Results in Individuals with Asymmetric Hearing Loss Using a Cochlear Implant and a Hearing Aid

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Abstract

Traditionally, cochlear implant (CI) recipients have had bilateral moderate-to-profound, severe, or profound hearing loss. Individuals with asymmetric hearing loss, who have at least a moderate-to-profound hearing loss in one ear but better hearing in the opposite ear, have not routinely been implanted because of their better hearing ear. Often these individuals do not benefit from amplification in the poorer hearing ear and have become unilateral listeners. Listening with just one ear presents many challenges in everyday communication. The overall goal of our research is to evaluate behavioral outcomes in individuals who have asymmetric hearing loss and receive a CI in the poorer hearing ear. To date, the findings explore a current clinical question in adults and children; that is, whether CI candidacy criteria should be expanded in cases of asymmetric hearing loss to include treatment of the poorer ear. In this chapter, we summarize three recent studies in adults and children with asymmetric hearing loss using measures of speech recognition, localization and hearing handicap.

Sound stimulation is necessary for normal development and function of the central auditory system. In animal models and humans, hearing loss affects the representation of sound to the central auditory system (Kral, 2013). The consequences of hearing loss depend, in part, on a combination of whether the loss is bilateral or unilateral and whether the degree is total or partial. In animals with congenital bilateral severe-to-profound hearing loss (SPHL), abnormalities occur that extend from the auditory nerve (Ryugo, Pongstaporn, Huchton, & Niparko, 1997; Ryugo, Rosenbaum, Kim, Niparko, & Saada, 1998) to the auditory cortex (Kral, Hartmann, Tillein, Heid, & Klinke, 2000). In humans, there are clear functional implications related to outcomes when the hearing loss is congenital, bilateral and severe to profound in degree. Treatment of SPHL with cochlear implantation in one or both ears has been well studied and several factors that are critical to successful outcomes have been identified. For example, age at implantation for children with congenital hearing loss is an important variable that affects communication function; the younger the child is at the time of implantation, the better the results (Nicholas & Geers, 2006, 2007). Likewise in adults, length of deafness is significantly correlated with speech recognition results (Blamey et al., 2013; Holden et al., 2013); the shorter the duration of deafness the better the outcomes.

Less is known, however, about unilateral or partial auditory deprivation. In the visual system in animals, unilateral deprivation early in life resulted in permanent impairment of binocular vision (Hubel & Wiesel, 1970). In the auditory system, animal studies have shown that when hearing loss was bilateral, the neural projections between the two sides of the pathway maintain a balance, although activity was reduced (Silverman & Clopton, 1977). Additionally, there was less effect on binaural interactions compared to monaural deprivation. In the latter case, a greater loss of binaural neural activity and a greater alteration of binaural interactions occurred than with bilateral deprivation.

Unilateral hearing loss (UHL) induces central auditory system reorganization in ways that differ from bilateral hearing loss. Typically stimulation of the intact ear in cases of UHL results in a change to the balance of hemispheric activity in the auditory cortex. Normally, stimulation creates an asymmetric activation pattern where one hemisphere (often the left) shows greater activation than the other hemisphere. With UHL, there is an increase in activity ipsilateral to the intact ear, resulting in symmetric hemispheric patterns rather than asymmetric (Burton, Firszt, Holden, Agato, & Uchanski,

2012; Khosla et al., 2003; Maslin, Munro, & El-Deredy, 2013). Changes to the balance of activity are thought to modify binaural interactions and auditory system structures.

Traditionally, cochlear implant (CI) recipients have had moderate-to-profound, severe, or profound hearing loss in both ears. Individuals with asymmetric hearing loss, that is at least moderate-to-profound hearing loss in one ear and better hearing in the other ear, have not routinely been implanted because of their better hearing ear. Often these individuals discontinue amplification in the poorer hearing ear due to lack of benefit. In other words, they become unilateral listeners. Listening with just one ear results in poor speech understanding in noise in self-report studies (McLeod, Upfold, & Taylor, 2008; Wie, Pripp, & Tvete, 2010), the inability to localize sound (Abel, Alberti, Haythornthwaite, & Riko, 1982; Humes, Allen, & Bess, 1980), problems understanding when speech is directed toward the poorer ear (Giolas & Wark, 1967), and increased listening effort (Feuerstein, 1992) even when the better ear has normal hearing. Individuals with asymmetric hearing loss, as described here, are at an even greater disadvantage, because their better hearing ear does not have normal hearing.

