Improvements in visual attention in deaf infants and toddlers after cochlear implantation

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DOI: 10.1080/16513860701745401

Publication Frequency: 4 issues per year

Published in: **Audiological Medicine**, Volume **5**, Issue **4** 2007 , pages 242 - 249

Abstract

The aims of this study were to examine the development of visual attention in deaf and hearing infants and toddlers, and assess whether improvements in visual attention were observed in the deaf sample after 12 months of cochlear implantation. A novel puppet task, based on a measure of attention developed with normally hearing infants, was administered to 88 deaf and 42 normal-hearing children at three time points: baseline, six and 12 months post-implantation for the deaf sample. At baseline, deaf children demonstrated significantly more inattentive looks during the puppet skits than hearing children, and these looks were of longer duration, confirming the results of prior studies which have documented deficits in visual attention in deaf children. Longitudinal analyses showed significant decreases in the frequency of inattentive looks for both groups, with a significant decrease in the duration of inattentive looks only for the cochlear implant group. The largest decrease in duration of off-task looks occurred at six months post-implantation, indicating that improvements occurred rapidly after restoration of auditory input. These results provided support for the 'division of labor' hypothesis which suggests that deaf children with no access or limited access to sound must monitor their environment visually, making it difficult for them to focus and attend to specific tasks. Cochlear implantation appeared to alter the developmental trajectory of visual attention in a positive manner. The clinical implications of visual attention for the development of early language, reading and social skills are discussed.

Keywords: visual attention; cochlear implants; auditory information; 'division of labor' hypothesis; brain plasticity

Introduction

Considerable evidence suggests that hearing and seeing are coupled systems in infancy. Early in development, infants with normal hearing look in the direction of sound, look at visual events whose temporal rhythms match what they hear, and process more deeply corresponding sights and sounds **1-3**. Thus, from the earliest stage of development, attention may be driven by multimodal connections **4**. For children who are severely and profoundly deaf, a lack of auditory input may affect their ability to direct, engage and disengage visual attention **5-7**. In contrast, previous studies have also noted that deaf children differ in their use of visual information, showing enhanced visual memory **8** and improved perception at the periphery of the visual field **9**. This has led some researchers to propose that there is significant cross-modal plasticity between the visual and auditory systems that could lead to improved visual attention in deaf individuals. The purpose of this

study was to evaluate visual attention in very young deaf infants and toddlers both before and 12 months after cochlear implantation.

The current study follows a series of experiments documenting deficits in visual attention in deaf children. Previous studies used a standardized, continuous performance task (CPT) that involved no sound to compare the performance of deaf and hearing children aged five to 13 years **5**, **6**. In this CPT task, children were presented with a continuous stream of numbers and were asked to press a button whenever a sequence of two digits ('1' then '9') occurred in succession **5**. This study provided the first experimental evidence that deaf children performed more poorly on a visual attention task than age-matched hearing children, and further, that older deaf children using cochlear implants (CI) performed better than older deaf children using hearing aids **5**. In a small, longitudinal study of deaf children using either cochlear implants (CIs) or hearing aids, performance on the CPT was assessed over an average of 18 months. Children in the CI group demonstrated improved performance, while those in the hearing aid group did not. These results were surprising and led to additional studies aimed at explaining the role that auditory input may play in the development of visual attention.

In a second study, we examined attention problems in deaf children more generally, evaluating performance on the CPT, as well as parent- and teacher-reported behavior problems on a standardized behavior checklist **10**. A large number of studies has documented elevations in behavior problems in deaf children, particularly those related to behavioral regulation **11**, **12**. The CPT consisted of three visual tasks, assessing: 1) sustained attention to the stimuli appearing on the screen; 2) selective attention and ability to discriminate targets from non-targets; and 3) distractibility as measured by the ability to inhibit responses to irrelevant information.

As hypothesized, hearing-impaired children performed more poorly across all three visual attention tasks, with an average of 71% scoring in the abnormal range of performance compared to 9% in the hearing group. After controlling for socioeconomic status and sex, significant differences were found in two of the three visual attention tasks (i.e. no group differences were found in the sustained attention task), with hearing status accounting for substantial proportions of the variance in performance (18-38%). Furthermore, nearly 50% of parents rated their hearing-impaired children as having clinically elevated hyperactive and externalizing behavior problems and one-third of teachers provided similar ratings. Significant associations were also found between performance on the CPT and parent- and teacher-reported behavior problems, with worse attention scores on the CPT correlated with higher ratings of behavior problems. These results indicated that visual attention, as measured on a CPT task, was related to clinically relevant behaviors that could be observed by both parents and teachers. This is significant given studies showing that deaf children are at greater risk for behavior problems **11**, **12**, such as impulsivity, distractability, and short attention spans **13**, **14**.

The third study replicated our earlier findings in a larger sample of deaf and hearing children (*n*=153). The CI group appeared to 'catch up' to the performance of their hearing peers on the CPT task between ages eight and 13 years **6**. Furthermore, children in the CI group who performed better over time on the CPT task were also rated by their parents as paying more attention to environmental sounds.

