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Reading abilities after cochlear implantation: The effect of age at implantation on outcomes at 5 and 7 years after implantation

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Summary

Objectives: The reading skills of deaf children have typically been delayed and this delay has been found to increase with age. This study explored the reading ability of a large group of children who had received cochlear implants 7 years earlier and investigated the relationship between reading ability and age at implantation.
Methods: The reading ages of 105 children, with age at implantation less than 7 years and onset of deafness below the age of three, were assessed 5 and 7 years after implantation using the Edinburgh reading test. Net reading age was calculated by using the difference between chronological age and reading age. Non-verbal intelligence was measured for a subset of 71 children, using Raven's coloured progressive matrices. Further investigation of this subset looked at the association of nonverbal intelligence, age at implantation and reading ability.
Results: There was a strong negative correlation at both 5 and 7 years after implant between net reading score and age at implantation. In the subset of 71 children who had an IQ score within normal range, those implanted at or before 42 months had age-appropriate reading both 5 and 7 years post-implant. This was not the case for children implanted after 42 months. Reading progress at the two post-implant assessment intervals were found to be highly related.
Conclusions: Age at implantation was a significant factor in the development of reading skills in this group. In children implanted below the age of 42 months, reading

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progress was in line with chronological age, which has not been the case previously with profoundly deaf children. With earlier implantation more common in present groups, and improved technology, there is every reason to be optimistic about the influence of cochlear implantation on the development of reading skills in deaf children.

1. Introduction

Attaining fluency in reading in childhood is essential for later educational attainments and later employment prospects, in addition to providing a means of participating fully in society. Many studies have shown that the great majority of deaf children find reading difficult, achieving significantly lower levels of reading attainment than their hearing peers throughout their years at school [1—7]. The gap between deaf children and hearing peers tends to widen with age [8]. Yoshinaga-Itano and Downey [9] assessed 33 deaf children aged between 10 and 12 years and found them reading three grade levels below their hearing peers. Harris and Moreno [10] assessed a similar group of children at 14 years of age and found that the average reading lag was over 4 years. Several decades of research and many debates about educational methods appear to have done little to change this picture [8,11].

A number of different factors have been identified as playing a specific role in deaf children's difficulties with literacy. One major problem is that many deaf children have a poor knowledge of the spoken language that is represented in a written text. For typically developing hearing children, the process of learning to read draws upon an extensive knowledge of both the vocabulary and grammar that they will encounter in their reading. By contrast, many deaf children come to reading with an impoverished knowledge of spoken vocabulary and grammar. Knowledge of spoken English has been shown to be an important concurrent predictor of reading ability for deaf children [12] and it is also an important longitudinal predictor of reading ability between the ages of 7 and 10 years [13]. Reading at higher levels also involves world knowledge in addition to linguistic knowledge, an area in which profoundly deaf children traditionally have had difficulty, unable to hear conversational comments, television and radio news for example.

Another important contributor to reading success for deaf children is their phonological awareness. The ability to identify and manipulate phonemes within words has been shown to be at the core of early reading success for hearing children learning to read English [14] but there has been considerable debate about whether similar skills are important for literacy attainment in deaf children. Part of the difficultly in evaluating the importance of phonological skills for deaf children lies in the problem of providing assessments that are appropriate both for children who communicate orally and those who sign. However, two recent studies [12,15] suggest that deaf children's ability to decode spoken sounds though speechreading may be a key skill even in children who are native users of British sign language.

The increasing availability of cochlear implants has held out the prospect of higher levels of literacy for profoundly deaf children. There is now a substantial body of evidence showing that cochlear implantation improves speech perception and production and facilitates the development of spoken language [16—24]. Following from this, there are now claims that children with implants find the process of learning to read more straightforward as a result of their enhanced language skills [18]. Reading in deaf children after implantation has been associated with greater use of phonological decoding strategies and linguistic competence and hence it has been claimed that cochlear implantation, in providing greater access to the phonology of the language, facilitates the development of literacy skills [25].