Several studies are underway at Washington University School of Medicine in St. Louis and St. Louis Children's Hospital to study the effects of hearing asymmetry. The overall goal of our research is to evaluate behavioral outcomes in individuals who have asymmetric hearing loss between ears and receive a CI in the poorer hearing ear. The findings to date explore a current clinical question in adults and children, that is, whether CI candidacy criteria should be expanded in cases of asymmetric hearing loss to include treatment of the poorer ear that has at least moderate-to-profound or severe hearing loss. In the following pages, we summarize three recent studies in adults and children with asymmetric hearing loss using measures of speech recognition, localization and hearing handicap.

Study 1: Asymmetric Hearing Loss – Adults

Ten adults with asymmetric hearing loss (one ear meeting CI candidacy criteria and the other ear with better hearing) were evaluated pre-implant and at six months post-implant. Participants were 26 to 82 years of age. Onset of SPHL was postlingual for seven participants and pre/perilingual for three participants. All except one pre/perilingual participant had long-term hearing aid

(HA) use in the better hearing ear and all except one postlingual participant had discontinued or never worn a HA in the poorer hearing ear. The test protocol was designed to incorporate measures and conditions that simulated real-life listening challenges (e.g., background noise, varied speaker locations, different loudness levels, and multiple talkers).

Speech recognition measures and presentation levels were as follows: the Consonant-Vowel nucleus-Consonant test (CNC, Peterson & Lehiste, 1962) at 60 dB SPL, the Hearing In Noise Test (HINT, Nilsson, Soli, & Sullivan, 1994) at 60 dB SPL in the presence of four-talker babble (4TB) at a +8 dB signal-to-noise ratio (SNR), TIMIT sentences (Dorman, Spahr, Loizou, Dana, & Schmidt, 2005; King, Firszt, Reeder, Holden, & Strube, 2012; Lamel, Kassel, & Seneff, 1986) at 60 dB SPL with 4TB at a +8 dB SNR, and TIMIT sentences at 50 dB SPL in quiet. For these measures the sentences and noise (when used) were presented from zero degrees azimuth. HINT sentences were also presented in the R-Space laboratory sound system (Compton-Conley, Neuman, Killion, & Levitt, 2004; Revit, Schulein, & Julsrom, 2002) that uses eight loudspeakers surrounding the listener. For this measure restaurant noise was presented at 60 dB SPL from all eight loudspeakers and the sentences were presented from zero degrees azimuth; sentence level was adjusted adaptively based on the participants' responses to obtain an SNR for 50% accuracy.

Localization was evaluated using 100 monosyllabic words presented pseudo-randomly from a 15 loudspeaker array (10 active and five inactive unbeknownst to the participant) at a roved 60 dB SPL (± 3 dB). The loudspeakers were arranged in a 140 degree arc in front of the participant, each 10 degrees apart. A root mean square (RMS) error was calculated based on participant responses. Additionally, a self-assessment of perceived communication function, the Speech Spatial and Qualities of Hearing Scale (SSQ, Gatehouse & Noble, 2004), was completed at each interval.

Figure 1 shows mean results for the postlingual group and the four fixed-level speech recognition measures. Pre-implant results are shown for the poorer hearing ear (with the participant's or a clinic HA) in black, the better hearing ear (aided) in white, and the everyday listening condition (HA in the better ear for all participants except one, whose everyday listening condition was HAs in both ears) in gray. Post-implant results are shown for the poorer hearing ear with the CI in black, the better hearing ear (aided) in white, and the bimodal condition (CI plus HA) in gray. For adults with postlingual

hearing loss, group mean results indicated significant open-set speech recognition in the implanted ear after six months for measures in quiet and noise. Furthermore, significant improvements in speech recognition and localization (see Figure 6 in Firszt et al., 2012 for localization results) were observed when comparing the 6-month bimodal condition to the pre-implant, everyday listening condition. For sentences at a soft level in quiet and localization the post-implant bimodal condition was significantly better than the better ear HA-alone condition.

