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Comparison of Bimodal and Bilateral Cochlear Implant Users

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Many cochlear implant users have difficulty with speech perception in noise, music appreciation, tone of voice recognition, and talker identification. These tasks rely on pitch perception, which is generally poor in cochlear implant users because of the speech-processing algorithm. Amplitude envelope information is extracted from the incoming sound; the temporal fine structure, which is important for pitch perception, is mostly discarded. Bilateral cochlear implantation provides benefit in terms of localization and speech recognition in noise, but does not solve problems related to poor pitch discrimination. Benefit may also be obtained by using a hearing aid on the contralateral ear to the implant: bimodal hearing.

Thirteen bimodal and thirteen bilateral cochlear implant users were compared on speech recognition with a competing talker, music perception, tone of voice recognition, and talker identification. In order to categorize the extent of residual hearing required for bimodal benefit, a unique cochlear implant subject with normal hearing in the contralateral ear was evaluated on speech recognition with a competing talker.

Although there was no significant difference in group mean scores between the bimodal and bilateral cochlear implant users, a slight advantage was seen for the bimodal users. Evaluation of the subject with normal hearing in the contralateral ear showed that the addition of low-frequency sound, even when unintelligible and limited to below 150 Hz, significantly improved cochlear implant speech recognition with a competing talker.

This research suggests that bimodal stimulation offers equal performance to bilateral cochlear implantation on these four tasks in adults. Bimodal stimulation should be attempted before considering bilateral implantation.

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Introduction

Traditional cochlear implant sound processors use a fixed-rate pulse carrier, modulated by low-pass filtered amplitude envelopes; the temporal fine structure is discarded. Pitch cues are poorly represented, although some newer processing strategies now attempt to provide some temporal fine structure. Many cochlear implant recipients now receive bilateral cochlear implants. Studies have shown improved localization and improved hearing in background noise, especially when the sources are spatially separated (for a review of thirty-seven studies see Murphy & O'Donoghue, 2007). Benefit has also been demonstrated from the use of a contralateral hearing aid in conjunction with the cochlear implant (bimodal hearing). The addition of natural low-frequency sound may provide some fine structure to assist pitch-related tasks. Schafer et al. (2007) used a meta-analytic approach and found no significant differences between bimodal and bilateral groups for any binaural phenomena.

This paper summarises two studies. The first assessed bimodal benefit in an unusual cochlear implant subject with virtually normal hearing in the contralateral ear (Part 1). The aim was to assess speech recognition with a competing talker in the ear using a cochlear implant, while systematically adding acoustic information to the normal-hearing ear. The second study compared bimodal and bilateral cochlear implant users on four tasks that rely on pitch perception: speech recognition with competing talker, music perception, affective prosody discrimination, and talker identification (Part 2).

Methods

Part 1

The subject was a forty-six-year-old male with a Clarion® HiRes 90k (Advanced Bionics Corporation, Sylmar, California) cochlear implant in his right ear and virtually normal hearing in his left ear ($\leq$20 dBHL re ANSI-1996 for octave frequencies between 0.25 and 8 kHz, except 35 dBHL at 4 kHz). He used an Auria® speech processor programmed with a clinical HiRes® S, map with default frequency allocation. He received the implant due to intractable tinnitus.

The target speech material was HINT sentences spoken by a male; the masker was a female speaking the IEEE sentences. The mean fundamental frequencies of the two voices were 109 Hz for the target male, and 214 Hz for the competing female. The target and masker were added at a signal-to-noise ratio (SNR) of 0 dB. The resultant signal was split into two channels; one channel was sent unprocessed to the ear with the cochlear implant via direct connection to the speech processor. The other channel was low- or high-pass filtered and routed to the normal-hearing ear via an insert ear phone. The cutoff frequencies were 150, 250, 500, 1000, 2000, 4000, and 6000 Hz. For the electroacoustic stimulation, the filtered acoustic information was presented to the normal-hearing ear at the same time as the full signal was presented to the speech processor. The subject was tested in three configurations: electroacoustic stimulation (cochlear implant in one ear plus filtered speech information in the other ear), cochlear implant alone, and acoustic information alone.

Part 2

Twenty-six postlingually deafened adult cochlear implant users took part. Thirteen wore a contralateral hearing aid (bimodal); thirteen had bilateral cochlear implants. All testing occurred in the subject's usual listening mode, i.e., bimodal or bilateral. All tests were presented in the sound field at a root mean square (rms) level of 60 dB(A). Test order was balanced across subjects using digram balanced Latin squares.

Speech recognition with competing talker

The target material was HINT sentences spoken by a male; the masker was a single female, male, or child talker. The female and male maskers were obtained from the IEEE sentence material. The female masker had an average Fo of 214 Hz; the male masker Fo was 101 Hz. The child masker was obtained from the Carnegie Mellon University Kids Corpus (Eskenazi, 1996). The child was a nine-year-old female with an average Fo of 246 Hz. A one-up, one-down adaptive procedure was used to estimate the subject's speech reception threshold (SRT).