The findings about the literacy attainment of children with cochlear implants have not, however, been consistent. A study of eight children with implants [26] found continued delays in reading ability 4 years after implantation, although it should be noted that the average age at implantation was high at 5.8 years. In another study, 16 implanted children had reading comprehension scores within 1 S.D. of hearing peers and again that there was a strong correlation between spoken language and reading performances [27]. In a more extensive study of 181 children, over half were reading at an age-appropriate level [25]. There was, however, considerable variability within the group with reading competence being linked to mainstream educational placement, wide dynamic range using recent technology, longer memory span and use of phonological coding. Reading attainment was predicted by linguistic competence, and by speech production skills, which may reflect phonological abilities [28].

Two recent European studies both report higher literacy attainment in deaf children with cochlear implants in comparison to peers with traditional hearing aids. A study of the achievements of deaf pupils in Scotland showed that those with implants scored comparatively higher on reading, writing and maths assessments [22] and a similar pattern emerged from a recent study of pupils in the Netherlands [29]. It is important to note, however, that both studies found children with implants to be delayed when compared with hearing children.

The evidence to date suggests that the provision of a cochlear implant can, at least for some children, have a significant effect on the language and literacy abilities of in the years immediately following implant. What is less clear is whether this early advantage persists and whether reading levels can match those of hearing peers. Previous research into the literacy attainment of deaf children has indicated that the lag between deaf children and hearing tends to increase with age as reading demands an increasingly complex set of skills to integrate ideas across a text and to deal with more abstract material [8,10]. It is therefore important to ask whether the improvement in reading ability, shown by deaf children in the years immediately following implantation, is maintained. To date there have been few large scale studies to investigate whether early gains hold up over a longer time. It is also important to ask whether literacy is affected by age at implantation since data on language outcomes [30] indicate that children who are implanted early show the greatest effects. It is therefore likely that similar effects of age at implantation will be evident in reading ability.

This study investigated the reading ability of a large group of children who had received cochlear implants 7 years earlier. It addressed two main questions: what is the relationship between chronological age and reading ability at 5 years after implantation and at 7 years; and is reading ability at each point related to age at implantation?

2. Methods

2.1. Participants

Participants were all children implanted at the publicly funded Nottingham Cochlear Implant Programme. The initial criteria for selection were that implantation occurred before the age of seven, onset of deafness was below the age of three and that reading data were available. There were a total of 105 children (55 boys and 50 girls) for whom age at implantation ranged from 16 months to 83 months with a mean of 50 months and a median of 48 months. For 60 children, aetiology was unknown, 27 had suffered from meningitis, 6 from CMV and the remaining 10 had other diagnoses (including Ushers and Charge Syndrome). Pre-implant hearing thresholds were greater than 105 dB in the better ear, and all children received the Nucleus™ cochlear implant, and were fitted with the most appropriate processing strategy. Mean chronological age at the time of the 7 years post-implant assessment was 11 years 1 month with a range from 8 years 4 months to 13 years 11 months. Children came from a range of social backgrounds, and educational provision from throughout the UK. Details about their preferred communication strategy before and after implantation can be found in an earlier paper [24].

2.2. Assessment of reading ability

As part of their scheduled 7 years post-implant assessment, all 105 children completed the Edinburgh reading test [31], which gives normative data for hearing children, and enables a reading age to be calculated for each child. As the test can be used from the age of 7 years, all children were old enough to complete the test; some children in the sample ($n = 77$) were old enough to complete it 2 years earlier, at 5 years post-implant, and these data are also reported. The Edinburgh reading test includes a range of subtests which assess vocabulary, sequencing and sentence comprehension; for the purposes of this study the child's overall reading age was used as it had been used successfully to track the reading attainment of children with otitis media with effusion into adolescence [32]. The reading assessment was carried out by teachers of the deaf from the Nottingham Cochlear Implant Programme, in cooperation with the child's local teachers.

