for reading level. The prediction was made relative to the reading-level-matched group, data are provided on the age-matched data for comparative purposes. *z*-scores for the PA tests were derived for each CI user with reference to the mean and standard deviation of the relevant reading-matched group and age-matched group. The mean *z*-score from the published assessments and the *z*-scores from the PA assessments relative to the reading-level-matched peers are plotted in Figure 1. "Easy" trials are the congruent trials where orthographic knowledge could be used to aid the phonological judgment. "Hard"

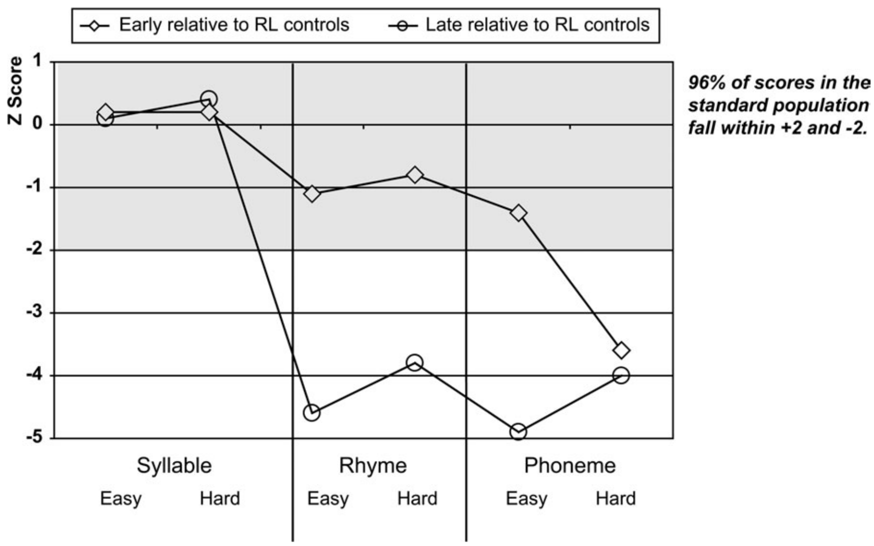

Figure 1 Line chart to show z-scores for PA tests (congruent and incongruent trials) relative to reading-matched group.

trials are the incongruent trials where orthographic knowledge could not be used to aid the phonological judgment. z-scores with values between +2 and −2 were considered to be within the performance levels of the standardized population.

PA Performance Outcomes Relative to Reading Matches

The data plotted in Figure 1 show that both early and late groups had good syllable awareness relative to hearing children of the same reading level. The profiles on the rhyme trials diverged for the early and late groups. The early group's performance was within −1 z-score when compared to the reading-matched group on both trial types. The late group's mean z-scores on the rhyme trials were well below −2 z-scores compared to the reading-matched group for both trial types. On the phoneme trials, the mean z-score of the early group on the congruent trials fell within the distribution of the reading-matched group (−1.4). In contrast, the late group's performance was well outside the −2 z-score cutoff on both hard and easy trials in relation to the reading-matched group. In summary, the performance of the early group more often fell within the distribution of scores of the younger reading-matched children than the performance of the late group.

PA Performance Outcomes Relative to Age Matches

The data plotted in Figure 2 show that compared to the age-matched children both early and late groups had z-scores that were within the age-matched population's distribution on the syllable task. On the rhyme task, both the early and late group had z-scores that placed them well outside of the normal distribution of their age-matched peers. On the phoneme trials, the mean z-score of the early group on the congruent and incongruent trials fell within the distribution of the age-matched group, albeit at the lower end of the distribution. In contrast, the late group's performance was well outside the −2 z-score cutoff on both hard and easy trials in relation to their age-matched group. In summary, the performance of the early group more often fell within the distribution of scores of the age-matched children than the performance of the late group. It is important to note, however, that there was a much wider degree of variation in the early group's age-matched peers (see standard deviations in Table 5) than that which was found in the late group's age-matched peers. This variation in the early group's age-matched peers probably reflects the likelihood that PA is still in a period of development in some of these younger hearing children. However, the variation in the benchmark population does directly influence the z-scores of the early group in a positive direction. Therefore, it is not possible to use

