The Impact of Cochlear Implants on Deaf Children's Literacy

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This chapter reviews recent studies looking at the impact of cochlear implants on the development of reading and writing of deaf children. Although there is good evidence that cochlear implants have significantly improved the spoken language of many children with severe-profound hearing loss, their impact on literacy – something that deaf children have traditionally found challenging – has proved to be considerably less consistent. In particular, benefits that are evident in the early years of education are often reduced as children progress through school. The aim of the chapter is to identify factors that affect the impact of cochlear implants at different stages of learning to read and write by considering both the skills that underpin early and later literacy for deaf children and factors affecting the efficacy of cochlear implants. The chapter concludes with a consideration of how the literacy development of deaf children with cochlear implants can best be supported through the use of interventions that enable the development of robust phonological coding.

phonological coding

speechreading

deafness

literacy

cochlear implants

Being able to read and write fluently is an essential skill in a modern, technologically-advanced society. The importance of literacy is reflected in the United Nations Development Programs' Human Development Index (HDI), which is intended to capture the elements that contribute to quality of life. The index includes such predictable measures as health, longevity and standard of living and it also includes the proportion of the population who are classed as literate. In developed countries, the literacy level among the adult population exceeds 95% but for many of the countries that appear at the bottom of the HDI rankings, the literacy level is less than 50%.

The definition of literacy used for the purpose of the HDI is relatively modest in that it is the ability to read a short, simple passage relating to everyday life. This level of literacy would be sufficient to read simple forms or notices but it would not be sufficient to meet the demands of education at secondary school, let alone at university. In order to succeed in education beyond the age of 11 years it is necessary to be able to read words that do not occur in everyday speech, to deal with abstract concepts and to integrate a sequence of ideas across a complex text. Functional literacy therefore requires a high level of reading ability (Marschark & Harris, 1996).

Those who have been concerned with the education of deaf children have long realized that enabling them to become fluent readers and writers is a key task. A striking illustration of this early focus on literacy can be found in a photograph taken in 1893 at the Horace Mann School for the Deaf in Boston of a literacy lesson. Ten girls and boys, sitting in a semicircle with their teacher, are watching another pupil who stands by the blackboard on which a passage of text is written in elegant copperplate. In spite, however, of widespread recognition of the importance of literacy for deaf children, their achievement in this area has typically been at a very low level that has not changed significantly since the first systematic assessments in the 1970s (Allen, 1986; Conrad, 1979; DiFrancesca, 1972; Lane & Baker, 1974; Lewis, 1996; Marschark & Harris, 1996; Mayer, 1998, 2007; Moog & Geers, 1985; Trybus & Karchmer, 1977).

This chapter begins by considering the core skills that enable children to become functionally literate and it highlights some of the challenges that deaf children face when they are learning to read and write. It then considers the potential benefits of cochlear implants for literacy and reviews evidence on their impact at different stages of becoming literate. Finally the implications for supporting children with cochlear implants to become good at reading and writing are explored.

<1> Core skills for literacy

There are many different models of how children learn to read but one of the most useful for thinking about the key challenges of literacy for both hearing and deaf children is the simple view of reading (Hoover & Gough, 1990). This model of reading describes two core components that lie at the heart of literacy - decoding and linguistic comprehension. Decoding is the ability to recognize a sequence of letters as a word. For hearing children, the ability to recognize the sounds (phonemes) represented by individual letters and letter strings and the ability to identify and manipulate these sounds within words underpin the development of decoding skills and predict success in the early stages of learning to read (Muter, Hulme, Snowling, & Stevenson, 2004). Linguistic comprehension is the ability to understand the meaning of meaning of what has been decoded. It involves understanding the meaning of individual words, individual sentences and the text as a whole. For hearing children, linguistic comprehension skills are predicted by oral language and vocabulary (Nation & Snowling, 2004).

In order for hearing children to become good readers and spellers, they need to be good at both decoding and linguistic comprehension. Deficits in either ability can lead to specific difficulties with reading and spelling in the form of developmental dyslexia (arising from problems with decoding) or reading comprehension impairment which, as its names implies, is a difficulty in understanding the meaning of text while being able to decode individual words (Hulme & Snowling, 2009). The essential nature of the two key components of reading should be obvious. In order to be a good reader it is necessary to be able to decode individual words and then to understand the meaning of what has been decoded at word, sentence and text level.

Although there remains some debate about the fine detail of the best model of reading for hearing children, especially in relation to the developmental sequence of phonological coding skills (Bryant, 2002), there is general agreement about the kind of skills that are necessary. Arguably, few researchers into hearing children's literacy would dissent from the simple view of reading outlined above. The same cannot be said of researchers into deaf children's literacy. There remains considerable debate about what skills are essential for children with severe-profound hearing loss to become good readers and spellers. In theory, they could learn to read in exactly the same way as hearing children but many researchers have argued that there are other ways for deaf children to become successful readers, involving a different route from the one used by hearing children. For example, some authors have advocated the use of a sign-bilingual approach in reading instruction, pointing to links between language ability in general (either oral or signed) and reading level (Mayberry, 2011) (see chapter X, this volume). However, it would seem that the two key skills of decoding and linguistic comprehension described in the simple view of reading are going to be essential for any child to become literate, so a model of reading must be able to explain how each of these skills is acquired and maintained.

