The Contribution of Short-Term Memory Capacity to Reading Ability in Adolescents with Cochlear Implants

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Abstract

Objective This study aimed to establish the relationship between short-term memory capacity and reading skills in adolescents with cochlear implants.

Methods and Materials A between-groups design compared a group of young people with cochlear implants with a group of hearing peers on measures of reading, and auditory and visual short-term memory capacity. The groups were matched for non-verbal IQ and age. The adolescents with cochlear implants were recruited from the Cochlear Implant Programme at a specialist children's hospital. The hearing participants were recruited from the same schools as those attended by the implanted adolescents. Participants were 18 cochlear implant users and 14 hearing controls, aged between 12 and 18 years. All used English as their main language and had no significant learning disability or neuro-developmental disorder. Short-term memory capacity was assessed in the auditory modality using Forward and Reverse Digit Span from the WISC IV UK, and visually using Forward and Reverse Memory from the Leiter-R. Individual word reading, reading comprehension and pseudoword decoding were assessed using the WIAT II UK.

Results A series of ANOVAs revealed that the adolescents with cochlear implants had significantly poorer auditory short-term memory capacity and reading skills (on all measures) compared with their hearing peers. However, when Forward Digit Span was entered into the analyses as a covariate, none of the differences remained statistically significant.

Conclusions Deficits in immediate auditory memory persist into adolescence in deaf children with cochlear implants. Short-term auditory memory capacity is an important neurocognitive

process in the development of reading skills after cochlear implantation in childhood that remains evident in later adolescence.

1. Introduction

Numerous studies have documented the benefits of cochlear implants for profoundly deaf children in terms of listening skills, receptive and expressive language development, and increasingly more subjective outcomes such as quality of life. Additionally, some specific cognitive functions have also been found to be relevant outcome variables following cochlear implantation, for example non-verbal reasoning and working memory [1,2,3]. Similarly there is now a considerable body of evidence concerning educational attainments, especially reading ability, in children who have received cochlear implants [4,5,6]. However, despite the overall conclusion that cochlear implants lead to significant gains in these skills, processes and attainments, there remains enormous variability in the degree of benefit derived by individual children. As a result emphasis is increasingly being placed on trying to identify the underlying cognitive or information-processing processes that are contributing to this variability. To date the majority of studies have focussed on processes and outcomes in young children and those of primary school age, mainly because from a pragmatic perspective it has been necessary to wait for the cohort of children implanted as infants to reach adolescence.

Decades of research has indicated that deaf children are at risk of leaving the education system with extremely poor levels of reading ability compared to their normally hearing peers [7,8,9]. Recent research has indicated that phonological processing skills are likely to be important in understanding the reason for this deficit [10]; good reading skills rely fundamentally on adequate language processes, in particular spoken language skills that are based on phonological processes [11,12]. Access to auditory information allows the use of letter-sound correspondences providing a basis for phonological decoding. Therefore it might be predicted that cochlear implants, which provide access to spoken language in profoundly deaf children, will result in improvements in reading ability. To a certain extent this is supported by the research literature, for example in studies by Vermeulen et al. [13], Lyxell et al. [2] and Fagan et al. [15] When implanted relatively early (under around 3½ years of age), deaf children can achieve reading accuracy and reading comprehension scores within the normal range [14,5]. However not all studies have supported this position, with hearing-aid users out-performing cochlear implant users in some instances [e.g.16, 17].

Most of the previous research in this area has been cross-sectional and focussed on children of primary school age. However a recent longitudinal study has explored the reading, spelling and phonological processing abilities of deaf adolescents aged between 15 and 18 years who have been using cochlear implants for at least 10 years [6]. Significant deficits were found in their phonological processing skills and these skills were a strong predictor of reading, spelling and expository writing abilities.

However, there is also a growing evidence base that indicates memory skills are also likely to make an important contribution to this variability in outcomes. Short Term Memory (STM) is used to encode and retain information for a short period of time, usually a few seconds, and is typically measured using digit or word span tasks. Working Memory (WM) is a more complex process because it involves not only encoding, and retention, but also further processing or manipulation of the material before producing an output. WM involves active attention and control processes in addition to the simple storage process of STM. Backwards digit span is a standard WM task, since it involves reversing the order in which the numbers are presented before producing the response. In hearing children STM ability, and particularly auditory STM has been shown to be related to tasks such as learning to read: developmental dyslexics have been demonstrated to have poor memory spans and good deaf readers have superior letter recall than poor deaf readers matched on non-verbal IQ [18, 19]. Although not so extensively researched, visual memory has also been found to be related to reading ability in deaf teenagers. MacSweeney [20] used a pictorial ordered recall task and found a significant positive correlation between visual STM and reading age.