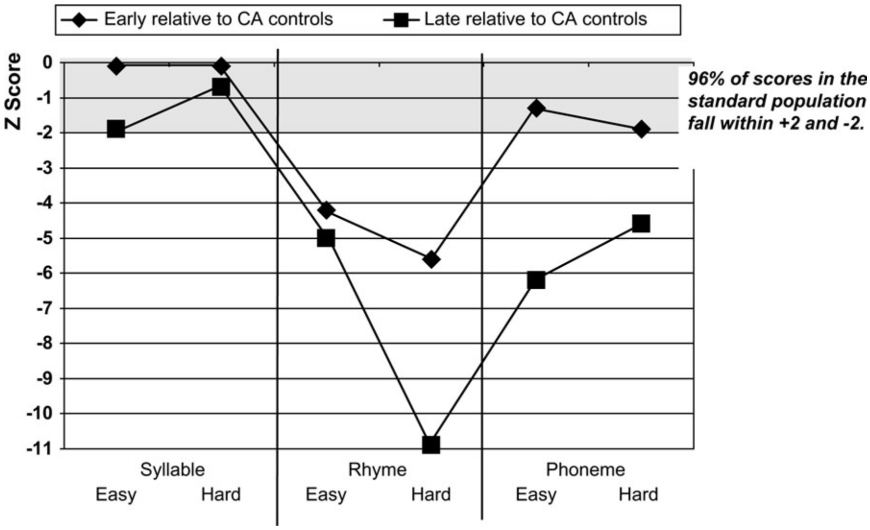

Figure 2 Line chart to show z-scores for PA tests (congruent and incongruent trials) relative to chronological age-matched group.

the *z*-score findings with reference to the age-matched groups to address the age of implant question.

Growth Rate in PA in CI Users

The mean percentage correct scores on the PA tests at Time 2 are in Table 6. Asterisks show where group means are significantly different to chance based on the binomial test. Given the variance in the number of trials in each subtest, the actual percentage score that differed significantly from chance differed slightly between the tests (between 52% and 58%). Chance was set at 33.3%. The ability to make phonological judgments when orthographic information cannot be used, as in the incongruent trials, is deemed a highly sensitive measure of PA. The percentage correct scores on incongruent tests at T1 and T2 are plotted in Figure 3. Visual inspection of the data shows only very marginal differences between the groups. The children fitted later had higher outcomes (as indicated by the mean percentage correct score) for the syllable trials and greater rate of growth on this test than children fitted earlier. On the rhyme and phoneme tests, the early group had higher performance at T1 and T2 and marginally greater growth rates than the children fitted later. Paired *t*-tests were computed to test the significance of the differences between performance at Time 1 and Time 2 on the incongruent trials for the early and late groups. The only significant difference was for the early group. The scores on the incongruent rhyme trials were significantly different at Time 2 ($t = -3.474$; $p < .01$, two tailed).

Individual Performance on PA

Individual's scores from each subtest of the PA measures (congruent trials and incongruent trials) at Time 1 were calculated to see if they were significantly above chance. The results showed that the number of participants whose score was significantly above chance was equivalent in the early group and the late group. Next we examined growth in the incongruent trials across the syllable, rhyme, and phoneme tests

Table 6 Mean percentage correct scores on the PA tasks at T2

Test	Children fitted early	Children fitted late
Syllable test	69.00* (29.15)	85.56* (12.82)
Congruent	71.56* (28.05)	88.1* (13.56)
Incongruent	64.22* (33.82)	80.33* (19.11)
Rhyme test	80.56* (29.65)	70.89* (22.39)
Congruent	76.78* (35.62)	79.78* (20.33)
Incongruent	84.33* (24.35)	64.67* (26.33)
Phoneme test	56.34* (26.84)	56.23* (17.51)
Congruent	61.00* (32.07)	68.78* (23.76)
Incongruent	51.67 (25.70)	43.67 (18.53)

Note. All participants completed all the experimental tests. One participant withdrew at T2. Standard deviations are in brackets. Asterisks mark scores that were significantly different to chance.