<2> Predictors of reading and spelling for deaf children

In order to understand how deaf children learn to read and spell it is useful to consider the evidence that has emerged from studies of the factors that predict literacy outcomes. It is important to consider the whole population of children with severe-profound hearing loss since they are most at risk for poor levels of literacy. This population contains children from a variety of educational settings – schools for the deaf, specialist units, and mainstream classrooms. Within this population a small minority will have deaf parents and be native users of a sign language. The majority will have hearing parents and many of these children will be predominantly or exclusively oral and have a limited knowledge of sign (Mitchell & Karchmeer, 2004). This heterogeneity of educational setting and preferred form of communication poses a challenge to researchers to find appropriate forms of assessment that can enable legitimate comparisons of children's reading and reading-related abilities.

Other characteristics of the sample in a given study are also important to note in evaluating the results. Level of hearing loss can affect literacy and children with a moderate loss are less likely to experience problems than similar children whose degree of hearing loss is more severe. Furthermore, children with complex needs are more likely to experience problems than those without. Although complex needs are typically identified, children with more subtle additional difficulties may go undetected. For this reason, focusing on children who have a nonverbal IQ score that is within 1 standard deviation of the mean should ensure that studies include only children for whom age-appropriate levels of literacy might be expected.

One of the first longitudinal studies of literacy (Harris & Beech, 1998) assessed children between the ages of 5 and 7 years from a range of educational settings, looking at a number of reading and language measures, including signing and fingerspelling. All the children had nonverbal IQ scores within 1 standard deviation of the mean, indicating that they were not experiencing general learning difficulties and so might be expected to learn to read at an age appropriate level. Three measures were found to predict reading from the first to the final assessment. These were speech intelligibility, phonological awareness (using a picture-based phonological matching task) and language comprehension. The latter was assessed using a verbal comprehension subtest from the British Ability Scales (Elliott, Murray, & Pearson, 1983) and allowing children to sign or speak when producing their responses. Language comprehension scores were, in turn, associated with signing ability but neither signing nor fingerspelling skills were associated with reading outcomes and there was a negative relationship between signing ability and phonological awareness.

This latter finding points to a general tendency for phonological skills to be more strongly emphasized in the education of deaf children whose communication is primarily oral. For example, early phonological skills, including rhyme judgment and rhyme generation, were found to predict reading progress between the age of 6 and 7 years in a sample of orally-educated French-speaking children (Colin, Magnan, Ecalle, & Leybaert, 2007).

Analysis of group data, especially where a sample of children is heterogeneous, can mask individual differences in reading ability. Another way to look at the skills that underpin age-appropriate reading and spelling is to identify the characteristics of children who are achieving at this level. This was the approach adopted in a comparison of matched groups of good and poor deaf readers at age 8 years (Harris & Moreno, 2006). It should be noted that the term ‘good reader’ in this study was a relative one since the better readers were reading within 10 months of chronological age and so might be better thought of as average readers when compared to hearing children. At group level and in comparison to the poor readers, the better readers showed greater reliance on phonological coding (as evidenced by a greater proportion of phonetic errors produced in spelling unfamiliar words) and they had better knowledge of orthographic patterns in spelling, that is, sequences of letters that occur in real words. However, the only skill that reliably distinguished all the better readers from poor readers was their performance on a test of speechreading (silent lipreading) where the better readers had higher scores than the poor readers. The group of better readers comprised children with good oral skills and also children who were native signers so the importance of speechreading was not restricted to one sub-group.

Speechreading ability also distinguished average and poor readers in a group of 11-year-old deaf children who were being orally educated. The children in this study were presented with an extensive array of assessments (Herman, Roy, & Kyle, 2014). The better readers had higher scores on a number of tests of phonological skill (including rhyme awareness, rhyme fluency and sound manipulation) and letter-sound knowledge, as well as speechreading. Speechreading was assessed using a standardized assessment, the Test of Child Speechreading (ToCS) (Kyle, MacSweeney, Mohammed, & Campbell, 2009).

There are two reasons for considering speechreading ability as potentially important for the development of literacy skills in children who are deaf. First, information gained through speechreading has been seen as providing support for phonological development in children with a significant hearing loss (Campbell, 1997). Secondly there is considerable evidence that speech perception is a multimodal phenomenon that is not restricted to the processing of auditory information. This is apparent in brain imaging studies of hearing adults. For example, one study (Rosenblum, 2008) compared functional magnetic resonance imaging (fMRI) scans of adults either listening to words or lip-reading a face that was silently mouthing the same words. The scans showed that was a high degree of overlap in the regions of the brain that were activated by the two tasks, with both speechreading and listening activating primary auditory and auditory-association cortex. Speechreading ability has also been shown to be associated with reading ability for hearing children (Kyle et al., 2009), supporting the view that phonological skills are best thought of as multi-modal rather than exclusively aural.