Music perception

Music perception was evaluated using the Montreal Battery of Evaluation of Amusia (MBEA) (Peretz et al., 2003); it comprises six subtests related to pitch, rhythm, and memory.

Affective prosody discrimination

The discrimination of affective prosody was assessed using the comprehension part of the Aprosodia Battery (Ross et al., 1997). There are four subtests with progressively less linguistic information. The perception of sarcasm was measured using the Attitudinal subtest (Orbelo et al., 2005).

Talker identification

Three male, three female, two boy, and two girl speakers from the Hillenbrand vowel stimuli were used to assess talker identification. The dependent variable was the number of correctly identified talkers: the exact score. The number of talkers who were identified correctly as being either male, female, or child was termed the 'category score'.

Results

Part 1

Figure 1 shows the percentage correct word scores as a function of cutoff frequency for acoustic only, cochlear implant alone, and electroacoustic conditions. Although the 150 and 250 Hz acoustic only conditions provided no intelligibility and the cochlear implant alone score was 3 per cent, when these signals were presented together, the word scores were 32 and 36 per cent respectively for 150 and 250 Hz electroacoustic stimulation. This is clearly not a simple additive effect; adding the cochlear implant performance to the acoustic only score would raise the curve negligibly by 3 per cent. A similar electroacoustic advantage was seen for 500 and 1000 Hz low-pass

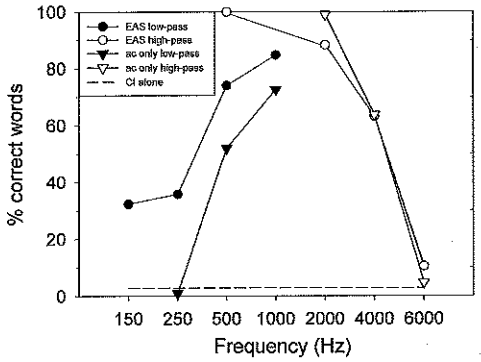

FIGURE 1 Percentage correct word score on HINT sentences presented with a female talker masker at 0 dB SNR. The cochlear implant alone score of 3 per cent is shown by a dashed horizontal line. The triangles represent scores for filtered acoustic stimuli presented to the normal-hearing ear at various cutoff frequencies. The circles represent scores for the combination of filtered acoustic stimuli to the normal-hearing ear and unfiltered stimuli to the cochlear implant ear (EAS: electroacoustic stimulation).

cutoffs. When the high-frequency electroacoustic data was examined, a different pattern was seen. The high-frequency electroacoustic stimulation did not offer any advantage over the acoustic only condition.

Part 2

Figures 2 to 5 show mean scores for the two groups (bimodal and bilateral) on HINT with female, male, and child maskers (Figure 2), MBEA (Figure 3), the Aprosodia Battery (Figure 4), and Talker identification (Figure 5). Results are also shown for normal-hearing listeners. An ANOVA test was used to examine the main effect of group (bimodal or bilateral) on the dependent variables for HINT (SRT with female, male, and child maskers), MBEA (score on the six subtests), Aprosodia (score on the five subtests), and Talker identification (exact and category score). Due to the multiple comparisons, a Bonferroni correction was used, and the significance level was set at 0.05/16=0.003. There was no significant difference between the mean scores of the bimodal and bilateral groups on any of the tests.

There were no consistent correlations between the test results, suggesting that subjects who were good at one particular test would not necessarily be good at other pitch-related tasks. There were no consistent correlations between hearing threshold levels in the bimodal users' aided ear and test results. Extent of music training or educational level did not influence performance any of the tasks.

Discussion

Part 1

In common with previous studies this research demonstrated that low-frequency acoustic sound provides significant benefit when combined with cochlear implant

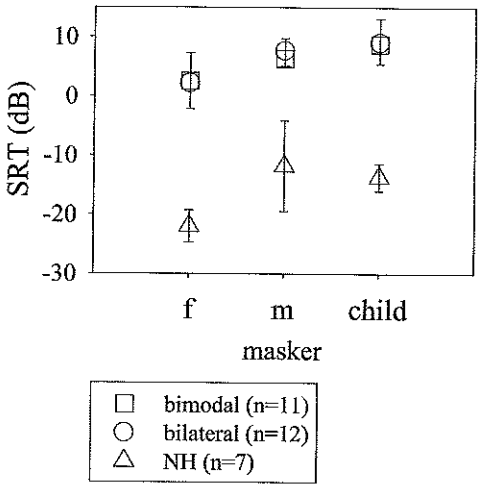

FIGURE 2 Mean SRT as a function of masker type in 11 bimodal (squares) and 12 bilateral (circles) cochlear implant users. Target material was HINT sentences spoken by a male; the maskers were a female (f), male (m), or child talker. Error bars represent ± one standard deviation. For clarity only the upward bar is shown for the bimodal group, and only the downward bar for the bilateral group. The normal-hearing (NH) data on seven subjects (triangles) were not age-matched, and were obtained in a previous study with an identical test procedure.

stimulation. A novel finding is that this electroacoustic advantage is limited to low-frequency sound, even if it only contains the fundamental frequency. This demonstrates that it is not simply additional sound which provides the benefit; it is the low-frequency sound specifically. If the trend of these findings can be extrapolated to regular cochlear implant users it suggests that they should benefit from electroacoustic stimulation by wearing a hearing aid on the contralateral ear, even with very limited residual hearing.