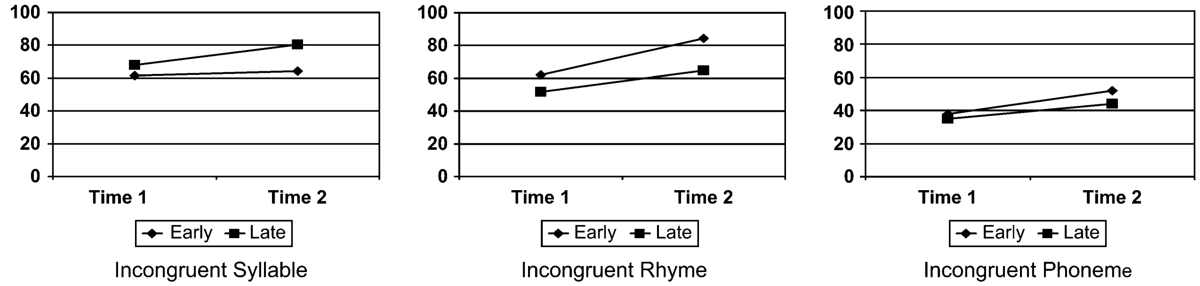

Figure 3 Line charts to show growth in PA (incongruent trials) in early and late CI groups.

and identified individual scores that showed a significant spurt in performance. A spurt in performance was classified as a score that went from less than or equal to chance level at Time 1 to significantly above chance at Time 2. This categorization was chosen over a numerical method (i.e., % growth over time) in order to try to tease out individuals who made *functionally significant* change over time. Children who spurted on the incongruent trials over time could be described as having developed phonological sensitivity that was independent of orthographic knowledge. On the syllable test, three participants went from below chance to above chance on the incongruent trials (participants 7, 8, and 10). Three participants spurted on the incongruent rhyme trials (participants 8, 10, and 12). Five children went from below chance to above chance on the incongruent phoneme trials (participants 2, 4, 6, 14, and 15). In total, nine participants made significant progress on incongruent trials over the course of the study. Five of these children were fitted early and four were fitted late. When the characteristics of these nine cases were compared to the participants who did not show significant development in incongruent trials over time, no single variable or combination of variables stands out as distinctive in all nine cases. However, six of the nine participants had relatively high nonverbal reasoning scores.

Receptive Vocabulary and Word Reading

Standard scores are an indication of where the observed score lies against a standard population. In the standardized tests of vocabulary and reading, the standard population is age-matched hearing children. The benefit of using this score to compare performance of the early and late groups is that standard scores take account of the difference in chronological age. The weakness of using standard scores from these tests is that the standardized population were hearing children and the tests were not designed for use with deaf children. Using age equivalent scores in clinical contexts is often misleading (see Bishop, 2003), but they are frequently used in studies showing outcome after CI fitting. Therefore, we also report the age equivalent scores to aid comparison with other studies.

The raw scores, standard scores, and age equivalent scores from Time 1 and Time 2 for the vocabulary test and the word reading test are provided for the early group and the late group in Table 7. The raw scores increased over time, which shows that both groups knew more spoken vocabulary and read more single words at Time 2 compared to Time 1.

With regard to vocabulary, the mean standard scores for the early group and the late group were well below -1 *SD* at T1 and at T2. The early group was around -2 *SD*s and the late group was around -3 *SD* at T1. The difference in vocabulary standard scores between the groups at T1 was significant ($t = 3.370$; $p < .01$, two tailed), but not at T2. The rate of progress in receptive vocabulary was higher in the late group than the early group over the time course of our study (see Figure 4).

The standard scores on the word reading test showed that the early group was within 1 *SD* of the hearing mean at T1 and at T2. The late group was below 1 *SD* at both time points. The difference between the groups on the standard scores was significant at T1 ($t = 2.593$; $p < .05$, two tailed), but not at T2. The standard score of the early group dropped slightly between T1 and T2, whereas the late group maintained their standard score over time. The late group maintained their rate of development in reading over time, but the growth rate in the early group was