Further evidence for the role that speechreading plays in literacy comes from another longitudinal study that examined reading progress over a three-year period, from the age of 7 to 10 years (Kyle & Harris, 2010). The children, who had severe-profound prelingual deafness, came from a range of educational settings – schools for the deaf, hearing-impaired units and mainstream classrooms – and included native signers, children who were oral and those who used a mixture of oral and manual communication. Across the sample of children, English vocabulary and speechreading skills at age 7 were positively associated with reading at age 10. These two skills can be seen as enabling children to develop the two key components highlighted in the simple view of reading (Hoover & Gough, 1990). Speechreading was the strongest predictor of single word reading ability (i.e., decoding), whereas vocabulary knowledge was the strongest predictor of written sentence comprehension (i.e., linguistic comprehension).

Before ending this review of the factors that underpin literacy for deaf children it is important to note that, while there are similarities between the reading development of deaf and hearing children, there are also differences. In particular, the emergence of phonological awareness and its relationship to reading seems to be more complex for deaf children than for hearing. When the children in the Kyle and Harris study were first assessed at age 7 years (Kyle & Harris, 2006), their phonological awareness scores were not correlated with reading ability. However, by the end of the study three years later, phonological awareness and reading were significantly correlated (Kyle & Harris, 2010). Longitudinally, it was reading ability that predicted later phonological awareness rather than the other way round. What this suggests is that deaf children’s phonological abilities may develop as a consequence of learning to read rather than being something that children bring to reading (See also Spencer and Tomblin, 2009); and that, early on, the development of phonological skills is mediated by speechreading.

The other point to note is that, while it is knowledge of English that is important for children who are learning to read English, linguistic comprehension involves far more than the recognition of individual words. Competence in sign language can potentially enrich children's understanding of what they read which is why many studies have shown relationships between reading ability and signing (Mayberry, 2011). Also, as noted above, developing good speechreading skills is equally possible for children who sign and for those who are oral (Harris & Moreno, 2006). Having now considered what skills appear to be important for deaf children to become literate we can turn to the potential impact of cochlear implants.

<1> Cochlear implants and literacy

There is now a very substantial body of evidence showing that cochlear implantation improves speech perception and production and facilitates the development of spoken language (Archbold et al., 2000; Cleary, Pisoni, & Geers, 2001; Geers, 2002; O'Donoghue, Nikolopoulos, & Archbold, 2000; Pisoni & Geers, 1998; Tait, Nokolopoulos, Archbold, & O'Donoghue, 2001; Thoutenhoofd et al., 2005; Watson, Archbold, & Nikolopolous, 2006; Watson, Hardie, Archbold, & Wheeler, 2008). In light of this evidence, we might expect that cochlear implants would make it easier for deaf children to develop both decoding skills and linguistic comprehension to support their literacy development. Having better spoken language skills should, in theory, enable deaf children to develop good phonological knowledge to underpin their decoding skills and also a better knowledge of the vocabulary and sentence structure of English to support the development of linguistic comprehension.

It has not, however, proved to be a straightforward matter to demonstrate an impact of cochlear implantation on literacy (Marschark, Sarchet, Rhoten, & Zupan, 2010). One reason why the evidence is not clear is that many different factors in relation to cochlear implants are likely to affect literacy outcomes for deaf children. First and foremost, cochlear implantation for children has changed enormously since the first pediatric implant was carried out in 1985, in Australia (Clark, 2003). Since then implants have improved both at the level of the hardware and software with considerable advances in the sophistication of both the electrode array implanted in the cochlear and in the speech processor. Implants have been carried out at systematically earlier and earlier ages and, with the advent of universal newborn hearing screening enabling the majority of instances of hearing loss to be confirmed in the first months of life (Pimperton & Kennedy, 2012), many children now receive an implant well before their second birthday. Bilateral implants are also becoming more common and, in the UK, these have been supported by the National Institute for Health and Care Excellence (NICE) since 2009 and are therefore provided by the National Health Service. Many children will combine use of cochlear implant in one ear with a hearing aid in the other (see Most, this volume). This rapidly changing picture of cochlear implantation means that *when* a study was carried out is nearly as important as *how* it was carried out.

More generally, as with the issues discussed earlier about factors that can affect deaf children’s ability to develop age-appropriate reading skills, there are a number of factors that can limit outcomes. Many children who receive a cochlear implant have complex needs, such as difficulties with visual perception or the lack of a supportive language environment, that place limitations on their capacity to become functionally literate (Edwards, 2007). And, as noted above, in addition to the children whose additional needs have been identified, there are other deaf children who do not have any recognized additional needs but who have a level of cognitive ability that suggests they may be vulnerable to general learning difficulties (Harris & Terlektsi, 2011; Marschark et al., 2010). It is therefore important to look carefully at the characteristics of any sample of children in a cochlear implant study when evaluating the outcomes and to place the greatest reliance on studies in which the children are carefully selected.

