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Localization and Speech Understanding by a Patient With Bilateral Cochlear Implants and Bilateral Hearing Preservation

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Abstract

Objectives—The authors describe the localization and speech-understanding abilities of a patient fit with bilateral cochlear implants (CIs) for whom acoustic low-frequency hearing was preserved in both cochleae.

Design—Three signals were used in the localization experiments: low-pass, high-pass, and wideband noise. Speech understanding was assessed with the AzBio sentences presented in noise.

Results—Localization accuracy was best in the aided, bilateral acoustic hearing condition, and was poorer in both the bilateral CI condition and when the bilateral CIs were used in addition to bilateral low-frequency hearing. Speech understanding was best when low-frequency acoustic hearing was combined with at least one CI.

Conclusions—The authors found that (1) for sound source localization in patients with bilateral CIs and bilateral hearing preservation, interaural level difference cues may dominate interaural time difference cues and (2) hearing-preservation surgery can be of benefit to patients fit with bilateral CIs.

INTRODUCTION

In this case study we describe the localization and speech-understanding abilities of a bilateral cochlear implant (CI) patient for whom low-frequency acoustic hearing was preserved in both implanted cochlea. This is the first report on the localization ability of a CI patient who could potentially access both interaural level difference (ILD) cues and interaural time difference (ITD) cues.

Localization on the horizontal plane was assessed using low-pass (LP), high-pass (HP), and wide-band noise signals. The rationale for using these signals comes from the Duplex theory of sound source localization. A thorough review of this theory and the supporting data are

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found in Blauert (1997) and Popper and Fay (2005). At issue in the present experiment was (1) localization accuracy for the LP signals in the bilateral acoustic hearing condition—which would reflect, primarily, access to ITD cues (Blauert 1997), (2) localization accuracy for the HP signals in the bilateral CI condition—which would reflect, primarily, access to ILD cues (van Hoesel et al. 2003; Grantham et al. 2007, 2008) and, critically, (3) localization accuracy in the combined CI and low-frequency hearing condition for wideband (WB) signals when both ITD and ILD cues were simultaneously available.

The patient's speech understanding was also tested. Patients undergoing standard hearing-preservation surgery have only one CI (e.g., von Ilberg et al. 1999; Gantz & Turner 2003; Kiefer et al. 2004). Our interest was whether hearing-preservation surgery is of benefit when a patient has two CIs.

PARTICIPANT AND METHODS

Subject

The patient with bilateral CIs and bilateral hearing preservation (bi-bi patient) was a 53-year-old man. A hearing loss of unknown origin was first identified at the age of 23 years, and by the age of 50 years he qualified for a CI. His left ear was implanted first, the other ear a year later. Both ears were fit with Cochlear Corporation N5 processors and Contour Advance electrode arrays (inserted nominally 17.8 mm). Hearing was preserved in both ears after surgery. The pre- and postimplant audiograms are shown in Figure 1. At the time of testing the patient had used his left and right CIs for 3 and 2 years, respectively.

Twenty-two younger (ages 21–40 years) and 12 older (ages 50–70 years) listeners with mean thresholds from 0.125 to 4 kHz under 20 dB HL served as the normative sample. Eleven bilateral hearing aid (HA) users with symmetrical, mild-to-severe, sensorineural hearing loss were also tested with and without their HAs. Mean thresholds at 0.25, 0.5, 1, 2, and 4 kHz were 19, 28, 45, 61, and 71 dB HL, respectively. Eighteen patients with bilateral CIs were also tested.

Localization Stimuli and Procedures

Three noise band signals were created for the localization experiment. All were 200 msec in duration and shaped with 20-msec rise-decay times (thus minimizing onset ITDs as cues to localization). The WB signal was band-pass filtered between 125 and 6000 Hz. The LP signal was filtered between 125 and 500 Hz. The HP signal was filtered between 1500 and 6000 Hz. In all cases the filter roll-offs were 48 dB/octave.

