Spatial Awareness and Localization: ReSound Live Remote Microphone and Behind-the-Ear Hearing Instruments

Shane Dodge, M.S.

Abstract

ReSound Live hearing instruments equipped with remote microphones offer certain advantages. Remote microphone placement takes advantage of the natural resonances of the human ear through the pinna effect. Research conducted on remote microphone devices has served to legitimize the remote microphone concept and validate the benefits of microphone placement within the concha cymba. Natural spectral cues are maintained, which enhances localization ability and spatial awareness. Further, a microphone tucked into the concha cymba area is effectively protected from wind noise. In order to enrich the listening experience, ReSound Live BTE hearing instruments have been shown to effectively mimic the pinna effect, which restores important acoustic cues for spatial awareness and localization.

Remote microphone placement is a concept developed by Resound. Appearing in the ReSound Live hearing instrument family as a smaller completely-in-the-canal device, ReSound Live remote microphone hearing instruments have satisfied the listening needs of many end-users as a cosmetically discreet, great-sounding product. It is not surprising that end-users fit with remote microphone (RM) hearing instruments have easily had their listening needs met. Being a significant new development in custom hearing instrument technology, ReSound Live hearing instruments equipped with remote microphones offer certain advantages. Remote microphone hearing instruments help maintain natural and directional localization cues through microphone placement in the concha cymba area of the pinna. Because behind-the-ear (BTE) and some traditional custom hearing instruments have less-than-ideal microphone placement, distortions can occur if sound collection from the pinna is not utilized. Taking advantage of the pinna effect helps to preserve natural localization and directional cues. These cues are additionally well-preserved in windy listening situations without the use of a wind noise reduction algorithm. For less-than-ideal microphone placement in hearing instruments such as BTEs, replication of the pinna effect is important for the preservation of localization and spatial awareness. As an element of good sound quality, ReSound Live BTE hearing instruments restore the pinna effect to give a sense of spatial awareness and localization.

Importance of Microphone Placement

It is well known that the human external ear serves to collect sound and offers an enhancement of higher frequency signals. This translates into an enhancement of the clarity of speech, in which approximately 50% of information is obtained from high frequency sounds. Microphone placement can significantly affect the signal-to-noise ratio (SNR), localization ability and spatial awareness (Dillon, 2001). Studies of microphone placement have shown the acoustic advantages of microphone placement in the ear. Griffing and Preves (1976) discussed how microphone placement in the pinna increases the SNR, which could result in improved speech discrimination. Westermann and Tøpholm (1985) demonstrated an enhanced localization performance for both normal-hearing and hearing-impaired subjects wearing in-the-ear (ITE) hearing instruments. Speech-shaped noise served as the stimulus, and localization tasks were attempted under three conditions: unaided, using ITE hearing instruments, and wearing BTE hearing instruments. Normal-hearing subjects performed similarly in the unaided and ITE listening conditions. Hearing-impaired subjects performed best in the ITE listening condition. These results support the significance of microphone placement within the pinna.

Protection from wind noise is another significant advantage of remote microphone placement. The turbulence caused by wind can create a great deal of microphone noise, particularly with hearing instruments utilizing directional microphones (Kates, 2008; Thompson, 2000). Static and impulsive noise generated by wind turbulence can impair speech intelligibility in windy conditions, as well as decrease wearing comfort.

Remote Microphone/Live BTE Studies

Two studies have been conducted which support and legitimize microphone placement within the concha cymba area of the pinna. Picanali and colleagues (2008) investigated the effect of remote microphone placement on directivity, as well as on high frequency gain. In another study, Van den Bogaert and colleagues (2008) investigated the significance of remote microphone placement related to the preservation of spatial awareness and localization ability.

To examine remote microphone placement in regards to directivity and high frequency gain, Picanali and colleagues (2008) measured head-related transfer functions (HRTFs) and the effects of wind noise on a manikin head, which was custom-made with a variety of interchangeable pinnae. Measurements were conducted with microphone placement within the concha cymba of the pinna and in a simulated BTE position outside the pinna (Figures 1 and 2).

Figure 1.
Microphone in the concha cymba position.

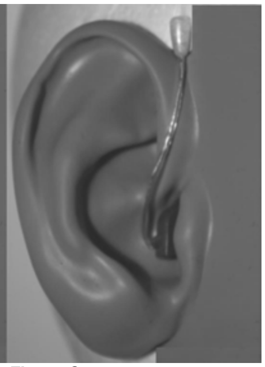

Figure 2.
Microphone in the simulated BTE position.

Measurements were obtained and compared in the following conditions: manikin only, manikin with CIC, with remote microphone hearing instrument, and with remote microphone hearing instrument with microphone in the simulated BTE position. For the assessment of a wind noise effect, wind was produced in various directions towards the manikin at 12 km/h. A speech signal was played during the recordings to serve as a reference. The angles of wind noise stimulus are shown in Figure 3.

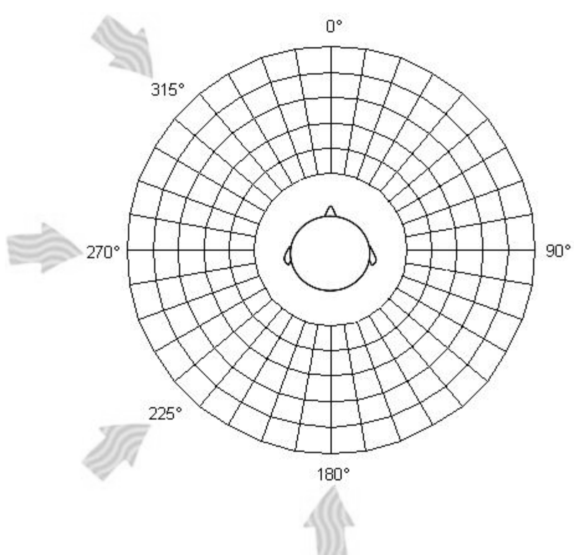

Figure 3. Wind source presented at 180°, 225°, 270°, and 315°.