Age-at-implantation also has an enormous impact on outcomes. In a study of reading levels 5 and 7 years post implant in children who were part of the Nottingham Cochlear Implant Programme (Archbold et al., 2008), age-at-implant accounted for 50% of the variance in reading ability, with children who had been implanted at a younger age achieving significantly higher reading scores. Similar findings emerged from another UK study (Johnson & Goswami, 2010) in which early-implanted children had better reading scores than later-implanted. A study of children in Belgium and The Netherlands (van der Kant, Vermeulen, De Raeve, & Schreuder, 2010) showed an almost identical pattern with 56% of the variance in reading comprehension scores being accounted for by age-at-implant and years of implant use (which are themselves highly correlated).

In addition to direct effects, age-at-implantation can also have indirect effects on literacy by affecting skills that relate to reading. Children who receive a cochlear later may develop better speechreading skills than children who are implanted earlier (Geers, Brenner, & Davidson, 2003); and they may also make greater use of sign language, having benefitted from early identification of hearing level and early communication support (Watson et al., 2008).

Another important factor is the age at which reading is assessed. The demands of reading are very different in the early stages when children are learning to read simple vocabulary and short stories, illustrated by pictures. With increasing age, the required vocabulary is more abstract and less frequent and the content also becomes less concrete and more abstract. The complexity and length of sentences increases, as does the length of passages to be understood. This additional complexity poses questions about the kind of reading assessment that is appropriate at different stages – questions that apply equally to the reading of deaf and hearing children. Assessments of young children's reading will focus mainly on vocabulary and simple sentences whereas assessment of the later stages of reading should include passage comprehension and the ability to understand complex ideas. Given the different demands of reading for younger and older students, it is useful to separate findings from primary school children from those in secondary education.

Finally it is important to recognize that there is considerable heterogeneity in the way that deaf children are taught to read and so the outcomes of cochlear implantation should be considered in the broader context of the education that children are receiving. In particular, a number of techniques are available to educators to support the development of deaf children's phonological skills, including visual phonics. The essence of visual phonics is that it uses a multisensory system of 46 hand cues and written symbols, used in conjunction with speech and speechreading, to represent aspects of the phonemes of a language and the grapheme–phoneme relationships (Waddy-Smith & Wilson, 2003): It is a system of oral/aural plus manual representation of phonemes (Trezek, Wang, Woods, Gampp, & Paul, 2007). At the end of this review, the potential value of direct interventions to support deaf children's phonological development, and enhance the benefits they receive from aiding, is discussed.

<2> Literacy in primary school

One of the first studies to evaluate the impact of cochlear implants on literacy was that of Geers and colleagues. This study followed a total of 181 children from across the United States and

Canada, all of whom had received an implant before the age of 5 years (Geers, 2003). Over half of the children were reading at an age-appropriate level at age 8 years. As with all studies, there was considerable variability within the group and a number of factors predicted reading ability. Both phonological coding and linguistic competence were predictive (Tobey, Geers, Brenner, Altuna, & Gabbert, 2003) although unlike other studies discussed earlier, there was no association between reading level and age-at-implantation: Receiving an implant at 2 or 3 years of age did not appear to provide any significant linguistic advantage over receiving it at age 4 or 5 years.

Another study of children, who were at the forefront of cochlear implantation, comes from data collected by the Nottingham Cochlear Implant Team (Archbold et al., 2008). The reading levels of 105 children were assessed at 5 years and 7 years post implant. There was wide variation in age-at-implantation and so the sample was divided into those implanted relatively early (by 42 months) and those implanted between 43 and 84 months. This wide variation in age-at-implant was typical of the first cohorts of children to receive a cochlear implant. Among the subgroup of children whose nonverbal IQ was 85 or above, those who had been implanted at or under the age of 42 months were reading at an age-appropriate level at both assessment points. In other words, they had reached parity with hearing peers.

Literacy outcomes are closely related to language skills for children with cochlear implants as might be expected since early listening and speaking skills can support the development of phonologically-based decoding skills as well as vocabulary and grammatical knowledge. A longitudinal study (Spencer & Oleson, 2008) found that 58% of the variance in word reading skills in a group of children with cochlear implants was predicted by earlier scores on tests of speech perception and production. The assessments of speech perception and production were carried out 48 months post implant and the reading assessments at 90 months post implant so there was, on average, a gap of three and a half years between the speech and literacy assessments. The children in this study had undergone surgery at the University of Iowa Hospitals.

The Dallas (Geers, Tobey, Moog, & Brenner, 2008) and Nottingham (Archbold et al., 2008) studies focused solely on children who had received a cochlear implant but other studies have compared literacy attainment in deaf children with cochlear implants and peers with hearing aids. There have been considerable technological advances in hearing aids over the last decade or so (Ackley & Decker, 2006) and many deaf children for whom a cochlear implant is not considered appropriate or desirable are now using digital aids. These can be expected to give considerably better access to speech than older, analogue devices. As with evaluations of the impact of cochlear implants, the date at which a hearing aid was fitted is highly relevant because of the relatively recent availability of digital aids.