For adults with prelingual hearing loss, speech recognition was limited in the CI-alone condition for words and sentences in quiet and sentences in noise. Figure 2 shows study results for the adaptive measure in the R-Space for the three pre/perilingual participants. For
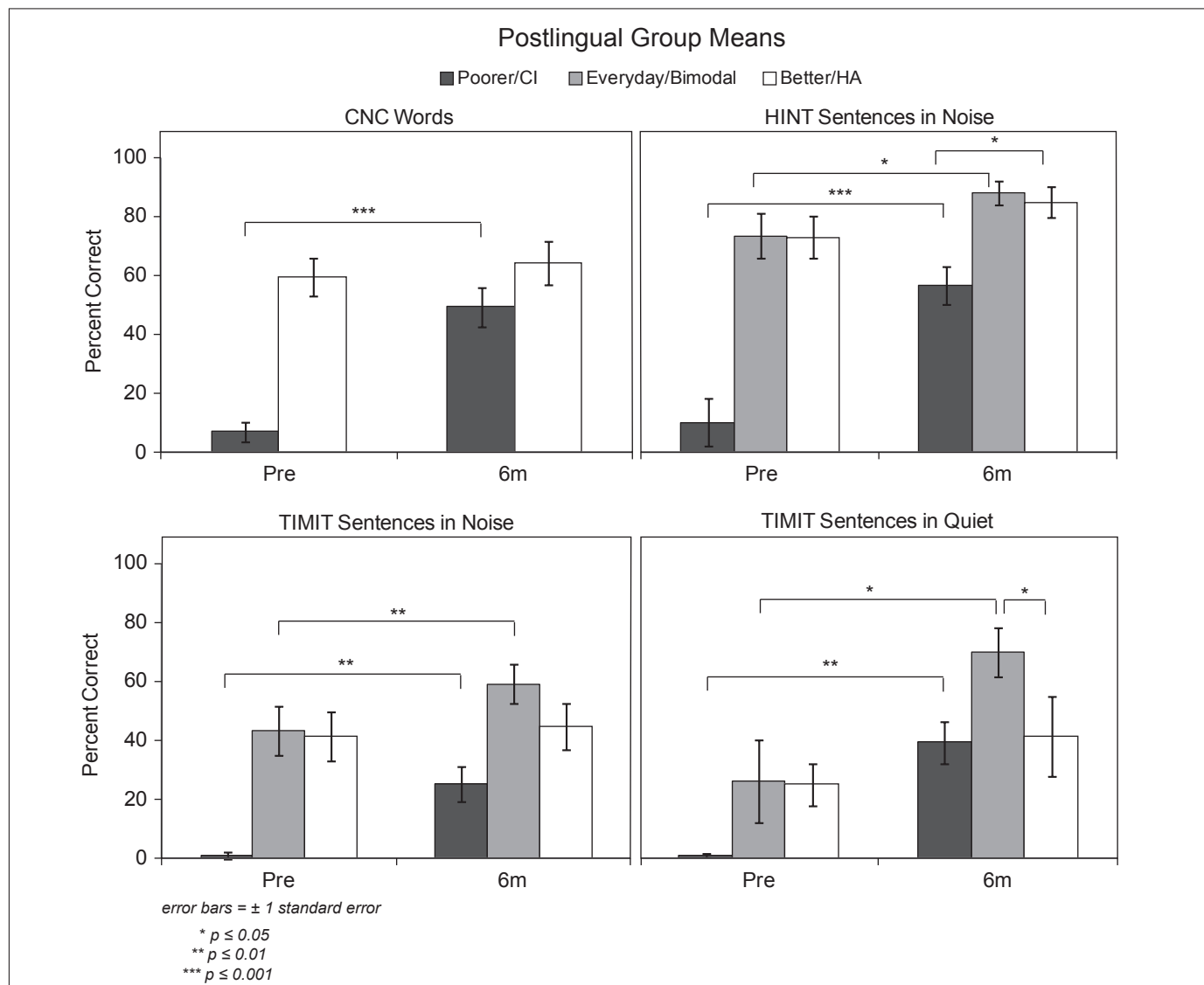

Figure 1. Group mean speech recognition scores (CNC words, HINT sentences in noise, TIMIT sentences in noise, and TIMIT sentences in quiet) pre-implant and at 6 month post-implant are shown for the seven postlin¬gual participants. Scores are shown in black for the poorer-hearing ear that was implanted, in white for the better-hearing ear with a HA, and in gray for the participants' everyday listening condition (bimodal at the postimplant interval). HINT, hearing in noise test; CNC, consonant-vowel nucleus-consonant; HA, hearing aid. (Reprinted with permission from Lippincott Williams and Wilkins/Wolters Kluwer Health: Firszt et al. 2012, Cochlear Implantation in Adults with Asymmetric Hearing Loss, (33)4, p. 526. Promotional and commercial use of the material in print, digital or mobile device format is prohibited without the permission from the publisher Lippincott Williams & Wilkins.)

this measure of SNR, lower scores indicate better performance. None of the pre/perilingual participants were able to understand sentences in the presence of restaurant noise (thus they were given a score at the greatest SNR, +22, since they were unable to do the task). Across measures and pre/perilingual participants, very few bimodal benefits were seen compared to the HA-alone condition. Localization abilities also were not significantly improved bimodally over the HA-alone condition for the pre/perilingual participants.

