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The effect of early auditory experience on the spatial listening skills of children with bilateral cochlear implants

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ABSTRACT

Objectives: Both electrophysiological and behavioural studies suggest that auditory deprivation during the first months and years of life can impair listening skills. Electrophysiological studies indicate that 3½ years may be a critical age for the development of symmetrical cortical responses in children using bilateral cochlear implants. This study aimed to examine the effect of auditory experience during the first 3½ years of life on the behavioural spatial listening abilities of children using bilateral cochlear implants, with reference to normally hearing children. Data collected during research and routine clinical testing were pooled to compare the listening skills of children with bilateral cochlear implants and different periods of auditory deprivation.

Methods: Children aged 4–17 years with bilateral cochlear implants were classified into three groups. Children born profoundly deaf were in the *congenital early bilateral* group (received bilateral cochlear implants aged ≤3½ years, $n = 28$) or *congenital late bilateral* group (received first implant aged ≤3½ years and second aged >3½ years, $n = 38$). Children with some bilateral acoustic hearing until the age of 3½ years, who subsequently became profoundly deaf and received bilateral cochlear implants, were in the *acquired/progressive* group ($n = 16$). There were 32 children in the *normally hearing* group. Children completed tests of sound-source localization and spatial release from masking (a measure of the ability to use both ears to understand speech in noise).

Results: The *acquired/progressive* group localized more accurately than both groups of congenitally deaf children ($p < 0.05$). All three groups of children with cochlear implants showed similar spatial release from masking. The *normally hearing* group localized more accurately than all groups with bilateral cochlear implants and displayed more spatial release from masking than the congenitally deaf groups on average ($p < 0.05$).

Conclusion: Children with bilateral cochlear implants and early experience of acoustic hearing showed more accurate localization skills, on average, than children born profoundly deaf.

1. Introduction

Listening with two ears helps us to localize sounds and to better understand speech in noisy environments via complex central auditory processing [1]. These skills are referred to as spatial listening. In the past spatial listening was not possible for the majority of profoundly deaf children, who were provided with only one cochlear implant (CI). More recently many children have received bilateral cochlear implants (BiCIs), although practice varies regarding whether these are given simultaneously or sequentially. There is no universally accepted optimal time period between sequential procedures, however there is growing evidence that unilateral auditory deprivation causes ‘aural preference syndrome’ [2] with long-term detriments to children’s spatial listening. Better understanding of the development of spatial listening skills for children with BiCIs is therefore needed for clinicians to make the best management decisions for children regarding when and for whom BiCIs are indicated.

Abbreviations: CI, cochlear implant; BiCIs, bilateral cochlear implants; SSL, sound-source localization; SRM, spatial release from masking; CI1, first cochlear implant; CI2, second cochlear implant.

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Spatial listening relies on central auditory processing of the differences in level, time and phase of sounds arriving at either ear [1]. Electrophysiological studies suggest that 3½ years (42 months) is a critical age for congenitally deaf children to develop symmetrical cortical P1 responses within normal limits via BiCIs [3,4]. Congenitally deaf children who receive only one CI experience unilateral auditory deprivation. This leads to altered central auditory processing [3,5,6]. The effect of age(s) at implantation on behavioural outcomes is not yet fully understood. Minimizing the delay between a first cochlear implant (CI1) and second (CI2) has been associated with superior sound lateralization [7], localization [8,9] and speech discrimination in background noise [10,11]. However other studies did not find a statistically significant relationship between age at CI2 and speech discrimination in noise [12] or minimum audible angle on a lateralization task [13]. The influence of age at CI2 can be difficult to assess using multiple regression models due to the high correlation between variables such as chronological age, age at CI1, age at CI2, inter-implant interval and time since CI2. A systematic review by Smulders et al. [14] concluded that whilst it is likely that younger age at CI2 is beneficial, further evidence is required.

Not all children using BiCIs were born profoundly deaf. However bilaterally implanted children with progressive and acquired hearing losses are sparsely represented in the literature on binaural hearing. Children with congenital profound deafness experience bilateral auditory deprivation and those receiving BiCIs in sequential procedures experience an additional period of unilateral auditory deprivation. In contrast children with bilateral acquired or progressive hearing loss experience some binaural auditory stimulation during gestation and from birth. Provided children's hearing is regularly monitored they may have relatively short periods of auditory deprivation because CIs can be provided in a timely manner once indicated. This might improve children's binaural listening via BiCIs since post-lingually deafened adults have better binaural listening skills with BiCIs than those born profoundly deaf [15].