A study of 152 deaf children in Scotland found that those with cochlear implants scored comparatively higher on reading and writing than peers with hearing aids (Thoutenhoofd, 2006); and a similar pattern emerged from a study of 550 deaf pupils in the Netherlands (Vermeulen, van Bon , Schreuder, Knoors, & Snik, 2007). In both studies, however, children with implants were delayed in their reading in comparison to hearing children. The mean age-at-implantation was 37 months for primary school pupils in the Scottish study and 74 months in the Dutch study. So age-at-implantation was comparatively late in both studies, especially the Dutch one, and this is likely to have had an impact on the outcome.

Two very recent studies have compared the outcomes for children with cochlear implants and hearing aids (Harris, Terlektsi, Kyle, & Corder, in preparation; Herman et al., 2014). Herman and colleagues (Herman et al., 2014) recruited 79 11-year-old children with severe-profound hearing loss from all parts of the UK. All children had attended an English speaking school on school entry and they used English as their dominant language. Almost two thirds of the children had one or two cochlear implants and the remainder used digital hearing aids. There were no differences in the reading scores of the children with cochlear implants and those with hearing aids on any of assessments of reading and language skills. Notably, however, only just over half the children (52%) were reading single words at an age-appropriate level and the distribution of scores was approximately 1 SD below the mean for hearing peers.

This pattern of results shows that, in spite of the high proportion of children with cochlear implants, there were still significant delays in reading among the sample of 79 deaf children. Herman et al. suggest that the reading scores of the deaf children would be likely to deteriorate over time when compared to hearing peers because many of the children who had age-appropriate single-word reading had low English vocabulary scores. As English vocabulary knowledge is an important longitudinal predictor of reading (Kyle & Harris, 2010, 2011), this suggests that more of the deaf children would be likely to have reading problems in the future. (This study is described in detail in chapter X, this volume.)

Data from an ongoing study of deaf children in primary school (Harris et al., in preparation) provides further evidence of the relative impact of cochlear implants and digital hearing aids on literacy. The aim of the study was to make a direct comparison of data on reading and reading-related skills collected on two similar cohorts, whose recruitment was a decade apart, with a view to finding out whether earlier diagnosis of hearing loss and better aiding has improved literacy levels. The data from the earlier study come from Kyle and Harris (Kyle & Harris, 2006, 2010, 2011) while the cohort of newly-recruited children were assessed between the end of 2013 and the beginning of 2014. The two cohorts are similar in age (6 years) and unaided hearing loss (around 99 dB) and they come from the same geographical area in the UK. The children in the two cohorts are also similar in having an IQ within 1 standard deviation of the mean and no additional difficulties. In the intervening years between the recruitment of the original and new cohorts, universal newborn hearing screen was rolled out in the UK, enabling the great majority of children with a hearing loss to be identified soon after birth. At the same time, there was an increase in the number of children who were able to receive a cochlear implant and/or digital hearing aids.

One difference between the two cohorts has become immediately apparent and this illustrates the technological advances in aiding that have occurred in the last 10 years. The unaided hearing loss of the two cohorts is identical but the aided loss is significantly lower in the recently-recruited cohort, with an average loss of only 39 dB (compared to 53 dB in the original cohort). Just over half the children have at least one cochlear implant compared with only 25% in the original cohort.

There have also been some notable changes in the children's educational setting. None of the children in the original cohort was being educated in a mainstream setting but, in the recently-recruited cohort, 10 out of the 42 children are being educated exclusively in mainstream. The remaining 32 children are either in schools for the deaf or specialist units, where they typically spend half their time within the unit working in small groups and the remainder of their time being educated alongside hearing peers (usually with individual support).

In terms of reading, the two cohorts are remarkably similar. However, there are two very striking differences. The recently-recruited children have significantly better spoken English vocabulary: In the original cohort the mean English vocabulary age was just over three years as compared to just over five years in the recent cohort – a difference of two years. The children in the new cohort also have better phonological awareness scores as assessed by a picture-based similarity task (Kyle & Harris, 2006). In the original cohort the mean score was 16/24 and this had increased by a small but significant amount to 18/24 for the new cohort. Closer analysis revealed that the improvement was in the rime similarity scores that had increased from 7/12 correct to 9/12. (The rime is the second part of a single syllable word and is often more difficult to perceive than the initial sound.) The children with hearing aids performed at a similar level to those with cochlear implants except on letter-sound knowledge where the children with implants show an advantage, correctly identifying an average of 22 letters compared to 16.