The signals were presented from a 13-loudspeaker array, at the height of the listeners' pinna with 15 degrees of separation, covering an arc of 180 degrees in the frontal plane. The 3.04 m × 3.35 m room was sound deadened by foam insulation and had a broadband reverberation time (RT_{60}) of 90 msec. Subjects sat in a chair at a distance of 1.67 m from the loudspeakers.

Each signal was presented four times from each loudspeaker. The nominal presentation level was 65 dBA with a +/−2 dB rove in level. Signal level was adjusted in 5 dB increments as necessary to make signals audible in the unaided conditions for the hearing-impaired listeners. Subjects were instructed to look at the midline (center loudspeaker) until a stimulus was presented. They entered the number of the loudspeaker associated with the target on a keypad. Localization accuracy was computed as overall root mean square error, or D (Rakerd & Hartmann 1986).

The bi-bi patient was tested with and without HAs. He did not wear aids at home or at work, and our results on localization must be evaluated in that light. He was fit with Phonak Ambra BTE HAs with Comply ear molds. Gain was set to low-frequency targets using the Audioscan Verifit system. Gain was not applied to frequencies above 750 Hz.

Speech Signals

Speech understanding in multispeaker babble noise was assessed in a booth using the AzBio sentences presented from a single loudspeaker. One list of 20 sentences each was used for each test condition. There were nine test conditions using unaided acoustic hearing alone, CIs alone, and combinations of acoustic hearing and CIs. These conditions are identified in Table 1. In the conditions with CI only, the ears were plugged and muffed. In this condition the CI processors were moved forward of the pinnae and attached to the ear pieces of the patient’s glasses. To maximize sensitivity to the multiple test conditions, performance in the best single CI condition was driven to 44 percent correct by decreasing the signal-to-noise ratio to −1 dB. This signal-to-noise ratio was then used for all test conditions.

RESULTS

Localization

LP Noise—Localization accuracy for the LP noise is shown in Figure 2 (top). The mean score for the young normal group was 8.1 degrees; for the older normal group, 8.8 degrees; for the bilateral hearing-impaired group without HAs, 14.7 degrees; for the same group with HAs, 15.4 degrees, and for the bilateral CI group, 55.1 degrees. When the bi-bi patient was tested with and without his HAs the scores were 11.5 and 17 degrees, respectively. Without HAs and with his bilateral CIs, the score was 17 degrees. With HAs and with bilateral CIs, the score was 16 degrees.

HP Noise—Localization accuracy for the HP noise is shown in Figure 2 (middle). The score for the young normal group was 8.3 degrees; for the older normal group, 9.3 degrees; for the bilateral hearing-impaired group without HAs, 17.3 degrees; for the same group with HAs, 21.3 degrees; and for the bilateral CI group, 32.5 degrees. When the bi-bi patient was tested without HAs and without CIs, he could not hear the signal. Without HAs and with his bilateral CIs, the score was 24 degrees. With HAs and without his CIs, he again could not hear the signal. With HAs and with bilateral CIs, the score was 24 degrees.

WB Noise—Localization accuracy for the WB noise is shown in Figure 2 (bottom). The mean score for the young normal group was 6.7 degrees; for the older normal group, 6.5 degrees; for the bilateral hearing-impaired group without HAs, 17 degrees; for the same group with HAs, 15 degrees; and for the bilateral CI group, 33.8 degrees. When the bi-bi patient was tested without HAs and without CIs, the score was 22 degrees. Without HAs and with his bilateral CIs, the score was 25 degrees. When the patient was tested with HAs and without his CIs, the score was 12 degrees. With HAs and with bilateral CIs, the score was 20.5 degrees.

Speech Understanding

The results are shown in Table 1. The patient was not accustomed to wearing HAs—the results reported here were obtained without aids. With only low-frequency hearing, the scores were near zero in the left ear, right ear, and combined conditions. With a CI, the scores were 25%, 44%, and 39% correct in the left, right, and combined conditions, respectively. With bimodal hearing, the scores were 22%, 64%, and 61% correct in the left, right, and combined conditions, respectively.

