Research Note

Speech Understanding in Noise by Patients With Cochlear Implants Using a Monaural Adaptive Beamformer

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Purpose: The aim of this experiment was to compare, for patients with cochlear implants (CIs), the improvement for speech understanding in noise provided by a monaural adaptive beamformer and for two interventions that produced bilateral input (i.e., bilateral CIs and hearing preservation [HP] surgery).

Method: Speech understanding scores for sentences were obtained for 10 listeners fit with a single CI. The listeners were tested with and without beamformer activated in a “cocktail party” environment with spatially separated target and maskers. Data for 10 listeners with bilateral CIs and

8 listeners with HP CIs were taken from Loisel, Dorman, Yost, Cook, and Gifford (2016), who used the same test protocol.

Results: The use of the beamformer resulted in a 31 percentage point improvement in performance; in bilateral CIs, an 18 percentage point improvement; and in HP CIs, a 20 percentage point improvement.

Conclusion: A monaural adaptive beamformer can produce an improvement in speech understanding in a complex noise environment that is equal to, or greater than, the improvement produced by bilateral CIs and HP surgery.

In a recent article, Loisel, Dorman, Yost, Cook, and Gifford (2016) described the value to speech understanding in a complex listening environment of two interventions that provided bilateral input to patients with cochlear implants (CIs). The interventions were (a) bilateral CIs and (b) hearing preservation (HP) surgery (i.e., surgery that preserves low-frequency acoustic hearing in the operated ear). Following successful HP surgery, patients have input from low-frequency acoustic hearing in both the implanted ear and in the ear contralateral to the CI as well as from a CI. The gain in speech understanding in noise was 18 percentage points for bilateral CIs and 20 percentage points for HP surgery. Thus, the provision of bilateral inputs is one means to improve speech understanding in noise for patients with CIs.

In this study, we compared, using the methodology of Loisel et al. (2016), the value of a monaural technology for CIs—an adaptive *beamformer*—to the value of the bilateral inputs in Loisel et al. (2016). Generally,

beamformers determine the difference in time of arrival of a noise source at two microphone locations and then, by applying an appropriate delay, subtract the inputs from each other. In an adaptive beamformer, this procedure is used to steer a null, or maximum attenuation, toward a noise source. The adaptive beamformer used in the present study, the Phonak UltraZoom (Sonova AG, Stafa, Switzerland), uses signals from two omnidirectional microphones located along the front-back axis of the CI case to dynamically attenuate noise sources (Elko & Pong, 1995; Hehrmann, Fredelake, Hamacher, Dyballa, & Buchner, 2012). In the test environment used in this experiment (i.e., with noise sources at $\pm 90^\circ$) the adaptive beamformer put the deepest null, or greatest attenuation, at $\pm 90^\circ$ (for a tutorial on noise reduction strategies for CIs, see Kokkinakis, Azimi, Hu, & Friedland, 2012).

Our comparison of monaural versus bilateral interventions to improve speech understanding in noise was motivated by two concerns. First, bilateral CIs are expensive and the health systems in many countries can ill afford the incremental cost relative to benefit (e.g., Summerfield, Marshall, Barton, & Bloor, 2002). This is the case, for example, in Great Britain, where bilateral CIs from the National Health Service are available for children but not for adults (Raine, 2013). Second, preservation of low-frequency hearing in HP surgery is by no means assured

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(e.g., Hunter et al., 2016; Lenarz et al., 2013; Skarzynski et al., 2014). For these reasons, it is useful to determine whether a monaural technology can provide an improvement to speech understanding in noise that is equivalent to the improvement provided by the two technologies described above.

Method

Participants

The participants were 10 listeners fit with an Advanced Bionics CI (Advanced Bionics LLC, Valencia, CA) and UltraZoom adaptive beamformer. Demographic data for the participants are shown in Table 1.

Test Stimuli and Environment

The target signals were female-voice sentences from the Pediatric AzBio test corpus (Spahr et al., 2014). The sentences were reproduced via the center loudspeaker of the R-SPACE listening environment (Compton-Conley, Neuman, Killion, & Levitt, 2004; i.e., at 0° azimuth). The maskers were male-voice sentences from the Institute of Electrical and Electronics Engineers (IEEE) corpus presented from loudspeakers at 90° and 270°. To create one masker, 10 sentences from the IEEE corpus spoken by a single male talker were concatenated with 0-ms delay, looped, and output continuously. To create the other masker, sentences from a different male talker were concatenated, looped, and output continuously.

