Electric-acoustic stimulation in adults: localization and speech perception

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This paper reports findings from a study that was aimed at investigating how best to prescribe devices that provide electric-acoustic stimulation. The localization and speech perception of adults who use electric-acoustic stimulation in one ear and acoustic amplification in the opposite ear were evaluated. Results indicated localization benefits when acoustic amplification was used in both ears. Systematic adjustments of the relative output and cross-over frequencies were implemented to determine the settings that optimized outcomes. Results from a case study indicated benefits for localization and speech perception when electric–acoustic stimulation in one ear was combined with a hearing aid in the opposite ear, after acoustic-to-electric levels and cross-over frequencies were optimized.

Keywords: Cochlear implant, Electroacoustic stimulation, Localization, Speech perception

Introduction

Electric–acoustic stimulation (EAS) is an option for people who retain hearing usable with acoustic amplification in the implanted ear. Research has shown that significant benefits can be obtained when combining acoustic and electric stimulation in the same ear, compared with electric stimulation alone (for a review, see Incerti *et al.*, 2013). So far, only a few studies have examined the impact of utilizing both ears for localization and speech perception in multiple noise sources in adults who use EAS implemented with a short-electrode research array (Dunn *et al.*, 2010; Gifford *et al.*, 2010).

While a variety of EAS fitting approaches have been reported in the literature, and varied fitting recommendations have been made in proprietary fitting software, none of the approaches have been empirically derived and validated. Two parameters that have been reported in the literature to affect speech in noise outcomes are: acoustic-to-electric frequency boundary allocation; and relative output levels (Vermeire *et al.*, 2008; Polak *et al.*, 2010).

As EAS technology is increasingly being made available in commercial devices, and as the number of recipients is increasing rapidly, an understanding how to best apply and adjust it is crucial. Furthermore, no study to date has systematically examined the effects of variations in acoustic-to-electric frequency boundary and output levels in the implanted and nonimplanted ear on binaural benefits for localization and speech intelligibility.

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Aim

The aims of this paper are to: (1) evaluate localization abilities in 12 adults who use a Nucleus cochlear implant system in one ear together with hearing aids in both ears, compared to the use of bilateral hearing aids only; (2) Evaluate the ability of using spatial separation between speech and noise for speech intelligibility, or spatial release from masking (SRM), by measuring speech reception thresholds (SRTs); and (3) Examine the effect of variations in acoustic-to-electric frequency boundary and output levels on localization and speech performance.

Methods

Participants

Twelve adults with a postlinguistic onset of deafness participated in this study. There were seven women and five men, ranging in age from 45 to 81 years (m = 63.9 years: SD = 11.8). All 12 adults had residual hearing in both ears (see Fig. 1).

All adults were implanted with a Nucleus cochlear implant system in one ear, and have been using the device with hearing aids in both ears for at least 12 months prior to the commencement of the study. Mean duration of implant use was 3 years and 11 months (see Table 1).

