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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 neurodevelopmental 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 [1–3]. Similarly there is now a considerable body of evidence concerning educational attainments, especially reading ability, in children who have received cochlear implants [4–6]. 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

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reading ability compared to their normally hearing peers [7–9]. 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. Refs. [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. Refs. [21–24]] 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. [25] 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 3–15 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.