For all participants, including the pre/perilingual participants without documented bimodal benefit, mean questionnaire ratings indicated improved perceived communication function at six months post-implant compared

Figure 2. Adaptive HINT scores in restaurant noise at the 6 mo interval for pre/perilingual participants are shown. Scores are expressed as SNR and are shown in black for the poorer-hearing ear that was implanted, in white for the better-hearing ear with a HA, and in gray for the participants' everyday listening condition (bimodal at the postimplant interval). HINT, hearing in noise test; SNR, signal to noise ratio; HA, hearing aid. (Reprinted with permission from Lippincott Williams and Wilkins/Wolters Kluwer Health: Firszt et al. 2012, Cochlear Implantation in Adults with Asymmetric Hearing Loss, Vol 33, 4, p. 528. Promotional and commercial use of the material in print, digital or mobile device format is prohibited without the permission from the publisher Lippincott Williams & Wilkins.)

to pre-implant. In summary, distinct patterns were observed for adults with postlingual versus pre/perilingual hearing loss. All postlingual adults had CI-alone speech recognition even when there was a prolonged period of deafness and no HA use. In contrast, pre/perilingual adults had minimal to no CI-alone speech recognition. Age at onset of hearing loss in childhood appears to be

a significant factor, despite substantial hearing levels in the non-implanted better ear.

Study 2: Varied Forms of Asymmetric Hearing – Adults

Three adult patient groups who were unilateral listeners with varied hearing modes were compared on the SSQ. The first group (UHL group; n = 30) had normal hearing in one ear and SPHL in the other ear. The second group (CI group; n = 20) had a CI in one ear and SPHL in the other ear. The third group (HA group; n = 16) used a HA in one ear and had SPHL in the other ear. In addition, participants of similar age with normal hearing bilaterally completed the SSQ (NH group; n = 21). The SSQ consists of 49 items that have respondents indicate their level of hearing ability/disability along a 10-point scale for each item; 10 indicates the greatest ability and 0 the greatest disability. Results were analyzed by domain (Gatehouse & Noble, 2004) and subscale (Gatehouse & Akeroyd, 2006). The three SSQ domains are Speech (14 items), Spatial (17 items) and Quality (19 items). Gatehouse & Akeroyd (2006) subdivided the domains into 10 subscales to provide greater detail when describing respondents' communication function. Subscales of the Speech domain were Speech in Quiet (SiQ), Speech in Noise (SiN), Speech in Speech Contexts (SiSCont), and Multiple Speech Stream Processing and Switching (MultStream). Subscales of the Spatial domain were Localization (Loc), and Distance and Movement (DisMov). Subscales of the Qualities domain were Segregation of Sounds (SegSnds), Identification of Sound and Objects (IdSnd), Sound Quality and Naturalness (Qlty), and Listening Effort (Eff).