Children with hearing impairment, with and without cochlear implants, have consistently been demonstrated to have reduced STM capacity through early childhood to late adolescence [e.g. 21,22,23,24] as well as auditory WM ability [e.g. 25, 1]. The impact of cochlear implantation on the development of these auditory and visual short term and working memory skills has not been extensively investigated, particularly over extended periods of time. Furthermore, the relationship between memory process and reading outcomes has received very limited attention, with previous studies focussing more on speech and language outcomes. For example in cross-sectional studies both Kronenberger et al. [26] and Pisoni et al. [1] report greater deficits in verbal STM compared with WM (measured by digit span forwards and backwards respectively) in children with cochlear implants, although both were impaired in comparison to hearing norms. Based on a longitudinal study of 110 children aged 3 to 15 years, Harris et al. [26] concluded that differences in the rate of development of STM/WM may influence speech and language outcomes and that the rate of development of STM/WM, and not just the actual level of STM/WM at a single time point, predicts later speech and language development. Harris et al. [27] found that baseline digit span forwards scores, and growth in digit span forwards scores over a period of at least two years, were stronger predictors of later expressive and receptive language skills than digit span backwards scores and growth in digit span backwards. Similarly Pisoni et al. [1] describe a pattern of results that suggests that deficits in immediate verbal memory capacity of deaf children relative to normally developing hearing peers remain approximately constant even after 8 years of cochlear implant use.

In summary, the cognitive processing factors most consistently and strongly found to be related to speech and language outcomes in implanted children are short-term memory (STM) and working memory (WM), but their relationship to reading outcomes is not well documented. In addition, such previous research as there is has focused primarily on young implanted children in the early stages of developing language and reading skills. Therefore this paper will extend previous research to focus on the relationship between memory processes and reading skills in adolescents with cochlear implants. It is hypothesized that (a) the reading skills of adolescents with cochlear implants will be poorer than those of their hearing peers; (b) early deficits in STM and WM persist into adolescence and (c) that these cognitive processes will be related to reading ability in this age group.

2. Method

2.1 *Design*

A between-groups design compared a group of young people with cochlear implants with a group of hearing peers on measures of reading, and auditory and visual short-term memory capacity. The groups were matched for non-verbal IQ and age.

2.2 *Participants*

All the young people on the Cochlear Implant Programme at a specialist Children's Hospital, aged between 12 and 18 years, whose main spoken language was English were invited to participate in the study by letter. However, adolescents with known disabilities in addition to their deafness such as neuro-developmental disorder (e.g. autistic spectrum disorder) or significant learning disability were excluded from the study. Participants with cochlear implants had been using their device for a minimum of 4 years, and their onset of deafness was before the age of 24 months.

The hearing participants were recruited from the schools attended by the young people with cochlear implants, so that they came from comparable socio-economic backgrounds. Teachers of the participants with implants were asked to provide the names of students whose ages were within 3 months of the age of the implanted participant, and these students were then also invited to participate by letter.

The resulting study sample comprised 18 young people with cochlear implants and 14 hearing adolescents. Table 1 presents the demographic characteristics of the participants. The two groups were not matched on gender, however, entering gender as a co-variate in the statistical analyses indicated that this variable did not have an impact on the results. All the children were fitted with Nucleus cochlear implants and the majority (12) were using the Freedom processor. Fifteen of the implanted children described themselves as oral communicators and the remainder as using a combination of spoken English supported by signs. All the participants spoke English as a first language as this is the language of the reading and neuro-psychological measures used in the study.

Ethical approval for the study was obtained from the appropriate regulatory organisations, and all participants gave signed, informed consent.

2.3 *Measures*

2.3.1 Reading

Three measures of reading were used from the Wechsler Individual Achievement Scale – Second Edition [28]. The WIAT is an assessment battery comprising tests of reading, mathematics and written and oral language for children aged 4 to 16 years, yielding Standard Scores for each of the sub-tests. The reading subtests can be combined to give an overall Reading Composite Score. Subtest Standard Scores have a possible range of 1 to 19, an average of 10 for a child of any given age, and standard deviation of 3. The Reading Composite Score has a population mean of 100 and standard deviation of 15. The test's normative data is based on hearing children.

