In Children with Profound Bilateral Hearing Impairment, is Sound Localization for Bilateral Cochlear Implant Users Better Than for Those Who Do Not Receive a Second Implant?

Tracy Saunders, M.Cl.Sc. (Aud) Candidate
University of Western Ontario: School of Communication Sciences and Disorders

This critical review examines the sound localization abilities of children with profound bilateral hearing impairment using two cochlear implants and compares these abilities to children who are using only one. Study designs are all case-control studies. Overall, research supports the inclusion of a second cochlear implant to optimize sound localization abilities. It is not yet certain how age at implantation, order of implantation (i.e. simultaneous vs. sequential), and time since implantation (i.e. 2 months vs. 2 years) individually influence sound localization abilities.

Introduction

In recent years, hearing researchers have exerted great effort to determine whether two cochlear implants (CIs) are better than one. At the onset of this investigation, it is likely that researchers looked to the myriad of hearing aid studies which have also compared bilateral to unilateral use. Even though CIs and hearing aids use vastly different technologies, it is reasonable to assume both investigations might assume a similar research approach. The early bilateral hearing aid studies focused their measurements on improved hearing in noise, sound quality, and sound localization. Not surprisingly, bilateral CI research followed suit and has studied these same parameters. This critical review will examine the third aforementioned parameter, sound localization, in children who are bilateral CI users.

Sound localization refers to a person's ability to detect the source of a sound. In the most basic part of this process, humans use interaural level differences (ILDs) and interaural timing differences (ITDs). These cues aid in localizing the sound source's position on the horizontal plane. One method for measuring azimuthal sound localization ability involves calculating a minimum audible angle (MAA). In this procedure, the smallest angle difference between two sound sources that can be reliably discriminated is found. It is important to mention that ITDs and ILDs do not lend any information about the elevation of a sound source. This requires the more sophisticated spectral filtering of the torso, head, and outer ear (modeled by the Head Related Transfer Function).

As noted earlier, binaural hearing aid and binaural CI research have followed similar paths. However, there are some important differences that must not be overlooked. Any science supporting the use of bilateral CIs must carefully consider risk; both surgical and financial. Surely, bilateral hearing aid use is much less affected by these physical and monetary burdens. One might argue that the benefit of bilateral cochlear implantation will only be fully acknowledged once it is found to outweigh any and all associated risks. As such, a detailed look at several aspects of bilateral CI use is warranted. This critical review will discuss one of these aspects: namely, sound localization.

Objectives

The primary objective of this research is to critically evaluate existing literature regarding sound localization ability of children with bilateral CIs. To assess benefit, results will be compared with children who are unilateral implant users.

Methods

<u>Search Strategy</u>
Computerized databases, including PubMed and CINAHL, were searched using the following search strategy: (Bilateral Cochlear Implant*) AND (Localization).

<u>Selection Criteria</u>
Studies selected for inclusion in this critical review were required to compare sound localization abilities in bilateral and unilateral conditions among a pediatric population. Parameters were included to limit search results to English only articles with humans less than 18 years old.

<u>Data Collection</u>
Results of the literature search yielded three case control studies congruent with the aforementioned selection criteria.

Results and Discussion

Three studies will be discussed in this critical review. Each study included children of different age groups.

This review will begin with the study which included the oldest children first, and then proceed to the younger groups next.

Case Control Study One

Litovsky et al. (2006) evaluated a group of 13 children, aged 3 to 16 years, with bilateral CIs at various intervals after receiving their second implant. The cause of deafness varied for the children and all were implanted sequentially. Time between first and second implant ranged anywhere from 1 to 12 years. At the study's commencement, 2 to 14 months had passed since the second CI was activated.

Sound localization ability was measured using a minimum audible angle procedure. Testing was conducted in a sound-treated booth, in which subjects sat at a table facing an array of 15 speakers, arranged in a semicircular arc with a radius of 1.5m, and positioned at 10° intervals
(-70° to +70°).

For each test block, two loudspeakers were selected at equal right and left angles and remained fixed for 20 trials. Children played a “listening game” whereby they were required to answer whether a spondaic word was presented from the right or left side (2-alternative forced choice). Stimulus levels averaged 60dB SPL and roved ± 4dB. After blocks in which the child scored ≥75% (15/20), the angle was decreased and otherwise, the angle was increased. This follows a multi interval 1-up/1-down adaptive procedure. The amount of angular increase or decrease was determined following the Parameter Estimation by Sequential Testing (PEST) procedure.

