CHAPTER THIRTEEN

Bimodal Hearing for Children: Effect of Frequency Region and Acoustic Bandwidth

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Abstract

Speech recognition with cochlear implants (CIs) is limited by poor spectral resolution and loss of temporal fine structure associated with envelope-based signal processing strategies. Bimodal hearing, with a CI in one ear and hearing aid in the opposite ear, may afford greater spectral resolution and temporal fine structure cues via acoustic hearing in the low- to-mid-frequency region of the non-CI ear. The present study evaluated 20 children with normal hearing in a simulated CI listening task in an attempt to determine the acoustic bandwidth needed for optimal bimodal benefit. Significant bimodal benefit was found with 250 Hz of acoustic hearing in the "non-CI" ear; no increase in bimodal benefit was noted with the addition of acoustic hearing beyond 750 Hz.

Cochlear implants (CIs) provide substantial communicative benefit such that average auditory only word recognition is now in the range of 60 to 70% for both adult and pediatric recipients (Holden et al., 2013; Gifford et al., 2014; Davidson et al., 2010). Speech recognition is limited by poor spectral resolution and loss of temporal fine structure associated with envelope-based signal processing strategies. Bimodal hearing may afford greater spectral resolution and temporal fine structure cues via acoustic hearing in the low- to-mid-frequency region of the non-CI ear. This holds great promise for CI users as bimodal hearing is more prevalent than ever. Indeed, approximately 60 percent of modern-day, adult CI recipients have aidable acoustic hearing in the non-implanted ear with audiometric thresholds up to 80-85 dB HL at 250 Hz (Dorman & Gifford, 2010).

Numerous studies have demonstrated bimodal benefit in quiet and in noise for CI recipients and in vocoder-based simulations with normal-hearing listeners (Dunn et al. 2005; Kong et al. 2005; Kong & Carolyn 2007; Chang et al. 2006; Ching et al. 2006; Mok et al. 2006; Dorman et al. 2008; Brown & Bacon 2009; Zhang et al. 2010). In fact, very little acoustic hearing is required in order to derive benefit from bimodal hearing. Specifically, research has demonstrated significant bimodal benefit with acoustic bandwidths as narrow as 125 to 250 Hz (e.g., Brown & Bacon, 2010; Zhang et al., 2010; Sheffield & Gifford, 2014; Sheffield & Zeng, 2012). Maximum bimodal benefit has been documented for acoustic bandwidths up to 500 Hz in noise for adult listeners (Sheffield & Gifford, 2014).

All previous studies examining the acoustic bandwidth required for bimodal benefit have been conducted with adult CI recipients. Comparable data for pediatric bimodal listeners could provide diagnostically relevant information to aid clinical decision making regarding bimodal or bilateral CI candidacy. Identifying the optimal hearing condition is especially crucial for children who are developing speech and language and are more reliant on bottom-up processing cues than adults (Snedeker & Trueswell, 2004). Indeed, there have been a number of studies reporting that children with normal hearing and hearing aids require broader acoustic benefit than hearing-matched adults for rapid word learning and speech understanding (Stelmachowicz et al., 2004, 2007; Pitmann et al., 2005).

This brief report describes our ongoing research efforts aimed at defining the acoustic bandwidth needed for optimal bimodal benefit for pediatric CI recipients. Our primary hypothesis was that children will require wider acoustic bandwidth for maximum bimodal benefit than has been observed with adult bimodal listeners.

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Experimental Details

Twenty children with normal hearing were recruited for participation. Participants ranged in age from 6 to 12 years with a mean of 9.2 years. Prior to testing, hearing was screened at 15 dB HL from 250 through 8000 Hz and tympanometry was completed to rule out middle ear effusion.

In order to simulate CI listening, a 15-channel vocoder was used (Litvak et al., 2007). Sentence recognition for the BabyBio corpus (Spahr et al., 2014) was completed at an individually determined signal-to-noise ratio (SNR). The SNR was chosen to yield approximately 50% correct in the simulated CI only condition. The mean SNR was 6.7 dB with a range of 2 to 15 dB. Acoustic hearing in the opposite ear was low-pass filtered with cutoffs of 250, 500, 750, 1000, and 1500 Hz. Bimodal benefit was defined as the difference in performance between the CI alone and CI plus acoustic (bimodal) conditions.

Results and Discussion

Figure 1 shows the bimodal benefit, in percentage points, for each of the bimodal conditions tested. Mean bimodal benefit increased with acoustic bandwidth such that there was a significant effect of condition [$F(1, 18) = 201.9$, $p < 0.0001$). Post hoc testing (Holm-Sidak) revealed that the bimodal 250 Hz condition was significantly better than the CI alone condition ($t = 10.8$, $p < 0.001$), and the maximum score is achieved in the bimodal 750 Hz condition ($t = 5.3$, $p < 0.001$). Though the trends in the current dataset are similar to those for adults (Zhang et al., 2010; Sheffield & Gifford, 2014), adult CI listeners exhibit no further increases in bimodal performance beyond approximately 250 Hz. These data are consistent with our hypotheses that children would require a wider acoustic bandwidth than adults for maximum bimodal benefit and that bimodal benefit would increase with increasing bandwidth.

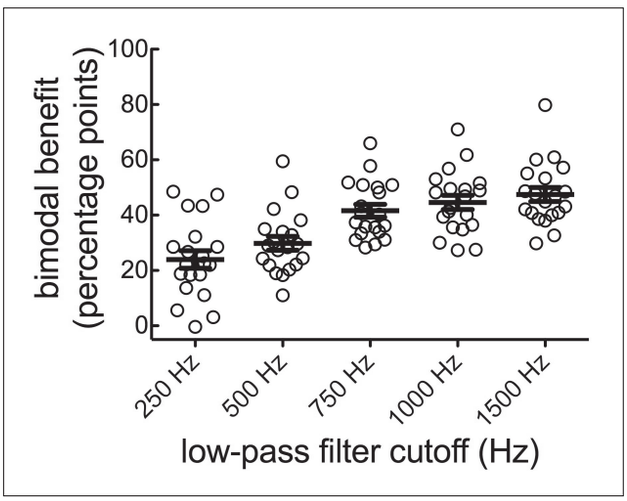

Figure 1. Mean bimodal benefit in percentage points for each of the bimodal conditions tested. Mean bimodal benefit clearly increases with bandwidth. The bimodal 250 Hz condition is significantly better than the CI alone condition, while the maximum score was obtained in the bimodal 750 Hz condition.

Summary

Significant bimodal benefit was observed with just 250 Hz of acoustic hearing in the "non-CI" ear for children listening to CI simulations. No significant increases in bimodal benefit were observed for the addition of acoustic hearing beyond the 750-Hz filter. This differs from what was seen in adults who reach a bimodal asymptote in the 250- to 500-Hz range (Zhang et al., 2010; Sheffield & Gifford, 2014). The current data suggest that 1) pediatric CI recipients may benefit from minimal acoustic hearing (<250 Hz) in the non-implanted ear, 2) bimodal benefit increases with increasing bandwidth up to at least <750 Hz, and 3) pediatric CI recipients may be able to make use of wider bandwidths of residual hearing than adults. Knowledge of the effect of acoustic bandwidth on bimodal benefit may help with clinical decision making regarding a second CI or bimodal hearing for optimal benefit. Ongoing projects are currently examining this research question with pediatric CI recipients.

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