Word Reading subtest. This test requires the participant to read aloud a list of words of increasing difficulty printed on a stimulus card. Three seconds are allowed for each response and the test is discontinued after seven consecutive incorrect responses. The raw score is the total number of words read correctly. This is converted to a Standard Score based on the test's normative data.

Reading Comprehension subtest. In this subtest participants are presented with written passages and are asked questions about the text. The length and complexity of the passages increase, with different starting points for children of different ages. The test measures reading speed as well as the ability to extract information from the written text. Reading speed, comprehension score and the accuracy of reading aloud specific target words combine to give an overall Reading Comprehension raw score, which is converted to a Standard Score.

Pseudoword Decoding subtest. In this subtest the respondent is asked to read aloud a series of increasingly long and complex nonsense words which are phonetically plausible, such as heb and mib. Five seconds are permitted for each response and again the raw score (total number of correct responses) is converted to a standard score.

2.3.2 Memory

Three tests of memory capacity were used: the Digit Span subtest from the Wechsler Intelligence Scale for Children, 4th UK Edition [WISC IV UK; 29], and the Forward Memory and Reverse Memory subtests from the Leiter International Performance Scale – Revised [Leiter-R; 30].

The WISC IV UK is a test of intelligence for children aged 6 to 16 years, standardised on hearing children, comprising 10 subtests that combine into 4 Composites. The Digit Span subtest is one of two subtests that comprise the Working Memory Composite, and has been widely used as a measure of immediate memory capacity in studies on deaf children including those with cochlear implants.

The Leiter-R is a standardised battery of tests of non-verbal abilities including visualisation, reasoning, memory and attention abilities. It can be administered without the use of spoken language by either the examiner or testee and it is therefore intended for use with children and adolescents who are deaf or have delayed language skills. This test has also been used in a number of studies with children with cochlear implants (e.g. 3, 31)

Digit Span subtest (auditory). In this test the child is presented increasingly long sequences of digits live voice and asked to recall them in the correct order. The first series has 2 digits, and there are two trials for each series length. The child is then asked to repeat the task, but to recall each series in reverse order. Testing is stopped when the child responds incorrectly to both trials of a series. Most commonly (both clinically and in research studies) the raw scores for the number of correctly recalled forward and reverse sequences are added together and then the total converted to a Scaled Score. However, separate Scaled Scores are provided for the forward and reverse sections of the subtest, and it is these which were used in the current study in order to distinguish STM capacity and working memory. The Scaled Scores have a population mean of 10 and standard deviation of 3. The average range is 8-12.

Forward and Reverse Memory subtests (visual). In the Forward Memory subtest the child watches the examiner point to pictures in a particular order in a series of grids. The grids comprise an increasing number of pictures, and the child is asked to copy the order in which the examiner has pointed to the pictures. In the Reverse Memory task, the child points to the pictures in the reverse sequence to that of the examiner. Testing is discontinued when the child has been unable to correctly recall six sequences. In accordance with the Leiter-R scoring procedures these two subtests were not combined to give an overall measure of visual memory capacity.

2.3.3 Non-verbal Intelligence

The Leiter-R includes a Brief IQ Screen. Four of the 10 Visualization and Reasoning battery subtests are combined to produce the screen: Sequential Order, Repeated Patterns, Figure Ground and Form Completion. The number of correct responses on each of these subtests is converted to a scaled score (mean 10, standard deviation 3), and the four scaled scores are then combined to produce the Brief IQ Screen which has a population mean of 100 and standard deviation of 15.

2.4 *Procedure*

Ethical and other relevant institutional research permissions were obtained. Written consent to participation was obtained from the adolescents and one of their parents/guardians. The tests were administered either at the hospital cochlear implant clinic or the participant’s school, depending on participant preference. In either case testing was conducted individually in a quiet room to minimise distractions. The tests were administered in the same order for each participant. Testing sessions lasted a maximum of two hours; participants were encouraged to ask for a break during testing if they experienced fatigue.

3. Results

One score from a cochlear implant participant was notably higher than that of the other young people with implants (on the Reading Comprehension subtest). However, given the known great variability in outcomes amongst pediatric implant recipients, the fact that the score did not exceed the conventional cut-off of three standard deviations from the mean, and its exclusion from the analyses did not alter the results, this score was included in the analyses.