The deaf children in the new study were matched on single-word reading to a group of hearing children. The hearing children were significantly younger, having a mean chronological age of 5 years 10 months that represented a difference of nearly three months. This shows that, even at this early stage of reading, the deaf children were already falling behind their hearing peers by a few months. There was, however, considerable variation in reading performance with some deaf children reading at a level that was equal to or better than their chronological age.

Taken together, these two recent studies (Harris et al., in preparation; Herman et al., 2014) suggest that deaf children who are currently in primary school are developing better skills than peers in earlier cohorts in the two key areas that are required for reading – phonological awareness and English vocabulary - although they have not as yet caught up with hearing peers in either of these skills or in reading. What we might hope to find is that, as these children progress through primary school and into secondary school, their reading will remain closer to that of hearing peers than in previous cohorts since their underlying reading skills are better. However, it seems likely that reading will still not be at an age-appropriate level for many of the children.

<2> Literacy in secondary school

As noted earlier, in the past deaf children have typically fallen further and further behind hearing peers as they progress through school and the demands of literacy systematically increase at word, sentence and text level. The first indication that the relative success of cochlear implantation for literacy reported for children in primary school might not be sustained into secondary school came from the Dallas study (Geers, et al., 2008). Twenty-six of the children assessed in the earlier study (Geers, 2003) were followed to see how their reading had progressed. Although the children had been reading at an age-appropriate level at the age of 8-9 years, they were showing an average reading delay of 2 years by the time they were 15-16 years old. This suggested that early reading success following a cochlear implant might not be sustained in the latter years at school.

There was also some evidence of a relative decline in reading ability between the two post-implant assessment points in the Archbold et al. (2008) study. There are some limitations on the value of a direct comparison between the post-implant assessment data at 5 and 7 years because not all of the children included in the first assessment were available for the second assessment, although there is no reason to suppose that there was any systematic bias in the sub-sample available for the later assessment. At 5 years post implant, the children with an early implant were reading 8 months above chronological age but two years later they were reading almost at chronological age level.

The concerns raised by the two earlier studies were confirmed in a study that made a direct comparison of three matched groups of young people in secondary school (Harris & Terlektsi, 2011). All participants in this study had severe-profound prelingual hearing loss and a nonverbal IQ that was at or above 1 standard deviation of the mean. They were assigned to groups according to aiding, with one group making use of hearing aids, one group having received a late cochlear implant (after 42 months) and the final group having received an implant before 42 months. The groups had similar nonverbal IQ scores although, as might be expected, the group with the late implants had a later age of diagnosis of hearing loss. Harris and Terlektsi found that all groups were reading significantly less well than hearing peers with the mean lag between reading age and chronological age being just over three years for both single-word reading and reading comprehension on the Edinburgh Reading Test. There were no differences among the three groups on single-word reading, but the children with hearing aids were reading considerably better on the Edinburgh Reading Test (Edinburgh, 2002) than children in the two implanted groups, with this difference being significant in the case of the early-implanted group. The mean reading lag for children with hearing aids was slightly less than two years compared to well over three years for young people in the two implanted groups.

The children in the study came from a range of educational settings – schools for the deaf, specialist units for deaf children and classrooms in mainstream schools – and some of the children were receiving an oral education while others were in classrooms where signing was used. It is important to note that there was no simple relationship between the language of the classroom and levels of literacy and there were good readers in both oral and signing classrooms.

A more recent report from Geers and colleagues (Geers & Hayes, 2011) presents a somewhat more optimistic picture of outcomes in secondary school, based on assessments of 112 young people who were followed up between the ages of 15 and 18 years. In this larger sample, almost half of the students (47%) had reading scores within one standard deviation of scores for hearing peers although scores on reading comprehension were generally better than scores on word recognition. Spelling scores were slightly better with 55% of students scoring within one standard deviation of hearing peers. Phonological coding scores were generally lower as measured by word decoding (where only 30% of deaf students were within the average range) and phonetic errors in spelling. Notably, the deaf students did not typically use a phonological approach to spelling an unfamiliar word in contrast to comparison group of hearing students who invariably did so, producing phonetic errors by attempting to spell a word in the way that sounded correct. Within the sample of deaf students, those who used primarily oral communication made significantly more phonetic errors than those who used sign and speech. Performance on nonword repetition was particularly poor, and none of the deaf sample was within one standard deviation of hearing peers. Nonword repetition is a demanding test of the ability to deal with novel phonological sequences and it has been shown to be highly predictive of difficulties with reading for hearing children (Gathercole, 2006).

Although almost half of the young people described in Geers and Hayes (2011) were reading at an age-appropriate level – which is better than the proportion reported in earlier studies - this means that just over half were not achieving at an age-appropriate level. Furthermore, phonological processing skills appeared to be a key factor in literacy outcomes, accounting for 38% of added variance. As might be expected, phonological processing skills were themselves highly inter-related.