DOI 10.1179/1467010014Z.000000000161

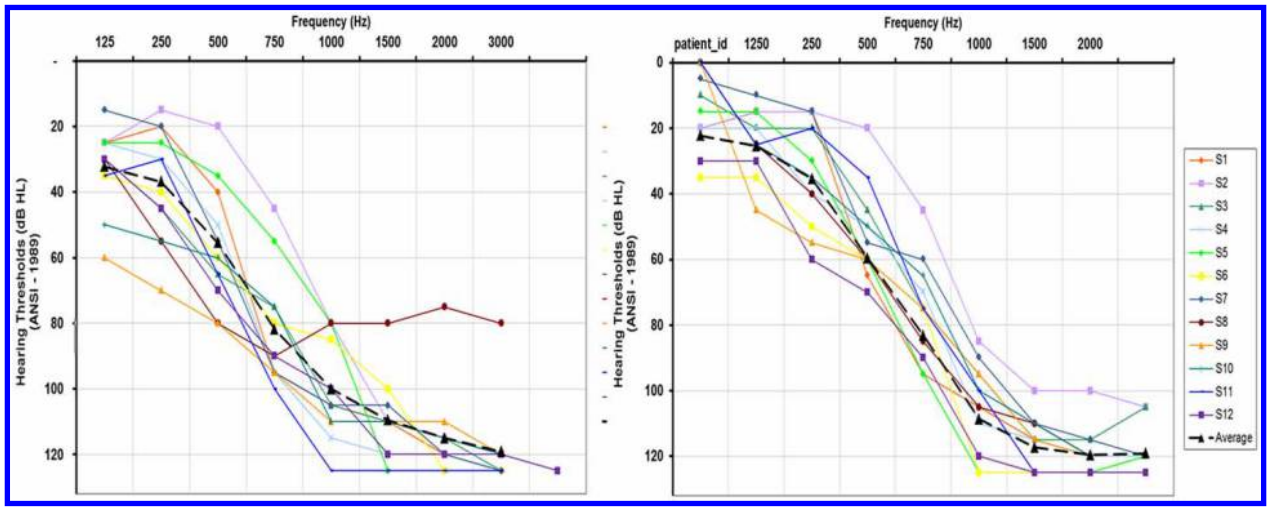

Figure 1 The hearing thresholds in the implanted (left panel) and non-implanted (right panel) ears for the 12 adults.

Procedure

Localization

Horizontal localization ability was measured using an array of 8 loudspeakers spanning a 180° range, spaced 22.5° apart. Pink noise bursts presented at 65 dB SPL at random and the listener indicated the loudspeaker (designated by a number) from which the sound came. Performance was derived by calculating the average root mean square (RMS) error in degrees. Assessments were carried out under two aided conditions: cochlear implant sound processor worn together with acoustic amplification in both ears (CI +2HA), and two hearing aids in both ears only (2HA only). Two runs with a total of 20 repeats for each sound source location (160 total) were completed for each condition. Chance performance was approximately 80° RMS error.

Speech perception in babble noise

The adaptive Australian Sentence Test in Noise and (Dawson *et al.*, 2013) was used to evaluate SRM. The sentence material was recorded by an Australian female talker. The SRT for 50% correct was adaptively determined in two listening conditions. In one condition, target speech and competing eight-talker babble were presented from the same loudspeaker

Table 1 Clinical devices worn by the 12 participants

Subject	Implant	Duration implant use (years)	Active channels	Rate per channel (Hz)	Frequency range (Hz)	Device implanted ear	Device non implanted ear
S1	Hybrid L24	6.1	18	900	688–7938	Hybrid processor (EAS)	Unitron BTE
S2	Hybrid L24	4.3	20	900	938–7938	Hybrid processor (EAS)	Siemens PC701 RIC
S3	CI422	1.7	17	500	688–7938	CP810 processor + Siemens Motion701	Phonak Savia art 311ds2 BTE
S4	CI422	1.9	21	900	688–7938	Hybrid processor (EAS)	Siemens PC701 RIC
S5	Hybrid L24	4.6	18	900	688–7938	Hybrid processor (EAS)	Phonak Audeo III
S6	Hybrid L24	5.5	16	900	438–7938	Hybrid processor (EAS)	Phonak Savia Art 411BTE
S7	Hybrid L24	5.8	17	900	688–7938	Hybrid processor (EAS)	Siemens Motion 301 BTE
S8	MRA	4.3	22	900	313–7938	Hybrid processor (EAS)	Phonak Supero BTE
S9	Freedom CA	8.1	22	900	188–7938	CP810 processor + Starkey ITC	Siemens Motion 301 BTE
S10	Hybrid L24	2.8	18	900	688–7938	Hybrid processor (EAS)	Phonak Naida BTE
S11	CI422	1.3	19	900	188–7938	Hybrid processor (EAS)	Phonak Savia Art 411 BTE
S12	CI422	1.1	22	900	188–7938	CP810 processor + Starkey ITE	Phonak Una BTE

placed at 0° azimuth (S0N0). In another condition (S0N90), target speech was presented from the front at 0° azimuth, and uncorrelated four-talker babble noise was presented from each of two loudspeakers placed at ±90° azimuth (effectively eight-talker babble). The SRM was defined as the difference between SRTs measured with co-located speech and babble and SRTs measured with spatially separated speech and babble. Participants wore their clinical devices, a cochlear implant sound processor and two hearing aids (CI +2HA). Four lists (each of 16 sentences) were used for each test condition to determine an SRT, and all testing was preceded by a practice run of 16 sentences.