This study therefore aimed to examine the effect of early auditory experience on spatial listening skills in children using BiCIs. We measured children's sound-source localization accuracy (SSL) by listening alone using a semi-circular array of loudspeakers. We assessed the benefit of BiCIs on speech understanding in noise by measuring spatial release from masking (SRM) i.e. the benefit in speech reception threshold (SRT) gained when competing background noise is spatially separated from the target speech signal. An alternative measure of speech understanding in noise is binaural intelligibility level difference, in which speech and noise are presented over headphones or directly to the BiCIs. In one condition both speech and noise arrive at both ears at the same time; in the other condition the noise is delayed at one ear [16]. SRM is a closer approximation to real-life listening situations than the binaural intelligibility level difference test, because in SRM the interaural differences in level, timing and phase are created by the participant's own head, as is the case in everyday life, rather than being chosen by the researcher. Moreover, in SRM assessment both monaural and binaural cues are available to the listener and testing in sound-field rather than by direct stimulation includes the influence of factors such as microphone characteristics as well as sound-processing strategy.

Children were allocated to groups based on the age at onset of hearing loss and the age(s) at implantation, using the critical age of three-and-a-half years identified by Sharma et al. [3]. Outcomes for the children with BiCIs are presented with reference to data from normally hearing children.

2. Methodology

2.1. Participant selection

The aim of the study was to gain insight into the effect of auditory experience during the first three-and-a-half years of life on children's spatial listening skills with bilateral cochlear implants. In the UK, behavioural listening tests that were developed for research are now being used to monitor children's listening skills as part of routine clinical care [17]. The present retrospective study pooled data that had been gathered as part of clinical practice (at the Yorkshire Auditory Implant Service) or for academic research (gathered at University College London and the University of York). Parents of the children participating in research studies at the University of York and University College London had provided written informed consent and the studies had been approved by the North West Research Ethics Committee and the Outer North East London Research Ethics Committee of the National Research Ethics Service respectively. The clinical and academic test centres used the same listening tests and similar apparatus.

At the Yorkshire Auditory Implant Service, bilaterally implanted children over four years of age with aided thresholds of 35 dB HL or better from 0.25 to 6 kHz bilaterally were offered spatial listening assessments at one, two and four years after receiving their CI2 as part of their clinical care. Exceptions to this were children who were not using both speech processors, due to technical problems or through choice, or children who were unable to participate in testing due to behavioural or developmental issues. At the University of York and University College London, children with BiCIs were assessed as part of research studies [18–20]. Some children were tested more than once and/or at more than one centre, in which case only the most recent assessment was used in the present analysis. The normally hearing children were all assessed at either the University of York or University College London and were a sub-set of the children whose results were published by Lovett et al. [19].

Data from the clinical assessments and research studies were pooled. Children who were assessed when they were less than four years old were excluded from the analysis because their results tended to be more variable and several young children failed to complete the assessment. The children with BiCIs were included in the analysis only if they could be categorized into one of the following groups.

Congenital early bilateral: children with congenital profound deafness who received simultaneous or sequential BiCIs at the age of 42 months or younger.

Congenital late bilateral: children with congenital profound deafness who received a unilateral CI1 at the age of 42 months or younger and sequential CI2 after the age of 42 months.

Acquired/progressive: children who, until the age of at least 42 months, had either normal hearing or a bilateral mild to severe hearing impairment and bilateral acoustic hearing aids. At some time after the age of 42 months these children acquired a bilateral profound hearing impairment or experienced a progression to a bilateral profound hearing impairment. They received simultaneous or sequential bilateral cochlear implants, with both ears implanted after the age of 42 months.

Normal hearing: children with normal hearing.

Profound deafness was defined as a sensorineural hearing impairment with unaided pure-tone thresholds of 90 dB HL or greater at both 2 kHz and 4 kHz. These frequencies represent the current criteria for paediatric cochlear implantation in the UK [21].

2.2. Participant characteristics

The data of 128 children with BiCIs were screened, of whom 80 children met the eligibility criteria and were included in the