This series of studies led us to conclude that sound may be an enabling condition for the development of visual attention, and that typically developing children are advantaged in this developmental process. This may be related to the ability of hearing children to use auditory input to monitor the environment for new events, while using vision to focus on specific tasks. Thus, for hearing children, auditory information may serve as a 'signal' to shift their vision when needed. In contrast, children with severe to profound sensorineural hearing loss cannot use auditory cues to monitor the environment and must instead use their visual attention to both scan their surroundings and focus on the task at hand **6**. This 'division of labor' hypothesis **6**, **15-17** was proposed to explain the poorer performance of hearing-impaired children on tasks that assessed visual attention. The purpose of the current study was to test this hypothesis in a large sample of deaf infants and toddlers, who later received cochlear implants, and an age-matched hearing control group.

Evidence for the 'division of labor' hypothesis can also be found in the adult literature. Studies indicate that hearing-impaired adults possess superior visual attention in the periphery of the eye-field compared to hearing controls **18-22**. Although the mechanisms underlying these advantages are unclear, the findings are congruent with the hypothesis currently being tested. If prelingually deaf children rely on visual attention to both monitor their environment and focus on tasks, then over time this practice may facilitate the development of enhanced attention to stimuli in the periphery of their visual field.

To date, visual attention has not been studied in hearing-impaired infants and toddlers. The Childhood Development after

Cochlear Implantation (CDaCI) study is the first to address visual attention in such a young cohort. This study also allows for a powerful test of the 'division of labor' hypothesis, because a large and geographically diverse sample of children was assessed both before and after cochlear implantation. Given the young age of the children in this study, we used an innovative puppet task that was designed to assess visual attention in infants and toddlers, aged five to 36 months. This task was utilized to test three hypotheses related to the 'division of labor' hypothesis. First, young hearing-impaired children were expected to scan their environments more frequently than age-matched, normal-hearing children. Secondly, each scan of the environment was expected to be longer in duration for hearing-impaired than normal-hearing children. Finally, after receiving a cochlear implant, the frequency and duration of time scanning the environment was expected to decrease and more closely approximate the behaviors of normal-hearing children.

Method

The Childhood Development after Cochlear Implantation (CDaCI) study is a multicenter, national cohort study of the effectiveness of paediatric cochlear implants (CIs). Participants were recruited from six clinical implant centers and two preschools that enrolled normal-hearing (NH) children **23**.

Participants

Inclusion criteria for children in the CDaCI study were: 1) age under five years; 2) severe to profound sensorineural hearing loss (CI only); and 3) parents committed to educating the child in spoken English. Exclusion criteria included cognitive impairment (i.e. a Bayley Mental or Motor score of less than 70 or Leiter International Performance Scale - Revised score of less than 66 **24**, **25**.**1** NH controls were matched to the CI children based on age and gender. The full CDaCI cohort consists of 188 deaf children receiving CI and 97 NH children. All participants were assessed at baseline (prior to implantation for the CI group) and every six months (from point of activation for the CI group) for three years. Institutional review boards for all centers approved the study protocol. A more detailed description of the full cohort is reported elsewhere **23**.

This study used a subset of the full cohort, including only children who were aged three years and younger at 12 months post-implantation, because this was the age range for which the visual attention task was designed. The subset consisted of 88 CI and 42 NH children. No significant differences were found between the groups in gender, race or ethnicity (see **Table I**). The CI and NH groups did differ on child age, parent education, and household income. Children in the CI group were slightly younger, fewer parents in the CI group had completed college, and their household income was lower. This subset of children did not differ significantly from the full cohort in terms of gender, race, ethnicity,e or caregiver education; however, they did differ from the full cohort on household income (χ^2 (7) = 16.61, p=0.02), evidencing more evenly distributed incomes than those found in the larger CDaCI cohort **23**.

Table I. Demographics of children three years or younger at 12 months post-implantation.

Characteristic		Normal hearing (*n*=42)	Cochlear implant (*n*=88)
Age (years)	Mean age (SD)	1.37 (.36)	1.16 (.34)
Gender% (*n*)	Male	37% (15)	56% (49)
	Female	63% (26)	44% (39)
Race	White	78% (32)	78% (67)
	African-American	17% (7)	8% (7)
	Asian	2% (1)	2% (2)
Ethnicity	Hispanic	7% (3)	16% (14)
	Non-Hispanic	93% (38)	84% (73)
Parents' education**	<High school	3% (1)	2% (2)
	High school grad	10% (4)	44% (39)
	College	88% (35)	53% (47)
Parents' Income**	<$15,000	0% (0)	3% (3)
	$15-29,999	7% (3)	14% (12)
	$30-49,999	0% (0)	19% (17)
	$50-74,999	20% (8)	18% (16)
	$75-100,000	12% (5)	21% (18)
	$100,000 +	51% (21)	16% (14)