Test Conditions

The listeners were tested in three conditions: (a) in quiet using an omnidirectional microphone, (b) in noise using an omnidirectional microphone, and (c) in noise using an adaptive beamformer. The order of the test conditions varied across listeners but was constrained so that the omni-in-noise condition always preceded the beamformer condition.

In all test conditions the target sentences were presented at 60 dB SPL. In the omni-in-noise condition, the level of the noise was increased for each listener so that

performance fell to between 30% and 60% correct, or as close as possible to these scores. This noise level was then used in the beamformer-in-noise condition.

Results and Discussion

The results are shown in Figure 1. The mean score in the omni-in-quiet condition was 86% correct; in the omni-in-noise condition, 44% correct; and in the beamformer-in-noise condition, 75% correct. There was a significant main effect of group, $F = 57$, $p < .0001$, and posttests (Holm-Sidak) indicated that all mean scores were significantly different. It is critical to note that the beamformer produced a 31 percentage point gain in speech understanding. This led to a score in noise (75% correct) that was within 11 percentage points of the score in quiet (86% correct).

Monaural Beamformer Versus Binaural Inputs

As noted in the Introduction, Loissele et al. (2016) tested patients with bilateral CIs and patients who had HP surgery using sentence material and a test environment identical to that used in this study. For that reason, we can directly compare the results from the two studies.

The combined results are shown in Figure 2. The top panel shows the results in all test conditions and the bottom panel shows the difference scores for each comparison. The mean difference score for beamformer versus omni was 31 percentage points; for bilateral CI versus better CI, 18 percentage points; and for CI plus bilateral acoustic hearing versus CI plus contralateral acoustic hearing, 20 percentage points. A one-way analysis of variance indicated a main effect for groups, $F = 4.131$, $p = .027$. Posttests (Holm-Sidak) indicated significantly better performance for the beamformer versus bilateral CIs but not for the beamformer versus HP surgery. Thus, a conservative description of these results is that the monaural beamformer produced an increase in speech understanding that was at least as large as that produced by the introduction of bilateral inputs. Inspection of Figure 2 (bottom) indicates that the beamformer consistently produced improvements

Table 1. Demographic data for the participants in the current study.

Subject number	Gender	Age	Length of deafness (years)	Experience with CI (years)	Etiology of hearing loss	CI ear
1	Female	68.0	39.6	5.3	Ototoxicity	RE
2	Female	69.9	4.9	11.0	Unknown	RE
3	Male	54.1	2.0	13.0	Nerve loss	RE
4	Female	58.0	5.7	1.2	Nerve impairment	LE
5	Female	80.9	10.5	4.6	Measles	LE
6	Female	70.9	10.7	13.4	Unknown	RE
7	Male	61.4	7.4	5.0	Unknown	LE
8	Female	70.4	3.4	0.7	Familial/hereditary	LE
9	Male	62.6	0.5	6.5	Unknown	RE
10	Male	64.8	40.9	13.3	Noise exposure	RE

Note. CI = cochlear implant; RE = right ear; LE = left ear.

Figure 1. Percent correct sentence scores as a function of condition. Each filled circle indicates the performance of a single listener. Omni = omnidirectional microphone; Beam = adaptive beamformer. The error bars indicate ± 1 SE.

of 20 percentage points or more. This was not the case for the two conditions that involved binaural input.

The patients with HP surgery in Loisel et al. (2016) were selected to have symmetrical and relatively good low-frequency thresholds. At 250 Hz, the mean threshold in the operated ear was 30 dB, and the thresholds in the operated ear and the contralateral ear were within 15 dB. These patients were representative of the best possible outcomes following HP surgery. If patients with less than the best outcomes had been included in the HP group, we have no doubt that the mean improvement in speech understanding would have been less.

More on Monaural Versus Binaural Inputs

Although we find high value for a monaural beamformer in our “cocktail party” test environment, the value of binaural inputs for patients with CIs should not be minimized. Listeners can locate a sound source on the horizontal plane with high accuracy only with binaural inputs, and sound-source localization is a factor in the higher level of patient satisfaction with bilateral CIs than unilateral CIs (Bichey & Miyamoto, 2008). Moreover, source localization allows listeners to orient to a talker when the talker’s location is not fixed and use both auditory and visual information for speech understanding (Van Hoesel, 2015). Visual information alone can add 30–40 percentage points to speech understanding scores in noise for listeners with CIs (e.g., Dorman et al., 2016).