MAA thresholds for each listening mode and every subject were defined as the smallest angle at which performance reached 70.9%. Children were tested under two conditions: (1) with both their CIs turned on and (2) with only their first CI turned on. (First refers to the order in which the implant was received.)

Results suggested that MAA thresholds were significantly lower in children when they received bilateral as compared with unilateral stimulation. In the bilateral mode, the MAA thresholds of the children ranged from 5° to 40°. The unilateral condition elicited thresholds ranging from 15° to 60°.

A limitation of this study lies in the formation of the unilateral group, whereby children who were bilateral cochlear implant users were asked to remove one of their implants. It is likely that this method was chosen to maximize internal validity. However, having children who are accustomed to bilateral use, perform a task in the unfamiliar unilateral mode may put them in a disadvantaged situation. As such, the unilateral condition may have been biased. (Since this study, the author has recognized this limitation and has begun using a separate unilaterally implanted group to compare unilateral versus bilateral effects.)

Case Control Study Two

Beijen et al. (2008) investigated sound localization abilities in young children with bilateral cochlear implants. Recognizing the limitation of having a bilateral CI user remove one implant for testing (discussed above), a separate control group was selected instead.

Five bilaterally CI children (mean age of 3 years 7 months), most of whom were implanted simultaneously, were compared with five unilaterally implanted children (mean age 5 years 3 months). Meningitis was the cause of deafness in all ten of the children. Each child had a minimum of 11 months experience with their cochlear implant(s).

As in the previously discussed study, sound localization ability was measured by asking children to determine the correct (right or left) origin of a sound source. Rather than having 15 loudspeakers arranged around a semicircular arc, this study used 4 fixed speaker positions (±90° and ±30°). The stimulus used was a prerecorded melody band that resembled a familiar children's song and was presented at a fixed level of 65dB.

When the stimulus was presented from ±90°, the children in the bilateral group scored significantly higher than the unilateral group (96% vs. 37%, $p<0.01$). With a reduction of the stimulus separation to ±30°, the bilateral group still achieved significant higher performance scores (92% vs. 40%, $p<0.01$).

In sound localization tasks, the use of fixed stimulus levels is typically avoided. Instead, many researchers will use a roved signal to reduce the monaural level cues available at each ear. Beijen et al. (2008) should have, but did not, discuss their reasons for using a fixed, rather than a roved signal.

Case Control Study Three

The last study to be discussed includes the youngest group of all. Grieco-Calub et al. (2008) compared the sound localization ability of 10 bilaterally implanted toddlers to those of eight who used unilateral implants.

The bilateral group ranged in age from 26.5 to 34.5 months and had a minimum of five months experience with their second CI at the time of testing. Only one child was implanted sequentially.

The study's experimental procedure was similar to that used by Litovsky et al. (2006). Minimum audible angles were measured, but rather than keeping the speaker position fixed for 20 trials, adjustments were made after every trial following a 3-up/1-down adaptive procedure (single interval). The amount of angular increase or decrease was determined following the PEST procedure.

The children in this study were too young to provide right/left answers as part of the standard MAA procedure. Therefore, an observer-based psychophysical procedure was use. Here, an observer assessed the toddler's behavioral response following the stimuli presentation and chose whether the source had been from the right or left (2-alternative forced choice). Additionally, two side monitors provided video reinforcement for the toddlers. Such a procedure has proven to be accurate in measures of infant psychoacoustics and auditory sensitivity (Olsho et al., 1987). As such, it is reasonable to assume this method's suitability in measuring sound localization abilities as well.

MAA threshold was defined as the smallest difference in angle between two sound sources that was reliably discriminated through 80% of the trials. Results from this study suggest that localization abilities were emerging in half (n=5) of the children who use bilateral CIs. Three of these children showed scores that approached age-appropriate performance. The other half of this group never scored above 80% correct, even at the largest angle separation (70°). None of the eight children with unilateral CIs could perform the task above chance.

This study used stimulus presentation levels that were both fixed and roved. This was done to investigate its effect on performance in children with bilateral CIs. As discussed previously, roving a signal is common practice in tests of sound localization.