In view of the wide age range of the children assessed, net reading age was calculated using the difference between chronological age and reading age. For example, a child with the same reading age as chronological age would have a net reading age of zero, a child with a delay of 1 year, a net reading age of −1 and, with a reading age 2 years greater than their chronological age, a net reading age of +2.

2.3. Assessment of intelligence

Given that reading level attained by deaf children with cochlear implants has been shown to be related to nonverbal intelligence [25], a sub-group of 71 children was identified for whom a percentile score from Raven's coloured progressive matrices of 35 or more had been recorded as part of their routine post-implant assessment. Raven's coloured progressive matrices provide a measure of nonverbal intelligence, commonly used with deaf children. It has the advantage of being a paper and pencil test that

Table 1 Net reading age (in years) at 5 and 7 years post-implant for children implanted early and late

	5 Years post-implant (N = 77)		7 years post-implant (N = 105)	
	Early (N = 27)	Late (N = 50)	Early (N = 37)	Late (N = 68)
Mean	+0.40	−1.79	−0.41	−2.94
S.D.	1.05	1.27	1.37	2.06

can be administered by teachers of the deaf who do not have extensive training in psychometric testing. These children were considered to have IQ within normal range and are comparable with samples used in earlier studies of deaf children's reading [10,12,15,33,34].

3. Results

3.1. Effect of age at implantation

The first analyses looked at the association between net reading score and age at implantation using a Pearson correlation. This showed that there was a strong negative association at both 5 years post-implant ($r = -0.80$, $N = 77$ and $p < 0.001$) and 7 years post-implant ($r = -0.74$, $N = 105$ and $p < 0.001$), indicating that children who were implanted earlier tended to have higher net reading scores. Fig. 1 shows the association between net reading age at 7 years after implantation and age at implantation for all 105 children.

In light of this preliminary finding, children were subdivided into two groups according to age at implantation, children implanted at or before 42 months were assigned to the early group and those implanted later than 42 months to the late group.

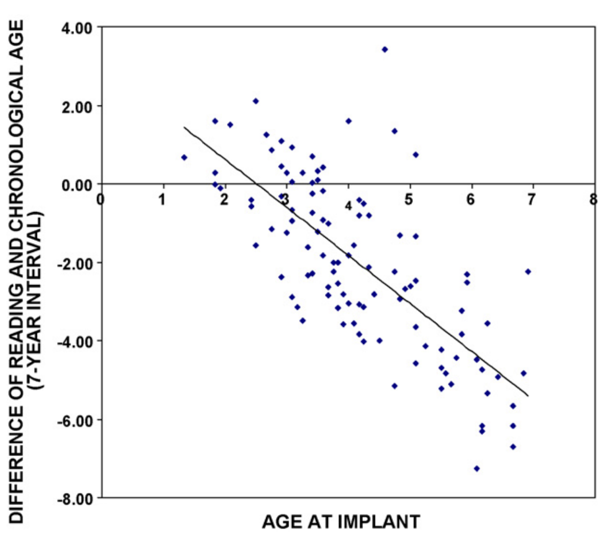

Fig. 1 Seven years after implantation: age at implantation versus "net" reading age (N = 105).

The decision to divide the sample at this point was determined by the distribution of the age at implantation within the sample. At 5 and 7 years post-implant, the 42 months cut off placed 27 children and 37 children in the early group. Dividing the sample at a younger age reduced the size of the early group to the point where statistical reliability was compromised.

Table 1 shows the mean net reading scores 5 and 7 years post-implant for the two groups. It can be seen that the children who received an implant at or before 42 months were reading close to chronological age whereas this was not the case for the children implanted later.

3.2. Analysis of sub-sample

Using net reading age at 7 years post-outcome as the dependent variable, a stepwise regression was carried out, entering Raven's percentile score at step one and age at implantation at step two. The results are summarised in Table 2. These show that non-verbal intelligence, when entered on its own, accounted for only 5% of the variance. When both variables were entered, 57% of the variance was accounted for, showing that age at implantation was a powerful and independent predictor of reading outcome 7 years post-implant. The regression analysis was repeated for net reading gain at 5 months post-implant. A similar pattern emerged with non-verbal intelligence alone accounting for 18% of the variance and the addition of age at implantation increasing this to 77%.