Part 2

The bimodal group performed better than the bilateral group on almost all of the tests, however, the differences were not statistically significant. It was expected that the bimodal users would perform better due to the presumed enhanced spectral resolution provided by the hearing aid. The lack of correlation between the different measures suggests that the four tasks are not simply measuring pitch ability. A test of pitch difference limen may have shown a difference between the groups, but this study aimed to use real-world tasks. Clearly there is much more to these real-world tasks than pitch discrimination.

The question of whether a patient will benefit more from a contralateral hearing aid or a second cochlear implant remains unanswered. In cases where there is no residual hearing in the unimplanted ear, the decision is more straightforward, as many studies have demonstrated the advantage of two implants over one. Studies comparing bimodal and bilateral implantation are fewer and less conclusive.

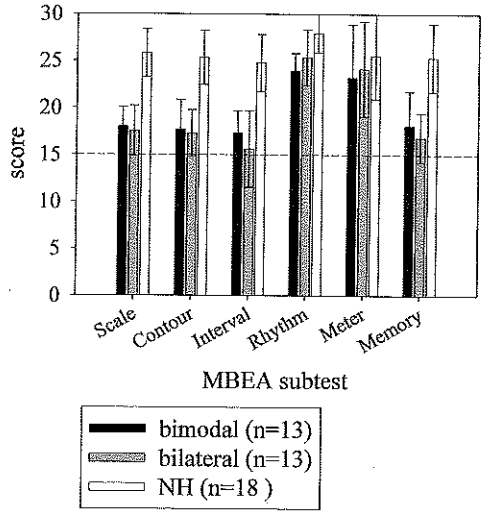

FIGURE 3 Mean scores (out of 30) for the six subtests of the Montreal Battery of Evaluation of Amusia in 13 bimodal (black bars) and 13 bilateral (grey bars) cochlear implant users. The dashed line represents chance performance. Error bars represent ± one standard deviation. The age-matched normal-hearing (NH) data (open bars) on 18 subjects were not obtained in this study.

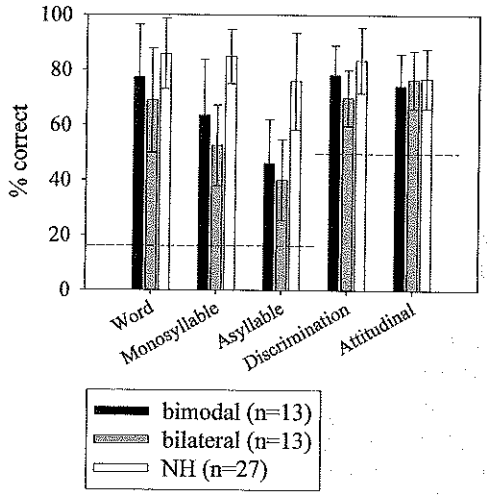

FIGURE 4 Mean percentage correct for the five subtests of the Aprosodia Battery in 13 bimodal (black bars) and 13 bilateral (grey bars) cochlear implant users. The dashed lines represent chance performance. Error bars represent ± one standard deviation. The age-matched normal-hearing (NH) data (open bars) on 27 subjects were not obtained in this study.

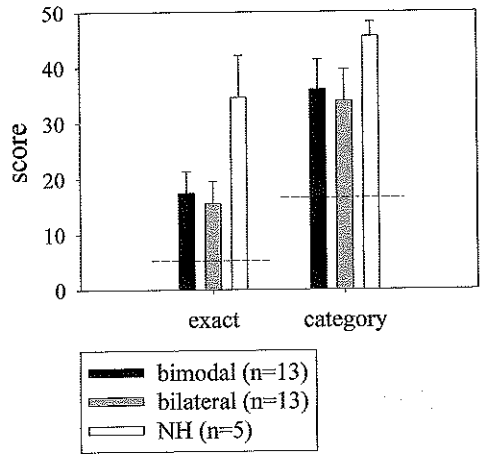

FIGURE 5 Mean scores (out of 50) for Talker identification in 13 bimodal (black bars) and 13 bilateral (grey bars) cochlear implant users. The dashed lines represent chance performance. Error bars represent ± one standard deviation. The normal-hearing (NH) data (open bars) on five subjects were not age-matched.

Conclusions

Low frequency acoustic sound provided significant benefit to speech recognition with a competing talker when combined with cochlear implant stimulation in a subject with normal hearing in the other ear. However, a comparison of bimodal and bilateral cochlear implant users on tasks requiring good pitch perception showed no significant difference between the groups. This research adds to the body of existing speech perception, language, and localization studies that show no significant difference between bimodal and bilateral cochlear implant users.

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