Figure 3 shows mean responses by domain and subscale for each of the participant groups, Speech domain in panel A, Spatial domain in panel B and Qualities domain in panel C. Responses are shown for the NH group in white, the UHL group in black, the CI group in dark gray, and the HA group in light gray. The NH group responses were significantly better than each of the three hearing-impaired groups for all subscales and domains. No matter the mode of hearing, all unilateral listening groups, even the UHL group with a normal hearing ear, perceived significant communication challenges in all areas addressed by the SSQ. Comparison of the three hearing-impaired groups identified few significant differences. The UHL group rated themselves significantly higher than the HA group for the Speech domain and four subscales (SiQ, SiSCont, IdSnd, and Qlty). The only
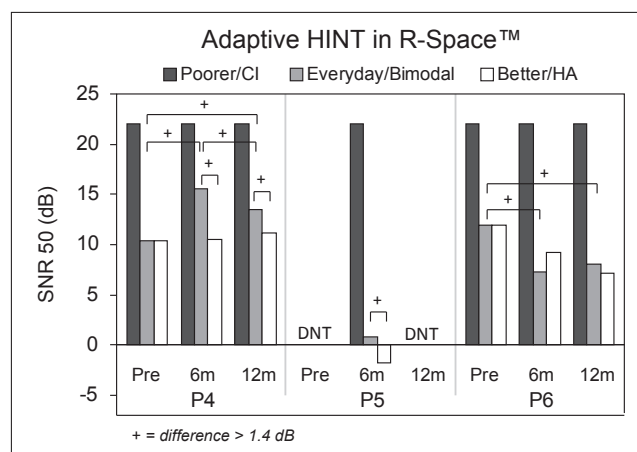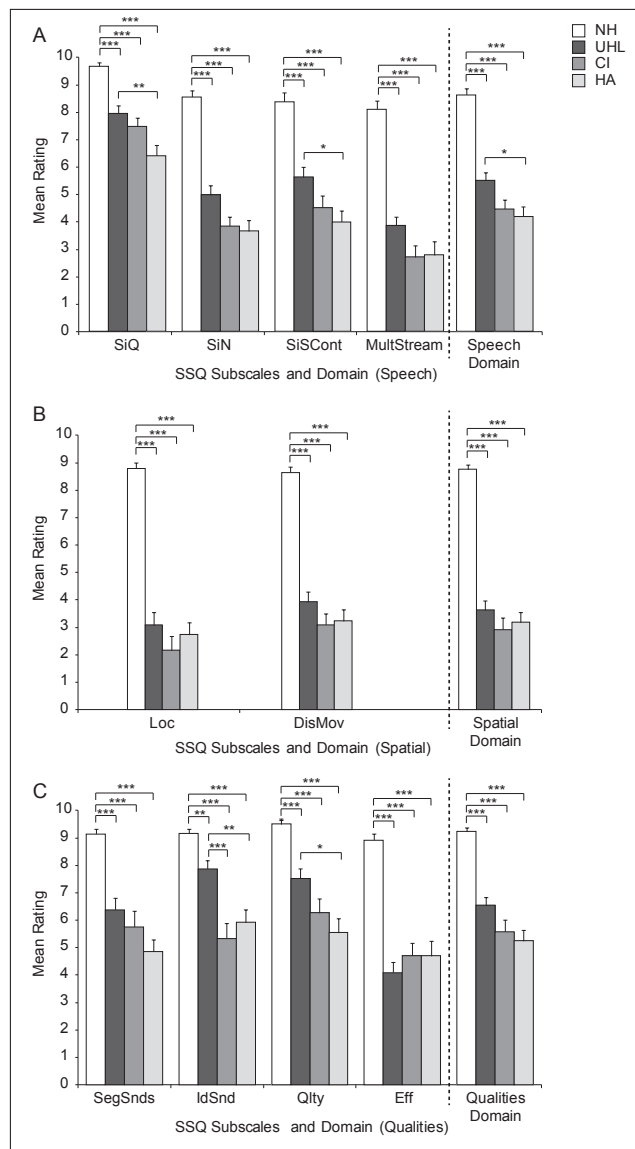
Figure 3. Group mean ratings are shown for subscales and domains (top panel Speech, middle panel Spatial, lower panel Qualities) for participants with NH, UHL, a CI, and an HA. Error bars represent standard error. Brackets and asterisks denote significant comparisons, ***p < 0.001, **p < 0.01, *p < 0.05. CI indicates cochlear implant; DisMov, Distance and Movement; Eff, Listening Effort; HA, hearing aid; IdSnd, Identification of Sound and Objects; Loc, Localization; MultStream, Multiple Speech Stream Processing and Switching; NH, normal hearing; Qlty, Sound Quality and Naturalness; SegSnds, Segregation of Sounds; SiQ, Speech in Quiet, SiN, Speech in Noise; SiSCont, Speech in Speech Contexts; SSQ, Speech, Spatial and Qualities of Hearing scale; UHL, unilateral hearing loss. (Reprinted with permission from Lippincott Williams and Wilkins/Wolters Kluwer Health: Dwyer et al. 2014, Effects of Unilateral Input and Mode of Hearing in the Better Ear: Self-reported Performance Using the Speech, Spatial and Qualities of Hearing Scale, (35)1, p. 131. Promotional and commercial use of the material in print, digital or mobile device format is prohibited without the permission from the publisher Lippincott Williams & Wilkins.)

statistically different rating between the UHL and CI groups was for IdSnd.