<1> An evaluation of the impact of cochlear implants

In summing up the impact of cochlear implants on literacy, two key findings are apparent. First, a number of studies (Harris et al., in preparation; Herman et al., 2014) have found that, even in the early stages of learning to read, children with cochlear implants are not achieving at the same level as hearing peers and are doing no better than the current cohort of children with digital hearing aids. However, some studies – notably those that are associated with particular cochlear implant programs (Archbold et al., 2008; Geers et al., 2003) - have reported more positive outcomes with significantly large numbers of children reading at an age-appropriate level. Second, all the studies that have assessed reading in secondary school have reported that relative ability declines and the gap with hearing peers increases.

In order to understand what this pattern of results suggests about the impact of cochlear implants it is useful to consider two rather different analyses of the strengths and weaknesses of the reading and reading-related skills of children with implants. The first analysis comes from the study of Herman et al. (2014) that was mentioned earlier and the second from a detailed analysis of the phonological skills of children with cochlear implants (Spencer & Tomblin, 2009).

It will be remembered that the majority of children who took part in the Herman et al. (2014) study had one or more cochlear implants but, overall, there were no differences between children with implants and those with digital hearing aids in performance on literacy and other measures. It is therefore relevant to look in more detail at the reading profiles of the children in their study. One important element of the study, that has not been mentioned so far, is that it made a direct comparison of the language and literacy profiles of deaf children with those of hearing children with dyslexia. This is a highly relevant comparison to make because hearing children with the most common form of dyslexia are known to have problems with phonologically-based decoding (Hulme & Snowling, 2009). Herman et al. used an extensive battery of tests that included literary skills, phonological skills, and language skills to assess both groups of children. The differences between the two groups are very revealing as to the nature of the particular difficulties that confront children with a significant hearing loss, but good aiding, as they learn to read and spell.

The profile of phonological deficits that predicted poor reading was very similar for the hearing dyslexic and deaf children. Tasks that involved the manipulation of sounds were strong concurrent predictors of reading. The two sound manipulation tasks used by Herman et al. (2014) were phoneme deletion and spoonerisms. Phoneme deletion involved repeating a word with one sound omitted (e.g., saying ‘afford’ without saying ‘a’ or ‘reindeer’ without saying ‘rein’) while spoonerisms involved the replacement of one sound in a word with another (e.g., replacing ‘f’ with ‘b’ in ‘fun’ to give ‘bun’). (For more detail of this study see chapter X, this volume.)

Spelling errors also provided evidence of phonological coding ability. Almost all children in the hearing dyslexic group made mainly phonetic errors (e.g., lepered for ‘leopard’), indicating that they were using phonological coding in spelling unfamiliar words. Children in the deaf group showed three equally common patterns of spelling error. One third made mainly phonetic errors (like the hearing dyslexic children), one third made mainly non-phonetic errors and the reminder showed a mixed pattern of both types of error. A predominance of non-phonetic errors (e.g., cuircle for ‘circle’) was found in the poorest readers and spellers.

The most striking difference between the groups was that only about 10% of dyslexic hearing children had English vocabulary and reading comprehension scores that were below average (when compared with typically developing hearing children) whereas the comparable figures for the deaf children were 60% for reading comprehension and 70% for vocabulary. The 48% of deaf children who were classed as poor readers all had both poor decoding skills (assessed on the basis of nonword reading) *and* poor language skills.

The results of this study suggest two things. First, many deaf children still have levels of spoken language that lag behind hearing peers, even though these levels have improved considerably with the advent of cochlear implants and digital hearing aids. It is notable that the English vocabulary levels in the newly-recruited cohort of deaf children described by Harris et al. (in preparation), although considerably better than those of the earlier cohort, were still one year below the children’s chronological age of six years. So, although the provision of early, effective aiding has improved language levels for deaf children there are still delays, at least for some children.

Second, the deaf children in the Herman et al. (2014) study typically had poor phonologically-based decoding skills. Thinking about the comparison with hearing children with dyslexia is useful in trying to understand what might be happening in deaf children with a cochlear implant or effective digital hearings aids. Although hearing children with dyslexia have poor decoding skills this is not immediately apparent from listening to their spoken language. It is only when children with dyslexia are asked to perform tasks that require high levels of phonological coding – especially ones that require manipulation of phonemes – that their problems become apparent. Hearing children with dyslexia may have had earlier difficulties with spoken language but, in most cases, these difficulties have been resolved well before they begin formal schooling (Hulme & Snowling, 2009). This highlights the fact that good spoken language does not guarantee good phonological coding.

Further insight into the phonological coding abilities of deaf children with cochlear implants comes from a detailed analysis of their phonological processing skills (Spencer & Tomblin, 2009). One of the benefits of cochlear implantation, and correspondingly better access to spoken language for children with severe-profound hearing loss, is that it is now possible to use a range of phonological assessments with this population. Such assessments were not possible in the past except for the minority of children with highly developed oral skills.