Table 7 Standardized test results on vocabulary and reading from T1 and T2

	Early group		Late group	
Test	T1	T2	T1	T2
Vocabulary test				
Raw score	42.11 (17.15)	49.11 (20.72)	31.80 (14.57)	45.33 (17.83)
Standard score	69.44 (15.69)	68.56 (17.83)	48.80 (10.81)	54.78 (15.77)
Age score (age, years)	4.9 (1.9)	5.7 (2.3)	3.8 (1.4)	5.0 (1.9)
Reading test				
Raw score	28.89 (20.13)	35.11 (18.86)	32.40 (14.56)	41.00 (15.52)
Std score	95.00 (12.81)	89.11 (12.02)	81.90 (9.08)	81.33 (8.99)
Age score (age, years)	6.11 (1.6)	7.5 (1.6)	7.4 (0.9)	7.4 (1.6)

Note. The age equivalent score on the reading test is not directly related to the raw score, rather the age equivalent score is derived from an ability score that is calculated based on the basal point on the word reading test. Standard deviations are provided in brackets.

marginally reduced over time. Overall, however, the early group was less delayed compared to hearing children at T1 and T2 than the late group.

Individual Growth in Vocabulary and Word Reading

We investigated individual growth in vocabulary and reading to find out whether there was more variation in the children fitted later and to see whether performance level at Time 1 had an impact on rate of growth. It might have been the case that the potentiality for growth was greatest where performance was lowest at Time 1. On these tests, we made no categorical judgment about what might be classified as a significant functional gain; therefore, we used the *purest* or *simplest* measure of growth from these assessments, namely raw scores.

Figure 5 contains the drop-line graphs of the raw scores on the word reading test and Figure 6 contains the drop-line graph for the test of spoken vocabulary. A median split was conducted, and the characteristics of the participants who made the most progress over time on reading and receptive spoken vocabulary were considered.

First, it is noteworthy that improvement in vocabulary and reading over time did not appear to be determined by the performance levels at Time 1. There were some children with relatively low performance at Time 1 who made good gains and some children with relatively high performance at Time 1 who made good gains over time. Having relatively poor performance at Time 1 did not appear to predict the degree of gain at Time 2. Thus, the increase in the vocabulary standard score in the late group was not likely to be due to their overall larger delay in vocabulary and reading at the start of the study. With regard to the variation within groups, of the nine children who made relatively good gains in spoken vocabulary four were fitted early (participants 1, 2, 5, and 7) and five were fitted late (participants 12, 14, 15, 18, and 19). Four of the participants who made good gains in word reading were fitted early (participants 1, 4, 8, and 9) and five were fitted late (participants 14, 15, 16, 17, and 18). Participants who made relatively rapid gains in vocabulary and word reading were drawn from both the early group and the late group. There were no data to suggest more variability between participants in the late group.

Individual Growth in PA, Vocabulary, and Reading—Summary

Participants who made good gains in vocabulary, reading, and PA tasks (incongruent trials) were identified. Children who made good progress over time were drawn from both the early group and the late

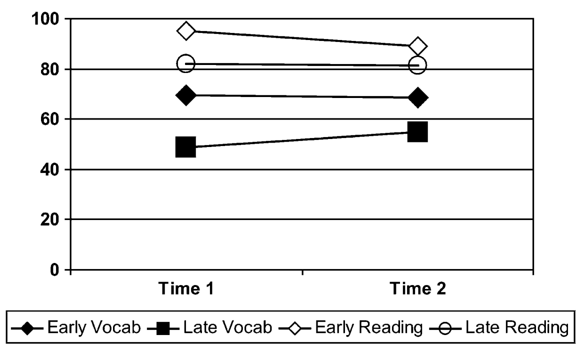

Figure 4 Line charts to show growth in standard scores on vocabulary and word reading in early and late CI groups.

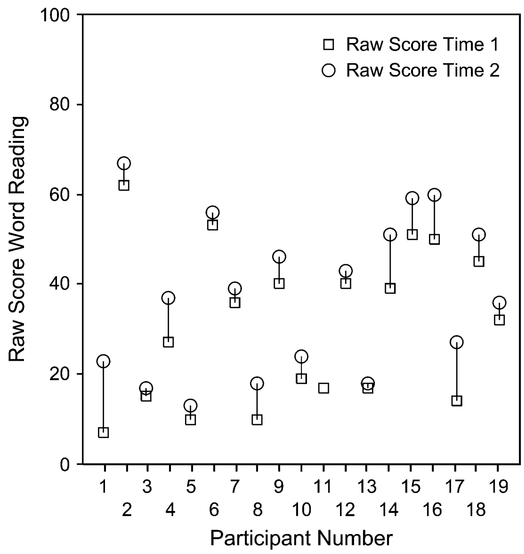

Figure 5 Individual growth rates between Time 1 and Time 2 on word reading in CI users.