DISCUSSION

LP Noise

The performance of the bi-bi patient in this condition is of interest because the LP noise minimized the availability of ILD cues. We assume that performance reflects primarily the use of ITD cues. In the acoustic-only conditions, the error without HAs was 17 degrees and with aids it was 11.5 degrees. These values are near the means (approximately 15 degrees) of the scores for the patients with bilateral HAs.

HP Noise

Performance in the HP noise condition was of greatest interest when the bi-bi patient used both his acoustic hearing and his CIs. Because he could not hear the HP noise, performance in the combined hearing and CI condition reflected his use of bilateral CIs. His level of performance, 24 degrees of error, was near the mean of the bilateral CI group and consistent with performance based on ILDs (Grantham et al. 2007, 2008).

WB Noise

In the WB noise condition the bi-bi patient had access to both ILD and ITD cues. When tested in the acoustic hearing alone condition with HAs, he achieved a score of 12 degrees error. This score is essentially the same as the score he achieved in the LP noise condition (11.5 degrees) and serves as a replication of his ability to use ITD cues for localization. When he used his CIs in addition to his aids, his score increased to 20 degrees error. Thus, when both ITD and ILD cues were available, his localization performance seemed to be dictated by ILD cues.

Speech Understanding

A large literature indicates that bilateral CIs engender a slightly higher level of performance, 6 to 10 percentage points on average, than a single CI when signals are presented from a single loudspeaker, that is, in environments that minimize the benefits of spatial hearing (e.g., Litovsky et al. 2009; Buss et al. 2008). Another large literature indicates that bimodal stimulation, when referenced to a single CI, can engender much larger increases in performance—20 to 40 percentage points (e.g., Shallop et al. 1992; Ching et al. 2004; Dorman & Gifford 2010). Given these outcomes, it is reasonable to assume that hearing preservation in at least one ear could be valuable for patients fit with bilateral CIs. For the bi-bi patient this was the case. In the bilateral CI condition, the mean score was 39 % correct. In the bilateral CI plus bilateral, acoustic-hearing condition, the score increased to 61% correct. Thus, we find ample reason to attempt hearing preservation in at least one ear of patients to be fit with bilateral CIs (see also, Punte et al. 2010).

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References

Blauert, J. Spatial Hearing: The Psychophysics of Human Sound Localization. Cambridge, MA: MIT Press; 1997.

Buss E, Pillsbury HC, Buchman CA, et al. Multicenter US bilateral MED-EL cochlear implantation study: Speech perception over the first year of use. Ear Hear. 2008; 29:20–32. [PubMed: 18091099]

Ching TY, Incerti P, Hill M. Binaural benefits for adults who use hearing aids and cochlear implants in opposite ears. Ear Hear. 2004; 25:9–21. [PubMed: 14770014]

Dorman MF, Gifford RH. Combining acoustic and electric stimulation in the service of speech recognition. Int J Audiol. 2010; 49:912–919. [PubMed: 20874053]

Gantz BJ, Turner CW. Combining acoustic and electrical hearing. Laryngoscope. 2003; 113:1726–1730. [PubMed: 14520097]

Grantham DW, Ashmead DH, Ricketts TA, et al. Horizontalplane localization of noise and speech signals by postlingually deafened adults fitted with bilateral cochlear implants. Ear Hear. 2007; 28:524–541. [PubMed: 17609614]

Grantham DW, Ashmead DH, Ricketts TA, et al. Interaural time and level difference thresholds for acoustically presented signals in post-lingually deafened adults fitted with bilateral cochlear implants using CIS+ processing. Ear Hear. 2008; 29:33–44. [PubMed: 18091105]

Kiefer J, Gstoettner W, Baumgartner W, et al. Conservation of low-frequency hearing in cochlear implantation. Acta Otolaryngol. 2004; 124:272–280. [PubMed: 15141755]

Litovsky RY, Parkinson A, Arcaroli J. Spatial hearing and speech intelligibility in bilateral cochlear implant users. Ear Hear. 2009; 30:419–431. [PubMed: 19455039]

Popper, A.; Fay, R. Springer Handbook of Auditory Research. Vol. 25: Sound Source Localization. New York, NY: Springer-Verlag; 2005.