As in the analysis of the whole sample, the effect of age at implantation was also investigated by comparing net reading scores for children implanted before 42 months with those for children implanted later. At 5 years post-implant, the mean net reading age for early-implanted children (n = 18) was +8 months (S.D. = 1 year 4 months) and for late-implanted children (n = 37) it was −1 year 9 months (S.D. = 1 year 4 months). A t-test showed a highly significant effect of age at implantation ($t = 6.66$, d.f. = 53 and $p < 0.001$). At 7 years post-implant, mean net reading age was −0.4 month (S.D. = 1 year) for early-implanted children (n = 23) and −2 years 11 months (S.D. = 2 years 2 months) for late-implanted children (n = 49). This difference was also

Table 2 Regression analysis on sub-sample of children with percentile Raven's scores of 35 or more

Variable	B	S.E. B	β	p	R^2
7 Years post-implant					
Step 1					0.05
Nonverbal IQ	0.03	0.02	0.23	0.05	
Step 2					0.57
Nonverbal IQ	<0.01	0.01	0.06	0.478	
Age at implant	−0.11	0.01	−0.74	<0.001	
5 Years post-implant					
Step 1					0.18
Nonverbal IQ	0.04	0.12	0.43	0.001	
Step 2					0.77
Nonverbal IQ	0.15	0.01	0.16	0.028	
Age at implant	−0.09	0.01	−0.81	<0.001	

highly significant (t = 7.58, d.f. = 70 and $p > 0.001$). The data for the two post-implant points are depicted graphically in Fig. 2. It should be noted that there was no difference between children who were implanted following meningitis and other children in the sample with both showing a strong effect of age at implantation on reading ability.

Finally, a partial correlation (controlling for nonverbal intelligence) between net reading ages at 5 and 7 years post-implant was carried out. This revealed a very strong positive relationship (r = 0.82 and $p < 0.001$) showing that reading progress at the two post-implant assessments was highly related.

4. Discussion

As noted in the introduction, previous research has documented the generally poor literacy attainment of deaf children and the increasing lag between reading age and chronological age as children get older [9,10]. The results of the present study support recent findings of better literacy outcomes in children who receive a cochlear implant [22,25,29]. They also provide evidence that early achievements in reading are maintained at 5 and 7 years post-implant. Strikingly, for children who were implanted before the age of 42 months, average reading progress was in line with chronological age at both assessment points. This was not, however, the case for children who were implanted later. They showed a significant reading lag at both 5 and 7 years post-implant.

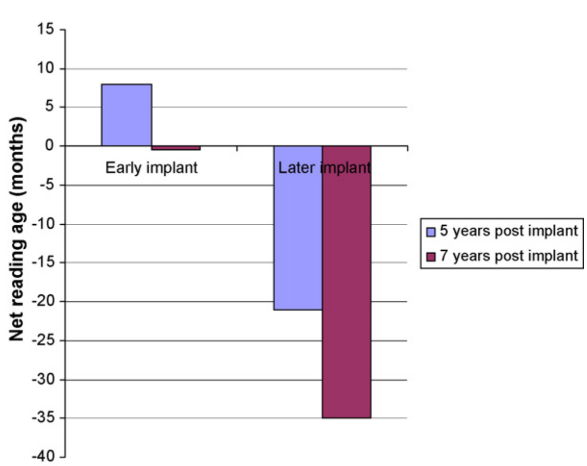

Fig. 2 Net reading ages for children implanted at or before 42 months and later.

The effect of age at implantation on reading ability was very marked in the study. The regression analysis showed that age at implantation had a highly significant effect, accounting for just over 50% of the variance after the entry of nonverbal IQ. Similar effects were evident in the comparisons between the net reading scores of children in the early- and late-implanted groups where there were significantly better scores for the children implanted at or before 42 months. Only five children in the sample were implanted at or before 24 months so it was not possible to analyse them as a specific group. However, it is tantalising to note that their net reading scores at 7 years post-implant ranged from +1.6 years to −0.12 years. If they are representative of what might be expected from implants under the age of 24 months, then it may be that the outcomes of children implanted more recently will be even better than those reported here.