The authors were surprised to find that three of the five bilaterally implanted children had worse MAA thresholds in the fixed stimulus condition. Considering fixed stimulus levels provide additional monaural cues, better MAA thresholds were expected. The authors made a minor attempt to explain these findings however in doing so, they failed to mention the order in which the fixed and roved stimuli were presented. If, for instance, the fixed stimulus always preceded the roved condition, there would be a considerate opportunity for learning.

Conclusion

Despite multiple differences between the three studies (unilateral condition, subject demographics, roved vs. fixed stimuli, etc.), all of the results suggest that, when it comes to sound localization, two CIs are better than one. Having said this, one may ask whether sound localization abilities in children with bilateral CIs ever approach those of their normal-hearing peers.

MAA thresholds for children without any hearing impairment are 12 to 19° at six months (Ashmead et al., 1987), 4 to 6° at 18 months, and reach 1 to 2° by five years of age (Litovsky, 1997). Once normal-hearing children are five years of age, their MAAs are not significantly different from those of the adult population (Litovsky, 1997).

In all of the studies discussed, not one child ever reached an MAA value that would be considered age-appropriate. As shown in Figure 1, the measured thresholds ranged from 5 to 40° and 20 to 42° in studies one and three, respectively. Study 2 did not calculate MAA values, but their data can be used to derive thresholds of 30° or lower for all bilateral CI users.

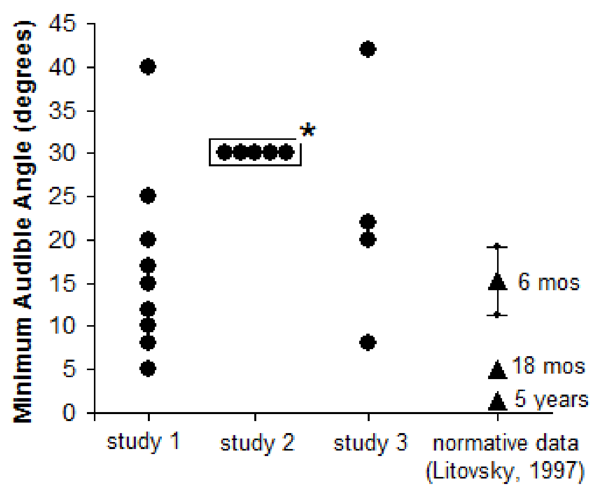

Fig.1. Minimum audible angles (MAA) for children using bilateral CIs. All children from study 2 scored a minimum of 80% correct at an angular separation of 30° and therefore their MAAs would be that threshold or lower. (Angles less than 30° were not investigated in this study.) Normative data are included for comparative purposes.

In conclusion, pediatric CI studies have shown that sound localization abilities are improved by using bilateral instead of unilateral stimulation. These findings accompany a growing body of knowledge which exists in support of bilateral cochlear implantation.

Recommendations

Even though many of the "two versus one CI" questions have now been answered, there is still a great deal of work to be done. In the realm of sound localization, research is warranted to determine whether children with bilateral CIs ever achieve the ability level of their normal-hearing peers. What exactly is the time course that sound localization abilities follow in children with bilateral CIs? What are the consequences for these children if they never develop "normal" sound localization? As bilateral CI research continues, it is imperative for these sound localization questions to be answered.

References

Ashmead, D.H., Clifton, R.K., & Perris, E.E. (1987). Precision of auditory localization in human infants. *Developmental Psychology, 23,* 641-647.

Beijen, J.W., Snike, F.M., & Mylanus, E.A. (2007). Sound localization ability of young children with bilateral cochlear implants. *Otology and Neurology, 28,* 479-485.

Grieco-Calub, T.M., Litovsky, R.Y., & Werner, L.A. (2008). Using the observer-based psychophysical procedure to assess sound localization acuity in toddlers who use bilateral cochlear implants. *Otology and Neurology, 29*, 235-239.

Litovsky, R.Y. (1997). Developmental changes in the precedence effect: estimates of minimum audible angle. *Journal of the Acoustical Society of America, 96,* 752-758.

Litovsky, R.Y., Johnstone, P.M., Godar, S., Agrawal, S., Parkinson, A., Peters, R., et al. (2006). Bilateral cochlear implants in children: localization acuity measured with minimum audible angle. *Ear and Hearing, 27,* 43-59.