Optimization of acoustic-to-electric output requirements

To determine the relative acoustic-to-electric output requirements, the participants were fitted with new hearing aids according to the NAL-NL2 prescription method. Real-ear measurements were used to verify that the gain targets were met as closely as possible. A systematic procedure for adjusting the hearing-aid gains when used with electrical stimulation to achieve best speech intelligibility was implemented. The procedure was repeated for low, medium, and high input levels. These procedures were also repeated for three different acoustic-to-electric cross-over frequencies, determined with reference to the frequency at which the hearing threshold was 60, 75, or 90 dB HL. The participant's localization and speech perception performance were measured for each of the settings.

Results

Localization

On average, the RMS error for 12 adults when they wore cochlear implant sound processor together with hearing aids in both ears (CI +2HA) compared with two hearing aids alone (2HA only) were 25° and 28°, respectively. Analysis of variance revealed no significant difference in localization performance between the two conditions ($P = 0.26$). Fig. 2 shows the response patterns for each participant.

Speech perception in babble noise

The mean SRT for sentence perception when listening to speech and babble presented from the front (S0N0) and when babble was spatially separated from the speech (S0N90) was 2.1 and 3.2 dB signal-to-noise ratio, respectively. Analysis of variance showed that, on average, the SRT measured with co-located speech and babble (S0N0) was significantly lower than the SRTs measured with spatially separated speech and babble (S0N90) condition ($P < 0.04$). No SRM was indicated.

Optimization of acoustic–electric output requirements: A case study

A 70-year-old male participant who received a Hybrid L24 cochlear implant in his left ear 6 years ago completed the optimization procedure (S9 in Fig. 2). The results showed that the preferred gain for speech intelligibility was within ±6 dB of the gain prescribed by NAL-NL2 targets for all three acoustic-to-electric cross-over frequencies evaluated. After familiarization with each of the device settings according to optimized acoustic-to-electric output levels, evaluations of localization and speech perception were completed. The results suggest that best performance in localization and speech perception was obtained when the optimized relative acoustic-to-electric levels were provided with a crossover frequency set at the frequency where hearing threshold was 75 dB HL.

Discussion

Localization

The study showed that, on average, there was no significant difference between localization scores when adults wore a CI in one ear together with two hearing aids compared to when they wore two hearing aids alone. The results suggest that the ability to localize the sounds was primarily dependent on participants being able to perceive sounds in both ears with the acoustic amplification provided by the hearing aids, and independent of whether there was electrical stimulation or not. These results for participants who received a Nucleus CI system with 22 electrode arrays and wore bilateral hearing aids are in agreement with a previous study by Dunn and colleagues (2010) who reported sound source localization ability in a group of 11 adults who received a Nucleus Hybrid 10 mm short array with six intracochlear electrodes and wore bilateral hearing aids.

Speech perception in babble noise

On average, the participants did not demonstrate an ability to use spatial separation between speech and noise for speech intelligibility, despite the use of devices in both ears. The question of whether systematic adjustment of electric and acoustic output levels and electric-to-acoustic frequency boundary allocation parameters would improve speech perception in babble remains to be investigated.

The current findings on amplification requirements are preliminary. The case study serves to demonstrate that the relative acoustic-to-electric output level and cross-over frequency affect performance with EAS. When data on optimization and evaluations from all participants become available, it will be possible to derive prescriptive parameters that optimize performance for people who use EAS.