Overall, the results highlight the similarity in perceived ability among these three unilateral listening groups in spite of seemingly very different modes of hearing. For two domains (Spatial and Qualities) and for six subscales (SiN, MultiStream, Loc, DisMov, SegSnds and Eff) there were no significant differences in how the UHL, CI and HA groups rated themselves on the SSQ. Although these three groups perceive their daily communication experiences very similarly, clinical approaches for treatment are quite different. Individuals with a single CI and a contralateral SPHL ear are more routinely considered for a second ear CI. In contrast, individuals with substantial bilateral hearing loss that includes only one ear in the SPHL range or individuals with unilateral normal hearing and a contralateral SPHL ear are rarely considered CI candidates. In Dwyer et al. (2014) a majority of the CI and HA group participants went on to obtain a CI for the SPHL ear. Six-month post-treatment results were significantly higher than pre-treatment results for both groups on all three SSQ domains and all 10 subscales. Post treatment, the CI group (now bilateral CI recipients) rated themselves significantly higher than the UHL group on the Spatial domain and the SiQ, SiN, Loc, DisMov, and Eff subscales. Post treatment, the HA group (now bimodal recipients) rated themselves significantly higher than the UHL group on Loc and Eff. This suggests that bilateral/binaural hearing as well as mode and quality of hearing are significant contributors to successful daily communication as viewed by the individual.

Study 3: Asymmetric Hearing Loss – Children

A small group of five children and adolescents (10 – 19 years of age) with asymmetric hearing loss (one ear meeting CI candidacy criteria and the other ear with better hearing) received a CI based on clinical recommendations and were evaluated after at least six months of CI experience (six months to five years). (Cadieux, Firszt, & Reeder, 2013). All participants consistently used a HA on the non-implanted ear. Three of the participants had a more favorable hearing history for the ear that was implanted (either non-congenital SPHL onset and/or consistent HA use and three to five years of CI experience) than the other two participants (congenital SPHL onset, no HA use, and only six months of CI experience).

Testing was completed in three listening conditions: CI alone, HA alone, and bimodal. Test measures included

CNC words at 50 dB SPL, CNC words at 60 dB SPL with 4TB at +8 dB SNR, HINT sentences in the R-Space with restaurant noise at 60 dB SPL (described above), and the Bamford-Kowal-Bench Speech in Noise test (BKB-SIN, Etymotic Research, 2005) with 4TB at 65 dB SPL and the sentence level beginning at +21 dB SNR and incrementally decreasing to 6 dB SNR. Localization was also measured in the same manner as described above.

The three participants with the more favorable hearing history had significantly better bimodal scores compared to CI alone or HA alone on one or more of the speech recognition measures. All three participants had significantly improved localization when comparing bimodal to either the HA- or CI-alone condition. The two participants with congenital SPHL onset, no HA experience and only six months CI use had limited or no CI-alone speech understanding. One of the two did significantly better bimodally than with either device alone for the R-Space. Neither had improved localization bimodally over the HA or CI alone.

Some children and adolescents with asymmetric hearing were able to benefit by receiving a CI for the poorer hearing ear and continuing to use a HA at the better hearing ear, becoming bimodal listeners. Reports by all five participants and their parents reported benefit in everyday listening situations with the addition of the CI compared to their previous unilateral listening condition with a HA. These study results suggest that additional study with a larger group of children is warranted to better understand the potential of cochlear implantation for this group of children.

Summary and Future Clinical Considerations

Continued study of the effects of unilateral input and subsequent treatment in this population is needed, including the effects of cochlear implantation. Implications of unilateral input that occurs early in life and whether binaural abilities can be accessed or developed later are not fully understood. To maximize the potential for those abilities dependent on binaural input, CI candidacy requirements need modification. Importantly, we should evaluate and consider treatment for each ear individually (i.e. optimizing hearing for both ears). Better hearing in one ear should not disqualify an individual for cochlear implantation of an ear with poor hearing and no HA benefit. This approach recognizes the binaural auditory system as a single system, rather than as two ears that are redundant. Current descriptions of these types of hearing profiles, for example, having one normal hearing ear and one deaf ear, should be changed to having an abnormal binaural system. There is clear evidence that what happens to one ear affects the function of the binaural system. As clinicians, we need to treat the entire system.

Acknowledgements

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