Table 2 presents the results of the non-verbal IQ, memory and reading tests for the group of young people with cochlear implants and the hearing control group. The mean non-verbal IQ of both groups fell within the normative average range, as did the Forward Memory and Reverse Memory span standard scores. The mean scores on Backward Digit Span were also below the average range in both groups of participants, but Forward Digit Span was just within the normal range for the hearing participants.

Analysis of variance (ANOVA) comparing the scores of the two groups on each of the measures revealed significant differences between the groups on Forward Digit Span, Word Reading, Reading Comprehension and Pseudoword Decoding, but not on Non-verbal IQ, or the Forward and Reverse Memory span tests of visual memory capacity. When Forward Digit Span scores were entered as covariates into the analyses for Word Reading, Reading Comprehension and Pseudoword Decoding, the differences between the cochlear implant and hearing groups no longer reached statistical significance.

Given previous research has indicated that outcomes following implantation are typically superior when the child has received the implant(s) before the age of 3½ years, a further analysis was conducted comparing the 12 adolescents who were younger than this at the time of implantation, with the group of hearing adolescents. T tests comparing scores on each of the reading and memory measures were performed. The only significant difference to emerge was for Forward Digit Span, t (1,24) = -2.86, p=0.009.

2.5 Discussion

The results of this study provide evidence regarding two important issues for furthering our understanding of specific cognitive processes in the development of reading skills in profoundly deaf children: the persistence of delays and deficits into adolescence, and the role of short-term memory processes.

In line with previous studies, the results of this investigation provide additional empirical support for the importance of immediate memory span in the reading outcomes of deaf adolescents who have been using cochlear implants for at least five years. Compared with hearing adolescents, those with cochlear implants were significantly poorer at reading individual words, in their comprehension of written material and in their ability to use phonological knowledge to decode ‘nonsense’ words. This is consistent with other studies [e.g. 13,17] that found reading skills in children with cochlear implants to be significantly below norms for hearing children. However this is in contrast to the findings reported by others [15,5,14] where the reading ability of the implanted children was within the average range for their chronological age. The most likely explanation for these conflicting findings lies in characteristics of the samples. The group of implant users in the current study received their cochlear implants at an average age of around 3½ years, with the oldest being 10½ years (due to a progressive hearing loss). There is considerable evidence that early implantation is more beneficial than later implantation in terms of outcomes in all areas of language development and literacy attainment, and therefore it is probable that the relatively late age of implantation for some of the implant users in our sample accounts for the high proportion whose reading and phonological skills were below the average range for their age. Indeed, when only those children who had received their implants before 3½ years of age were compared with the normally hearing adolescents, there was no significant difference in the reading outcomes, supporting this contention.

In this study, as expected, the adolescents with cochlear implants also performed significantly worse on an auditory immediate memory span task (Forward Digit Span) compared with their hearing peers. This is consistent with the findings of many previous studies [1, 23]. In addition, our results confirm greater deficits in forwards digit span than backwards digit span, with both being impaired when compared with hearing norms, as also demonstrated previously [1, 25]. Thus the results of the current study indicate that delays in reading acquisition, and deficits in auditory/verbal short term memory capacity, persist into adolescence in deaf children even after access to speech sounds has been restored by the use of cochlear implants for many years. Interestingly, the deficit in auditory short-term memory was apparent even in the sub-sample of children implanted earlier than 3½ years. This suggests that there may a fundamental and irreversible change in the brain's structure and/or functioning resulting from congenital or early childhood sensorineural deafness.

The second issue addressed by this study concerns the role of short-term memory capacity in the development of reading skills in deaf adolescents following implantation. When STM capacity was controlled for in the comparison of word reading, reading comprehension and nonsense word decoding skills between the groups, the hearing adolescents were no longer significantly better at these skills than the deaf adolescents. This confirms that auditory memory capacity is an important neurocognitive factor underlying phonological processing, word reading and reading comprehension. Interestingly, it appears that it is not just in the early stages of learning to read that auditory memory capacity is significant, continuing to be of relevance in older readers. This is consistent with evidence from neuroimaging studies that indicate that structural changes in white matter, particularly in the frontal lobe, continue throughout adolescence and into early adulthood [e.g. 32].