Punte, A.; Vermeire, K.; v. de Heyning, P. Bilateral electric acoustic stimulation: A comparison of partial and deep cochlear electrode insertion. In: v de Heyning, P.; Punte, AK., editors. Cochlear Implants and Hearing Preservation. Vol. Vol. 67. Basel, Karger: Adv. Torhinolaryngology; 2010. p. 144-152.

Rakerd B, Hartmann WM. Localization of sound in rooms, III: Onset and duration effects. J Acoust Soc Am. 1986; 80:1695–1706. [PubMed: 3794076]

Shallop J, Arndt P, Turnacliff K. Expanded indications for cochlear implantation: Perceptual results in seven adults with residual hearing. Journal of Speech-Language Pathology & Applied Behavior Analysis. 1992; 16:141–148.

van Hoesel RJ, Tyler RS. Speech perception, localization, and lateralization with bilateral cochlear implants. J Acoust Soc Am. 2003; 113:1617–1630. [PubMed: 12656396] von Ilberg C, Kiefer J, Tillein J, et al. Electric-acoustic stimulation of the auditory system. New technology for severe hearing loss. ORL J Otorhinolaryngol Relat Spec. 1999; 61:334–340. [PubMed: 10545807]

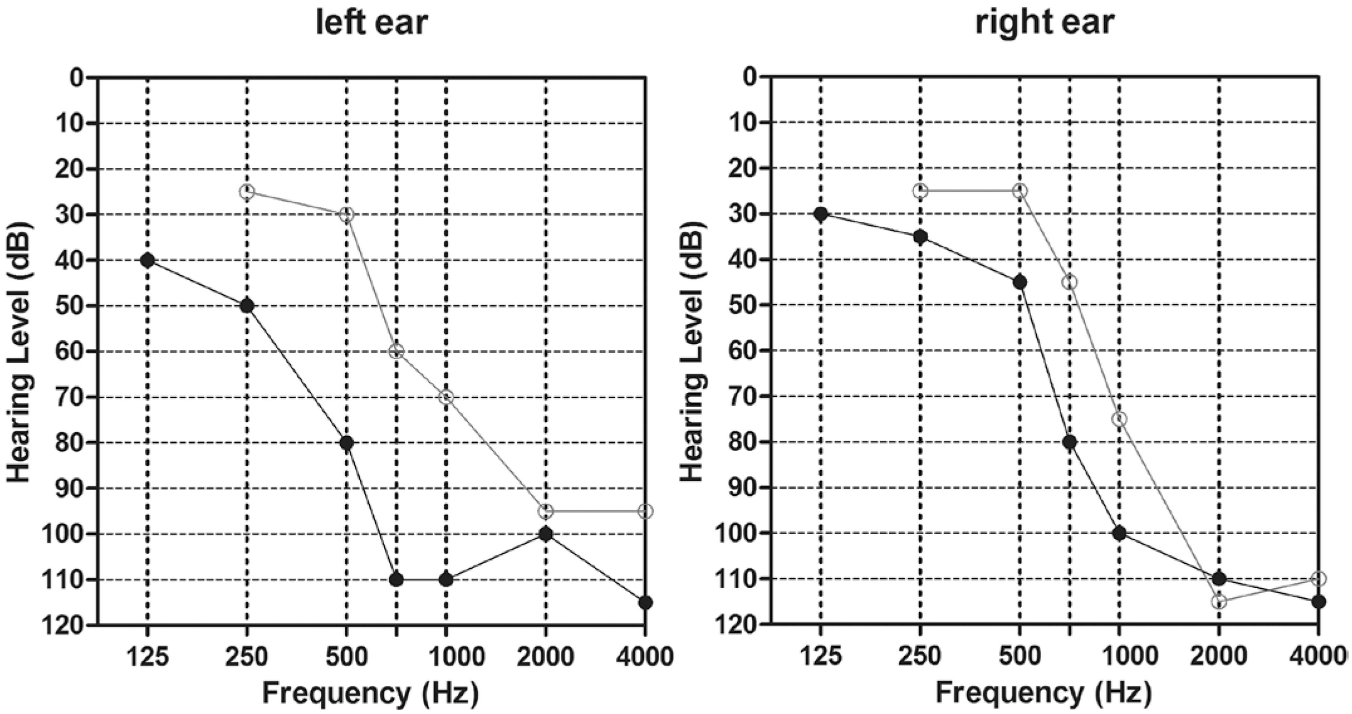

Fig. 1.