group. Furthermore, in both groups there was one participant who failed to make any significant progress in an area between Time 1 and Time 2 (participants 3 and 13). It is difficult to specify distinguishing characteristics of the two participants who made minimal progress over time, but the two participants who made the best gains over time (participants 14 and 15) seem to have a distinctive profile that sets them apart from

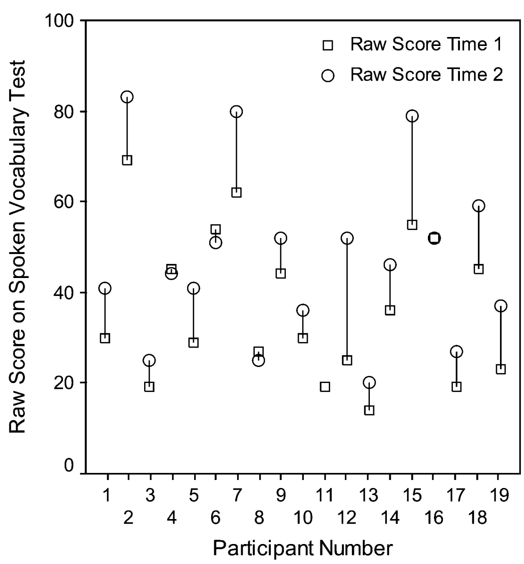

Figure 6 Individual growth in spoken receptive vocabulary between Time 1 and Time 2 in CI users.

the other children in the study. They both had relatively high levels of receptive spoken language prior to implant fitting *coupled with* high nonverbal IQs as measured by the matrices test of nonverbal reasoning. These two participants were both fitted with a CI relatively late in childhood and they were both female.

Discussion

Being able to make judgments about the phonological structure of words is thought to be an indication of the degree to which the lexical representations that underpin spoken language are phonologically organized (Swan & Goswami, 1997). We set out to investigate whether the age of CI fitting had an impact on the degree to which deaf children were sensitive to the phonological structure of spoken language. We expected to find that children who had a CI early in childhood would show greater PA than children who had an implant later in childhood. We derived this prediction on the basis of evidence concerning critical periods for auditory nerve functioning in children with CI (see Sharma et al., 2002) and from Locke's mainstream theory of neurolinguistic development (Locke, 1997).

This is the first investigation of PA in deaf children who use CI, so we are not able to discuss the findings of our study within the context of a wider body of very similar research, but we can contextualize our results with reference to three points that we made in the Introduction. First, the mainstream theory on reading and PA shows that these developments are reciprocally related in hearing children. Second, based on a very small body of prior research on vocabulary development of CI users, the current state of knowledge suggests that it is likely that (a) the rate of growth is attenuated by duration of implant use and (b) there is wide individual variation between children, even those fitted at similar ages, but it is possible that more variation occurs in children fitted after 5 years of age. We explored the age of implant hypothesis by looking at the data in three ways. We compared the performance outcomes of the CI users to a benchmark group of hearing children matched for reading level. We compared growth rates in the CI groups and we examined individual profiles in terms of performance outcomes and growth rates.

The performance of the early group on the PA tests fells within the standard distribution of the younger reading-matched children more often than the late group's performance did. This advantage for the early group was evident on the easy trials at syllable, rhyme, and phoneme level where spelling knowledge could have been used to aid phonological judgments, and also on the hard, orthographically incongruent trials at the syllable and rhyme level. We consider the orthographically incongruent trials to be the most robust test of awareness of the phonological structure of lexical representations. In contrast, the late group's performance, on the intra-syllabic levels of rhyme and phoneme did not fall within the normal distribution of the reading-level-matched group even on the easy orthographically congruent trials. Given the reciprocity between literacy instruction and PA, the older children in the late group could have had an advantage in PA given their longer exposure to literacy instruction and more years of experience with print. The congruent trials were an important aspect of the overall design of our battery because if the age difference had given the late group an advantage then we would have found much higher outcomes for the late group especially on the congruent trials relative to the younger reading-matched children. These results suggest that the difference in chronological age that existed between our groups of CI users did not have a large confounding effect. The results suggest that the early group had higher levels of PA than the late group.