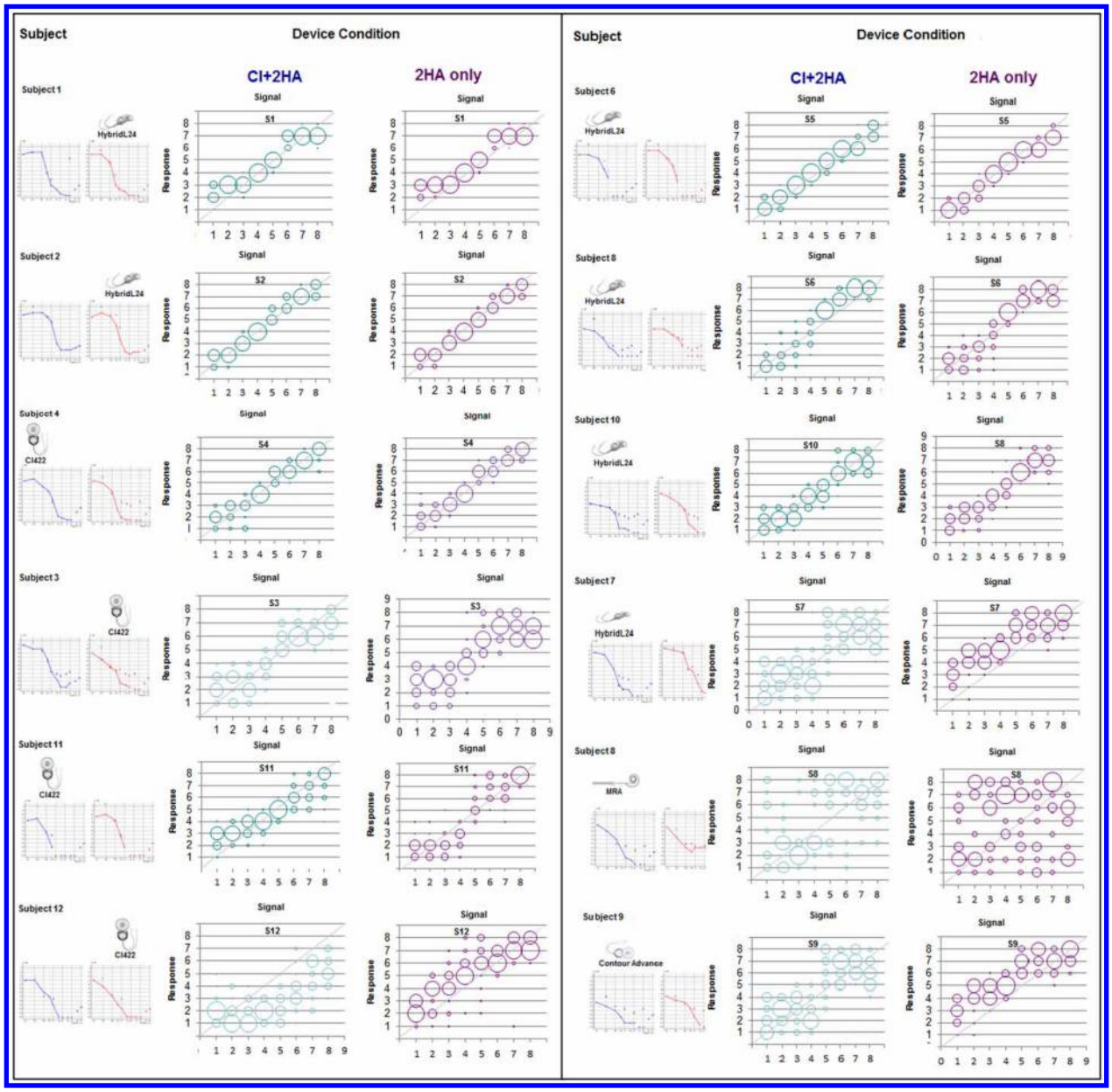

Figure 2 Pure tone audiogram and implant type are shown together with the localization response pattern for 12 participants when wearing cochlear implant with two hearing aids (CI + 2HA) in green; and two hearing aids only (2HA only) in purple. The localization pattern shows stimulus angle on the horizontal axis and response angle on the vertical axis. The size of the symbols is proportional to the frequency of response. The diagonal line denotes complete agreement between stimulus and response.

Conclusion

This study shows localization benefits for adults who used EAS in one ear combined with a hearing aid in the opposite ear.

Acknowledgments

We are grateful all participants for their contributions to this study. We acknowledge the financial support of the Commonwealth of Australia through the establishment of the HEARing CRC and the Cooperative Research Centres.

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