At 7 years post-implant, when the children were aged around 10 years, the mean reading lag was less than 7 months for early-implanted children who had a nonverbal IQ score within normal range. It is important to stress that the inclusion of IQ scores in the analysis was an important control because children with a low score, which is likely to reflect significant additional difficulties, are unlikely to have age-appropriate reading scores especially in a language like English where a deep orthography places a high demand on memory. It is also worth noting that the standard deviation of the net reading score was around 1 year for the young-implanted children at 7 years post-implant. This shows that by no means all children were reading at an age-appropriate level but the pattern of the distribution was not dissimilar from that for hearing children of the same age.

Although the reading ability of the early-implanted children at 7 years post-implant exceeded that of children who were implanted later, there is an important issue to consider before drawing firm conclusions about the significance of this finding. Children who were implanted after 42 months were older at the time of the 7 years post-implant assessment than those implanted at or before 42 months. It could therefore be argued that the reading skills being assessed for late-implanted children were more complex than those being assessed in early-implanted children, especially in relation to text-level skills where deaf children may have additional difficulties [8]. Given that the reading skills of many deaf children tend to fall further and further behind hearing peers as they get older, this is an important concern. In a recent follow-up of an earlier study, many children continued to develop their reading skills into adolescence in line with chronological age. However there was wide variation and some children did not move beyond the scores they had achieved at the age of 8 and 9 years [35].

One way of addressing this concern is to compare the early-implanted group at the 7 years follow-up with the late-implanted group at 5 years post-implant. At this point they were much more similar in age. Fig. 1 shows that, on this comparison, there was still a large difference between the groups. Whereas the early-implanted children had a mean net reading score of −0.4 months the late-implanted children had a score of −1 year 9 months (using the figures for the children for whom there were valid nonverbal IQ scores). It would appear from this comparison that the difference between the two groups cannot be explained by the difference in age at the time of the 7 years post-implant assessment.

It does, however, remain a possibility that the reading levels that were evident at the 7 years post-implant assessment for the early-implanted group will not be sustained as children progress through the later years of school. As noted Section 1, the process of reading becomes increasingly complex as the demands of infrequent vocabulary, complex syntax and text integration increase every year. It is therefore important to carry out longitudinal studies well into adolescence to show whether the reading attainment of children implanted early is sustained. It will also be important in future research to investigate the kind of reading strategies that are used by deaf children who receive a cochlear implant early in life. Previous research on deaf children's literacy has shown that working memory span is strongly associated with reading level and this suggests that the ability to make use of phonological coding is a key to reading success for deaf children [10,36]. We would predict that successful early implantation enables deaf children to develop robust phonological coding skills and, if this is the case, these should be evident in their reading strategies.

Another issue for further research is the extent of the sensitive period for plasticity in development of the central auditory system in relation to literacy. As noted above, in our study, the cut off point for dividing children according to age at implant was mainly taken on statistical grounds. Research into cortical auditory evoked potentials (CEAPs) has found that children implanted before 42 months show a fundamentally different pattern of response to children implanted later [37]. The suggestion is that there is considerable plasticity in central auditory development up until 42 months but that the sensitive period ends around this age. However, other research suggests that there are differences in outcomes for children implanted before and after 24 months [38,39] and even before and after 12 months [40]. It thus remains an open question as to the maximum age at which successful implantation will lead to age-appropriate reading.

Finally, it should be noted that the average age of implantation of children in the present study was a great deal higher than that achieved today and, in addition, there has been considerable development of implant technology. Earlier implantation and the provision of state-of-the-art implants would be expected to have an additional positive effect on literacy and there is every reason to suppose that increasing numbers of children who are born deaf will leave school with age-appropriate literacy skills.

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