Spencer and Tomblin (2009) selected a wide range of assessments for their study, mainly taken from The Comprehensive Test of Phonological Processing, commonly known as the CTOPP (Wagner, Torgesen, & Rashotte, 2001). There were three tests of phonological awareness. The elision task was similar to the one used by Herman et al. (2014) and required children to say a word with one of the sounds omitted. The blending task required the putting together of separate sounds to make a word (e.g., can + dee = candy). In a picture rhyme task children had to choose a rhyming word to match a cue word and ignore two related distractors. Phonological memory was measured using a digit repetition and a nonword repetition task.

In addition, the rapid letter naming and rapid number naming tasks from the CTOPP were also administered. Performance on rapid automatized naming (RAN) tasks has been shown to be related to reading ability for hearing children and it has been argued that such tasks capture a unique ability that is independent of phonological processing (Powell, Stainthorp, Stuart, Garwood, & Quinlan, 2007). The CTOPP RAN tasks require children to name, as quickly as possible, two 4x9 arrays in which 6 items (either letters or numbers) are repeated. The reason that this process is described as 'automatized naming' is that the items come from a very small set and so their names should be easily – automatically - accessible.

The tasks were administered to two matched groups of children. There were 29 deaf children with a mean age of 11 years 9 months, all of whom were cochlear implant users. They were matched with a group of hearing children on word comprehension ability. Both groups had an age range of several years but the hearing controls were, on average, two years younger than the deaf children. The hearing children had higher scores than the deaf children on both the rhyme and blending tasks but similar scores on the elision task. For the deaf children, performance on both the blending task and nonword repetition were significantly related to reading in the audiovisual version of the tasks. All perception tasks were presented in two versions, once using a prerecorded CD (auditory only) and once using a live presentation in which the experimenter pronounced the test items and so provided information about lip patterns. The fact that, for deaf children, it was only performance under audiovisual presentation that was associated with reading ability hints at the particular importance of the visual component of phonology for deaf children since, for hearing children, there were significant associations under auditory presentation condition as well.

The hearing children were also better on the memory for digits task and on nonword repetition although the two groups had identical digit spans. On the RAN tasks, there were no significant differences between the two groups. However, for the hearing children, speed of letter naming had a very high correlation with speed of number naming, whereas there was no such correlation for the deaf children. There was also a difference in the relationship between these two tasks and reading. For the hearing children, scores on both RAN tasks were correlated with reading, but for the deaf children only letter naming was correlated. This suggests that the general ability to rapidly name familiar items was somewhat different in the two groups, with the specific ability to name letters being more important for the deaf children. It would be intriguing to find out whether this finding could be replicated in another sample.

In discussing their findings, Spencer and Tomblin note that some of the deaf children in their study had not reached ceiling in the rhyme task even by the age of 10 years. Most hearing children have a very sound knowledge of rhyme well before they begin school and so it would appear that, for deaf children with cochlear implants, awareness of rhyme emerges gradually over time for most but not all. Spencer and Tomblin note that the development of phonological coding skills in deaf children is likely to have a more reciprocal relationship with reading than for hearing children, as the study by Kyle and Harris (2010) went on to demonstrate.

<1> Conclusions

It is clear from this review of the literature that cochlear implants have brought benefits to deaf children. However, the benefits for spoken language appear to be more consistent than the benefits for literacy. While many deaf children become excellent readers, this is by no means true of all deaf children, even those who have received an early cochlear implant. Good phonological coding skills and good knowledge of the spoken language are important for reading, and the children who have the most secure abilities in both areas are the ones who go on to become good readers.

One way to think about the benefit of cochlear implants is to draw a comparison with hearing dyslexic children. Children in this latter group are known to benefit from interventions that support the development of phonological skills, especially in the early years of school (Muter et al., 2004), but they also require continuing support as they enter secondary education. The fact that children who were followed up as part of a specific cochlear implant program have tended to have particularly good outcomes points to the general value of continuing support from specialist teachers.

There is clearly more to be done to arrive at a consensus about how the benefits of cochlear implants can be maximized to ensure that age-appropriate levels of literacy become the norm for deaf children. However, some evidence is beginning to accrue. Explicit instruction in phonological skills such as rhyme and phoneme awareness can benefit deaf and hard-of-hearing children who can access and use spoken language (Miller, Lederberg, & Easterbrookes, 2013). It is however a particular challenge to support deaf children who are signing to develop good decoding skills. For such children, in particular, both speechreading and visual phonics may be of value.

The potential value of speechreading has been highlighted in two longitudinal studies (Kyle & Harris, 2010, 2011), although so far there have not been any intervention studies. The advantages of speechreading is that it is perfectly compatible with the use of sign that is accompanied by speech; it is notable and some of the best speechreaders in the Harris and Moreno (2006) study were also fluent signers. The potential value of visual phonics has been demonstrated in a number of studies (Narr, 2008; Trezek et al., 2007) that have recruited children from a variety of educational settings. Visual phonics provides additional information about speech sounds that add to the information that children can gain from the auditory and visual components of speech. Both speechreading and visual phonics have the potential to provide children who have received a cochlear implant with additional information about speech sounds that can enable them to develop robust decoding skills, thus paving the way for the development of age-appropriate levels of literacy.

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