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Electrophysiological evidence for altered visual, but not auditory, selective attention in adolescent cochlear implant users

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ABSTRACT

Objective: Selective attention fundamentally alters sensory perception, but little is known about the functioning of attention in individuals who use a cochlear implant. This study aimed to investigate visual and auditory attention in adolescent cochlear implant users.
Methods: Event related potentials were used to investigate the influence of attention on visual and auditory evoked potentials in six cochlear implant users and age-matched normally-hearing children. Participants were presented with streams of alternating visual and auditory stimuli in an oddball paradigm: each modality contained frequently presented 'standard' and infrequent 'deviant' stimuli. Across different blocks attention was directed to either the visual or auditory modality.
Results: For the visual stimuli attention boosted the early N1 potential, but this effect was larger for cochlear implant users. Attention was also associated with a later P3 component for the visual deviant stimulus, but there was no difference between groups in the later attention effects. For the auditory stimuli, attention was associated with a decrease in N1 latency as well as a robust P3 for the deviant tone. Importantly, there was no difference between groups in these auditory attention effects.
Conclusion: The results suggest that basic mechanisms of auditory attention are largely normal in children who are proficient cochlear implant users, but that visual attention may be altered. Ultimately, a better understanding of how selective attention influences sensory perception in cochlear implant users will be important for optimising habilitation strategies.

1. Introduction

The maturation of neural systems is contingent upon sensory experience, particularly during infancy. Alterations to sensory input during developmental 'critical periods', when the brain is rapidly undergoing change, can fundamentally impact the functional organisation of the cortex [1,2]. For example, in the absence of hearing higher-order areas of the auditory cortex can be recruited to process visual information [3–5]. While such cross-modal plasticity may convey a processing advantage for visual information, this re-organisation of the latent auditory system can compromise the hearing restoration benefits provided by a cochlear implant (CI) [6]. In addition to plasticity, however, sensory perception is fundamentally shaped by selective attention. Selective attention refers to neural mechanisms that filter incoming sensory signals, boosting neural and behavioural responses to relevant stimuli and suppressing responses to irrelevant events [7,8]. Moreover, converging evidence suggests that attention also acts to guide plasticity, highlighting which neural circuits should undergo modification [9]. Attention should therefore be critical to learning to use a CI, but little is known about the functioning of selective attention in implant users. Here, we use electroencephalography (EEG) to investigate visual and auditory attention in children with a CI.

Numerous studies have shown that early access to sound is associated with a normalisation of auditory cortical development, as indexed by various EEG components. Sharma and colleagues [10,11] found that early-implanted (<3.5 years old) children's P1 latency quickly decreases to resemble that found in normally-hearing children, while neural responses in later implanted children remain less mature. Indeed, enduring alterations in auditory P1 latencies are observed if implantation occurs after seven years of age ([10–11], for a review see [12]). The outcomes of these studies show that the input provided by an implant is sufficient for normal development of the central auditory system. These observations of normalised neural responses are consistent

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with functional outcomes that have linked earlier implantation with better speech perception abilities (for a review, see [13]). Identifying sensitive periods for auditory development has driven an urgency to implant children at earlier ages, with congenitally deaf infants now receiving prostheses as early as six months of age. When implanted early and given appropriate habilitation and support, CI recipients generally achieve good speech perception abilities in quiet conditions. Nevertheless, social and noisy environments (e.g. school rooms, playgrounds, shopping centres, etc.) can still present perceptual challenges to these children.

Selective attention plays a fundamental role in sensory perception, especially in noisy environments or when stimuli are degraded. Mechanisms of attention allow us to focus on task-relevant sensory information and ignore irrelevant events, and can be deployed voluntarily according to task demands (termed 'top-down' attention) or captured involuntary by highly salient stimuli ('bottom-up' attention) [7]. Deaf individuals (with and without a CI) have been shown to have some enhanced visual skills that are likely the result of both cross-modal plasticity between the visual and auditory system, as well as changes in visual attention [14]. Typically, no differences have been found between hearing and non-hearing groups' in visual acuity, as measured in low-level perceptual tasks that alter contrast sensitivity, motion velocity and sensitivity, brightness and the temporal resolution of stimuli [15–19]. But more consistent between-group differences have been observed under conditions of selective attention and/or processing of peripherally located and salient items [20–22]. These outcomes have been explained in terms of a deafness-induced spatial redistribution of attention to the periphery, which may allow for monitoring the environment in the absence of hearing. Importantly, changes in visual attention may contribute to the known variability in speech perception performance of CI users. For example, it has been shown that auditory word recognition performance in non-proficient CI users (relative to proficient performers and normally hearing individuals) deteriorates in the presence of highly salient and moving visual stimuli [23].