Given the above, a reasonable next step in technology development is bilateral CIs with linked bilateral beamformers. As noted above, bilateral CIs provide sufficient sound-source localization for listeners to access visual information for speech understanding when the talker position is not constant. Moreover, speech reception thresholds are lowered by almost 2 dB for bilateral beamformers relative to monaural beamformers (Hehrmann et al., 2012). For

Figure 2. (Top) Percent correct scores as a function of condition. (Bottom) Difference scores from conditions shown at top of figure. Plotting conventions are the same as in Figure 1. Omni = omnidirectional microphone; Beam = adaptive beamformer; Acontra = low-frequency acoustic hearing in the ear opposite the implant; Abilat = low-frequency acoustic hearing in both ears due to hearing preservation (HP) surgery in the cochlear implant (CI) ear.

patients fit with bilateral CIs and bilateral beamformers, the combination of better access to visual information about speech and a better signal-to-noise ratio for the acoustic signal should lead to very high levels of patient performance and satisfaction.

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References

- Bichey, B., & Miyamoto, R.** (2008). Outcomes in bilateral cochlear implantation. *Otolaryngology—Head and Neck Surgery*, 138, 655–661.
- Compton-Conley, C., Neuman, A., Killion, M., & Levitt, H.** (2004). Performance of directional microphones for hearing aids: Real world versus simulation. *Journal of the American Academy of Audiology*, 15, 440–455.
- Dorman, M., Liss, J., Wang, S., Berisha, V., Ludwig, C., & Natale, S.** (2016). Experiments on auditory-visual perception of sentences by unilateral, bimodal, and bilateral cochlear implant patients. *Journal of Speech, Language, and Hearing Research*, 59, 1505–1519.
- Elko, G., & Pong, A.-T. N.** (1995). A simple adaptive first-order differential microphone. *Proceedings of the IEEE Workshop on Applications of Signal Processing to Audio and Acoustics* (pp. 169–171). New Paltz, NY: IEEE.
- Hehrmann, P., Fredelake, S., Hamacher, V., Dyballa, K.-H., & Buchner, A.** (2012). Improved speech intelligibility with cochlear implants using state of the art noise reduction algorithms. *Proceedings of the ITG Symposium on Speech Communication*, 10, 1–3.
- Hunter, J., Gifford, R., Wanna, G., Labadie, R., Bennett, M., Haynes, D., & Rivas, A.** (2016). Hearing preservation outcomes with a mid-scala electrode in cochlear implantation. *Otology & Neurotology*, 37, 235–240.
- Kokkinakis, K., Azimi, B., Hu, Y., & Friedland, D.** (2012). Single and multiple microphone noise reduction strategies in cochlear implants. *Trends in Amplification*, 16, 102–116.
- Lenarz, T., James, C., Cuda, D., O'Connor, A. F., Frachet, B., Frijns, J. H. M., ... Uziel, A.** (2013). European multi-centre study of the Nucleus Hybrid L24 cochlear implant. *International Journal of Audiology*, 52, 838–848.
- Loiselle, L., Dorman, M., Yost, W., Cook, S., & Gifford, R.** (2016). Using ILD or ITD cues for sound source localization and speech understanding in a complex listening environment by listeners with bilateral and with hearing-preservation cochlear implants. *Journal of Speech, Language, and Hearing Research*, 59, 810–818.
- Raine, C.** (2013). Cochlear implants in the United Kingdom: Awareness and utilization. *Cochlear Implants International*, 14(Suppl. 1), S32–S37.
- Skarzynski, H., Lorens, A., Matusiak, M., Porowski, M., Skarzynski, P., & James, C.** (2014). Cochlear implantation with the Nucleus Slim Straight electrode in subjects with residual low-frequency hearing. *Ear and Hearing*, 35, e33–e43.
- Spahr, A., Dorman, M., Litvak, L., Cook, S., Loiselle, L., DeJong, M., ... Gifford, R.** (2014). Development and validation of the Pediatric AzBio sentence lists. *Ear and Hearing*, 35, 418–422.
- Summerfield, A. Q., Marshall, D. H., Barton, G. R., & Bloor, K. E.** (2002). A cost-utility scenario analysis of bilateral cochlear implantation. *Archives of Otolaryngology—Head & Neck Surgery*, 128, 1255–1262.
- Van Hoesel, R.** (2015). Audio-visual speech intelligibility benefits with bilateral cochlear implants when talker location varies. *Journal of the Association for Research in Otolaryngology*, 16, 309–315.