The results of the growth rate analysis support the findings from the performance data. Based on the knowledge from prior research on growth post-implant fitting (see Connor et al., 2006), we might have expected to find slower rates of growth in our early group (who had been using their implants for 4 years 8 months at Time 1) and relatively faster growth rates in the late group (who had been using their implants for around 3 years at Time 1). However, the growth rate data on the PA tasks showed that the early group made the most significant progress over time (measured on the orthographically incongruent rhyme trials). The raw data showed a trend of growth in syllable awareness for the late group, and the lack of a significant difference between performance at Time 1 and Time 2 might have been due to a ceiling effect on syllable awareness at Time 2. However, the early group (who had a similar level of syllable awareness at Time 1 to that of the late group) went on to make significant progress in rhyme awareness and growth in phoneme awareness at Time 2. During the time course of our study, the late group's growth was limited to the very earliest level of PA, that of syllables. This finding suggests that there could be a subtle, but potentially significant difference in PA development that is related to age of implantation. Certainly, we found no evidence of attenuation in growth rates in PA over the 3- to 5-year post-implant period.

Our interpretation of Locke's theory is that intra-syllabic awareness is predicated on early exposure to spoken vocabulary development. Therefore, we predicted that children who had critically delayed exposure to spoken vocabulary would have limited awareness of the segmental structure of spoken language. The findings from the performance outcomes and growth rates appear to lend some support to this prediction.

Although our data showed no evidence of attenuated growth with prolonged CI use on PA, we did find this pattern with regard to receptive vocabulary. The early group had higher performance outcomes on receptive vocabulary relative to the standard population at Time 1 and at Time 2, but the late group made more progress over the year than the early group. The investigation of individual profiles showed that the rapid progress in the late group was not due to the lower levels of vocabulary knowledge at Time 1. Neither was it due to extremely good performance in just one or two members of the late group. Rather we found that several children who had received their implant between ages 5 and 7 years made very significant progress in receptive vocabulary over the course of our study. This finding is contrary to that of El-Hakim and colleagues (2001), who reported that vocabulary growth was slower in children fitted after the age of 5 years compared to children fitted before age 5.

With regard to reading, we found that this was an area of relative strength for both early and late CI groups. The early group's reading scores were within 1 *SD* of the hearing normative mean and their scores were higher than the late group's scores at both time points. The growth rate in reading was equivalent across both groups and we found that children who were fitted early and late made good progress in vocabulary and word reading over the course of a year. We also found children in both groups who made no significant progress on any test during the course of the study. There was no evidence from our study to support the findings of El-Hakim and his colleagues that there might be more variability in outcomes in children fitted after the age of 5 years. In our study, the two children who made the most significant progress were both fitted with an implant later in childhood. Based on these two cases, and also the trend for higher nonverbal skills in the participants who made highly significant progress in PA over time, our data lend support to the proposal that nonverbal skills have an augmentative effect on outcomes after cochlear implantation (see Geers, 2002).

Conclusions

If one intends to make comparisons with hearing peers then it can be argued that early cochlear implantation is preferable because the gap between deaf and hearing children will appear to be less pronounced on PA. However, even when children are fitted early with an implant they are likely to be at the tail end of the hearing population with regard to awareness of the segmental units (rhymes and phonemes) even in comparison to younger reading-matched children. Children fitted with a CI later in childhood (i.e., between the ages of 5 and 7 years) can make good functional progress in PA, vocabulary, and reading. For some children, progress will be rapid and comparable to children who are fitted earlier in childhood (i.e., between 2 and 3.6 years). Children fitted later will have a greater discrepancy between their performance level and the performance level of hearing children of the same age but this is probably because they started to use an implant later in childhood. CI seem to enhance receptive vocabulary and reading outcomes compared to hearing aids, so it may be preferable for children to have the opportunity for improved development earlier in childhood. However, there is wide and functionally significant within-group variation in outcomes between implant users. The variation in outcome does not appear to be determined solely by age of fitting and nonverbal skills are likely to exert a significant influence on performance outcomes and growth rates in PA post-implantation. Further research on the dynamic interaction between environmental and steady-state factors that give rise to such wide variation in outcome post-cochlear implantation is needed.