The aim of our study was to determine if visual and auditory attention differentially affects information processing in a group of adolescent CI recipients and age-matched normally-hearing controls. Using event-related potentials (ERPs) we investigate the influence of attention on both early, perceptual processing (the N1 event-related potential) and later more cognitively-related processing of visual and auditory information (P3-related activity). Further, in both modalities responses to frequently occurring 'standard' stimuli and rare and salient 'deviant' events are recorded. Based on evidence that visual perception is altered by deafness, we predicted that while visual and auditory neural responses would be modulated by attention in both groups of children, attentional processes would be enhanced for deviant stimuli in CI users.

2. Materials and methods

2.1. Participants

Participants were 12 children aged between 12 and 17.5 years. Six of these children were CI recipients (three males) with a mean age of 14.45 years (range 12 to 16.9 years, SEM = .82 years) and six were children with normal hearing (NH, two males) that had a mean age of 15.5 years (range 13.9 to 17.5 years, SEM = .53 years). There was no difference between the ages of CI and NH children ($t_{10} = -1.09$, $p = .303$). The procedures of this study were approved by The University of Queensland Medical Research Ethics Committee. Parents provided written informed consent for their children's participation in the experiment.

Children with CIs were recruited from Hear and Say (Auchenflower, Brisbane, Australia), a paediatric auditory-verbal cochlear implant centre. Five children had been diagnosed as having bilateral profound sensorineural hearing loss at birth and another child at 12 months of age. The clinical details of these children are shown in Table 1. The speech perception abilities of CI children were determined from a review of their clinical test results, which included open- and closed-set tests. Speech perception scores were assigned to each child according to the categories of auditory performance index [24], which has nine hierarchic classifications (numbered 0–8). Higher scores reflect better speech perception abilities, with a score of 8 indicating an ability to perceive speech very well through audition alone in both quiet and noisy conditions. For the ear used during the experiment children in the present study had scores of 6, which indicates very good speech perception abilities in quiet conditions (open-set accuracy of $\geq$75%), or 5, which denotes good speech perception abilities in quiet conditions (>50% but <75% accuracy). Children with bilateral cochlear implants were tested using the first implant to be fitted and the other implant was removed, as was any aiding device in the non-implanted ear. For all children speech perception was better in the tested (first implanted) ear (see Table 1). Normally hearing children were recruited through a university newsletter. All parents reported their children as having no cognitive or attentional impairments and to have normal (or corrected-to-normal) visual acuity.

2.2. Stimuli

As shown in Fig. 1, participants were presented with alternate visual and auditory stimuli. For each modality there was a frequently presented 'standard' stimulus and infrequently presented 'deviant' and 'target' stimuli. The visual stimuli had five vertical sinusoidal gratings (3.0° × 2.9°) that were arranged at each corner and in the centre of a grey display (RGB: 128, 128, 128). The corner gratings were located diagonally from the centre grating at 8° of visual angle [as per [20]]. The gratings on the standard

Table 1
Clinical demographics of cochlear implant (CI) users.

Subject	Age (yrs)	Gender	Age at onset of profound deafness (yrs)	Age at implantation (yrs)	CI side	Speech processor	Implant	Speech perception score (L)	Speech perception score (R)
1	13.7	M	Birth	2.1	L + <u>R</u>	Freedom	N24	5	<u>6</u>
2	12	M	1	1.9	L + <u>R</u>	Freedom	N24	4	<u>5</u>
3	16.9	F	Birth	1.7	L + <u>R</u>	Freedom	N22	4	<u>5</u>
4	12.5	M	Birth	1.3	L + <u>R</u>	Freedom	N24	2	<u>6</u>
5	15.6	F	Birth	3.9	R	Freedom	N24	–	6
6	16	F	Birth	2.7	<u>L</u> + R	Freedom	N24	<u>5</u>	2

Note: For children with bilateral CIs the ear tested is underlined, as is the speech perception score for that ear. Speech perception scores are shown for left (L) and right (R) ears and are based on the categories of auditory performance index (for details see Section 2.1). All children used a Cochlear Ltd. implant and processor (type is shown for the ear tested).