Although some of the results of this study replicate others, there were some unexpected findings and a number of questions remain unanswered. Firstly, despite the groups being well matched in terms of non-verbal IQ, the means for both groups were somewhat below population norms. This again is most probably due to sampling artefacts; the teachers of the hearing participants may have suggested they were approached not just based on their age, but also their knowledge of the student's overall ability level. Secondly, both the Forward and Backward Digit Span scores of the normally hearing adolescents were lower than would be expected based on published norms. The latter was particularly low, being almost two standard deviations below the norm. There is no obvious explanation for this, and it not clear what the implications are for the interpretation of the other findings of the study.

There are a number of methodological issues that warrant mention. Perhaps most importantly, this study did not include language ability as a possible confounding variable. Hoover and Gough [33] propose that reading comprehension is the product of decoding and language comprehension, so it would be expected that access to speech sounds after CI and resultant improved speech perception ability and spoken language skills would result in better learning of letter-sound correspondences and thus provide a more secure basis for phonological decoding. However, vocabulary and syntax also influence reading skills of deaf children [e.g.

34, 12]. Vermeulen et al. [13] conclude that language comprehension skills after CI explain a significant amount of the variance in reading comprehension scores. Therefore future exploration of the relationship between short-term memory span and reading skills in implanted adolescents would be improved by inclusion of measures of receptive and expressive language ability, for example vocabulary knowledge and syntax.

Finally, this study's results should be considered preliminary in terms of the reliability of its findings, given the relatively small sample sizes (although they are typical of many published studies in this field), and the lack of matching on gender between the groups. In particular the numbers of participants in the analyses comparing the early-implanted children with the hearing adolescents was small, so the lack of statistically significant findings should be interpreted with some caution.

In conclusion, this study provides empirical evidence to support the contention that auditory short-term memory capacity is a crucial element of neuro-cognitive function in the acquisition of reading skills in deaf children, even after a significant period of auditory stimulation using cochlear implants. It suggests that stimulation of the auditory centres of the brain following profound deafness early in development is not by itself sufficient to reverse the negative impact of very early auditory deprivation. However since cochlear implants do not restore normal hearing these deficits in memory capacity may also be the result of the continuing process of auditory deprivation throughout childhood and adolescence, although to a lesser degree, though hearing with a cochlear implant. The implications of these findings from a clinical perspective, therefore, are in the need to identify those deaf children who have deficits in auditory memory capacity as early as possible and implement remedial interventions to strengthen their working memory skills. However although a wide range of resources are available in terms of classroom activities and games as well as computerised training packages that aim to strengthen memory skills, unfortunately there is currently little empirical research demonstrating their effectiveness. This would be a fruitful area for future research in deaf children including those with cochlear implants.

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Table 1. Characteristics of the cochlear implanted and hearing participants.

	Cochlear Implant	Hearing
Age in years (mean; sd)	14.30 (1.36)	14.21 (1.53)
Gender (M:F)	11:7	3:11
Educational Placement (n)		N/A
Mainstream	5	
Unit for children with hearing loss	7	
Specialist school for the deaf	6	
Average pre-implant aided hearing loss (mean; sd)	73.52 (18.01)	N/A
Age at onset of deafness in months (mean; sd)	10.48 (7.34)	N/A
Age at implantation in months (mean; sd)	43.06 (26.16)	N/A
Implant experience in years (mean; sd)	128.35 (29.5)	N/A
Cause of deafness (n)		N/A
Connexin 26 mutation	6	
Genetic, non syndromic	2	
Waardenburg Syndrome	2	
Brancio-oto-renal Syndrome	1	
Meningitis	1	
Congenital rubella	1	
Unknown	5	

Table 2. Comparison of mean scores (with standard deviations) on tests of non-verbal IQ, reading and memory tests completed by adolescents with cochlear implants and hearing controls.

Test	Cochlear Implant	Hearing Controls	ANOVA P (2 tail)	ANCOVA * P (2 tail)
Non-Verbal IQ	92.11 (10.68)	91.50 (13.21)	0.886	
Forward Digit Span	5.35 (2.23)	8.57 (2.95)	0.003	
Backward Digit Span	7.53 (1.42)	7.71 (2.79)	0.834	
Forward Memory (visual)	10.67 (1.97)	10.64 (2.53)	0.976	
Reverse Memory (visual)	9.93 (2.17)	9.94 (2.07)	0.983	
Word Reading	75.33 (17.30)	90.79 (13.08)	0.009	0.409
Reading Comprehension	83.41 (19.62)	99.00 (12.88)	0.016	0.404
Pseudoword Decoding	79.50 (15.27)	90.64 (12.09)	0.033	0.719

* Covariate: Forward Digit Span