Audiograms pre- and postsurgery. Open circles indicate preimplant thresholds. Filled circles indicate thresholds at the time of testing.

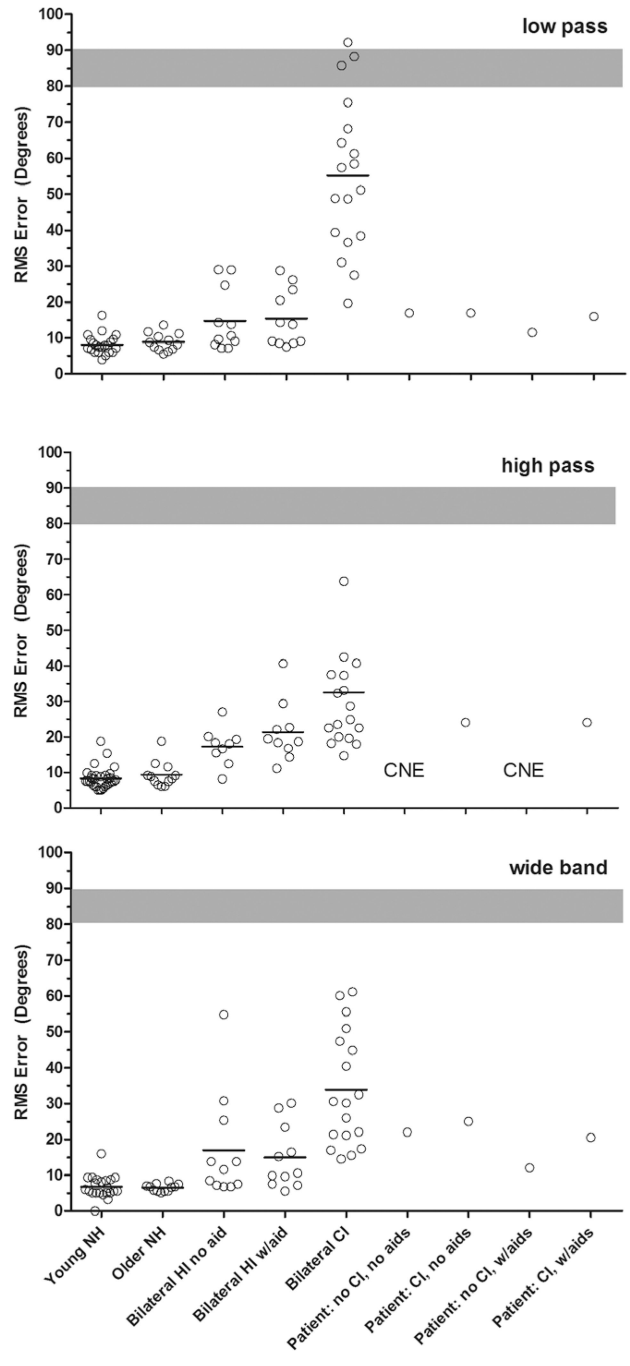

Fig. 2.

Localization accuracy for low-pass noise (top), high-pass noise (middle), and wideband noise (bottom). Subjects: younger and older NH patients, bilateral HI listeners with and without hearing aids, bilateral CI patients, and a patient with bilateral CIs and bilateral hearing preservation. Test conditions: with and without implant, and with and without amplification (aids). Horizontal lines indicate mean scores. Shaded areas indicate chance

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performance. CNE, patient could not hear the signal, RMS, root mean square; NH, normal hearing; HI, hearing impaired; CI, cochlear implant.

TABLE 1

Sentence recognition at −1 dB signal-to-noise ratio

	Left	Right	Bilateral
Acoustic hearing	0	5	0
Cochlear implant	25	44	39
Cochlear implant + acoustic hearing	22	64	61