Appendix A: Examples of PA test trials

Test	Trial type	Cue	Target	Distracter	Distracter
Syllable test	Monosyllabic O−	Bird	Shop	Yoyo	Body (ph)
	Monosyllabic O+	Bed	Dog	Jumper	Pillow (s)
	Disyllabic O−	Baby	Lego	Chin	Doll (s)
	Disyllabic O+	Toilet	Spider	Bus	Tin (ph)
	Trisyllabic O−	Potato	Museum	Switch	Cheese (s)
	Trisyllabic O+	Butterfly	Pyjamas	Bike (ph)	Ant (s)
Rhyme test	O+	Sock	Clock	Doll	Hat (s)
	O−	Draw	Floor	Bath	Pen (s)
	O+	Fan	Man	Coat	Fox (ph)
	O−	Fruit	Boot	Door	Frog (ph)
	O+	Face	Race	Nose (s)	Fork (ph)
	O−	Hair	Pear	Bow (s)	Hill (ph)
Phoneme test	Singleton O−	Comb	Key	Tie	Hair (s)
	Singleton O−	Giraffe	Jelly	Doctor	Lion (s)
	Singleton O+	Farm	Fat	Van	Cow (s)
	Clustered O−	Skirt	Circus	Doll	Coat (s)
	Clustered O−	Cloud	King	Bath	Rain (s)
	Clustered O+	Tree	Tent	Map	Grass (s)

Note. The distracters were chosen to consist of semantically related and phonologically related items. Analyses of the results showed that neither the nature of the distracters nor the number of related distracters had an impact on performance levels. O−, orthographically incongruent; O+, orthographically congruent; s, semantically related distracter; ph, phonologically related distracter.

Appendix B: Pretest components

1. The receptive vocabulary check consisted of all the pictured items (cues, targets, and distracters) in the experimental trials. Pictures were grouped into sets of four using a random number generation system. Four black and white line drawings were presented on a card. Participants pointed to the picture that was named by the experimenter. On completion, familiarization for any unknown items was provided. For the deaf participants, it was necessary to give training for approximately 10% of the items. The hearing participants recognized all the vocabulary.

2. The naming check consisted of each picture used in the experimental tests. The pictures were presented on a single card. Participants named all the items. Semantic strategies were used to facilitate naming of items when necessary. This level of support was required for a minority of items (i.e., 10%–15%) for the deaf participants and was occasionally required for some of the younger hearing participants. The naming check was administered to ensure that participants were able to generate the intended label for the pictures used in the task. The ability to do this could not necessarily be implied from performance on the receptive vocabulary check.

3. Familiarization in PA concept was not assumed. The familiarization scripts for all three tests were structured in a similar way. Training began with the experimenter using her own name to highlight the relevant phonological unit (i.e., syllable, rhyme, or phoneme). Then the child's own first name was used. At this second stage, the child was encouraged to actively engage in the training by clapping out syllables, generating a rhyming string, or generating words with the same initial phoneme. First names were used at this early stage in order to support attention and increase participant's motivation to take part in an unfamiliar and potentially difficult task.

The set phrases given below were used.

Syllable:	long/short words, chunks
Rhyme:	sound the same at the end
Phoneme:	sound at the beginning

The technical words, syllable, rhyme, and phoneme were only used if a child used them first.

1. Three training trials using picture cards were given. Feedback was provided after each trial and incorrect trials were repeated once.
2. Four practice trials were given on the computer in order to familiarize the child with the computer and with making a speeded response using the button box. Feedback was given at the end of the block of practice trials. No trial was repeated.

We reasoned that giving practice trials in card format as well as on the computer was necessary. If only the computer practice trials had been administered there was a risk that making the push button response on the computer could have been distracting for the child. This might have limited the participants' opportunity to benefit from corrective feedback.

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Notes

1. Throughout this paper, the term *deaf* refers to children with severe or profound hearing impairment (i.e., average unaided threshold responses to four pure tones presented at 0.5, 1, 2, and 4 kHz of above 71 dB HL in the better ear).
2. Seventeen of the participants were under the care of the GOSH CI center and two were under the SOECIC center at the start of this study.

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