Results obtained demonstrate that microphone placement in the remote microphone condition provides a significant enhancement of high frequency sounds (Figure 4).

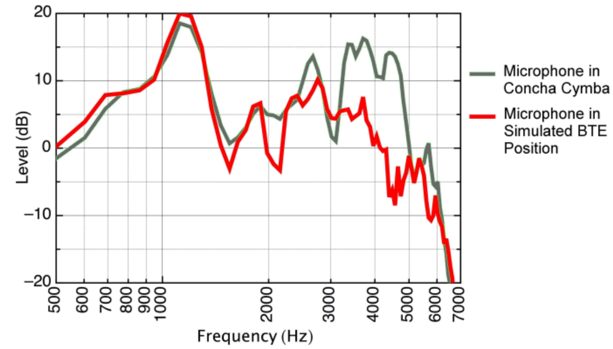

Figure 4. Recorded high frequency advantage for concha cymba microphone placement over simulated BTE position from 3500 to 5000 Hz.

Comparing remote microphone placement to the simulated BTE position, there is a clear enhancement of high frequency sounds due to the pinna effect. The peak-notch-peak pattern between 2500 and 3500Hz has frequently been reported in HRTF characterization studies (Blauert, 1996). The lack of this pattern, as noted in the simulated BTE position, is often linked with front-back localization confusions.

Spectrograph comparisons obtained with microphone placement in the concha cymba area of the pinna and in the simulated BTE position show vast differences (Figure 5).

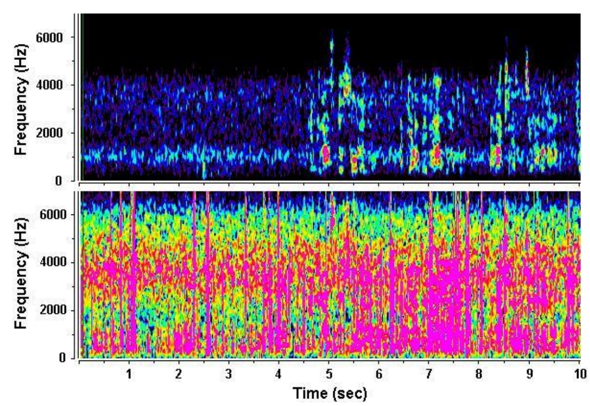

Figure 5. Spectrograph recordings of remote microphone in concha cymba (top graph) and simulated BTE (bottom graph) positions in the presence of wind noise.

When interpreting spectrographs such as the ones depicted here, the colors represent the intensity of energy measured. Blue colors are lower intensity, yellow colors show medium intensity and pink colors indicate high intensity. The top spectrograph was measured with the remote microphone in the concha cymba area. The blue coloration indicates low wind noise at the microphone, and the peaks within the recording indicate that the speech signal is easily discernable. The bottom spectrograph represents the remote microphone in the simulated BTE position. The pink coloration indicates high wind noise levels at the microphone, and a lack of discernible peaks in the recording demonstrates that the speech signal is being masked by the wind noise.

The effects of remote microphone placement and restoration of pinna effect in BTEs on localization was examined in studies conducted by Van den Bogaert et al (2008, 2009). Remote microphone investigations focused on left-right and up-down localization, as well as front-back confusions. Left-right, up-down, and front-back test set-ups are shown in Figures 6, 7 and 8.

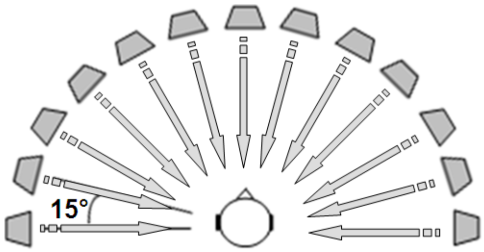

Figure 6. Schematic for left-right localization setup.

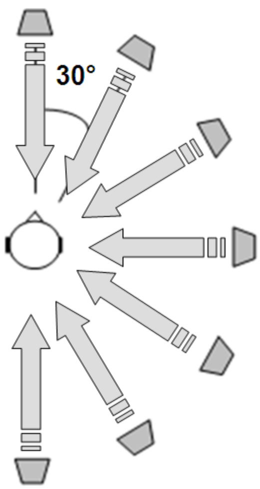

Figure 7. Schematic for front-back localization setup.

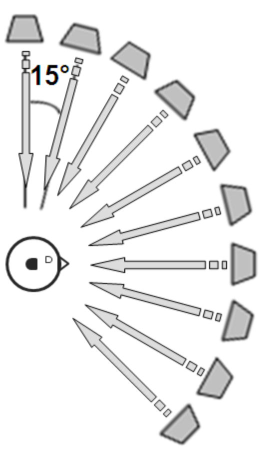

Figure 8. Schematic for up-down localization setup.

Testing was completed on test subjects with normal hearing and test subjects with sensorineural hearing loss. Hearing instruments were programmed with similar settings for normal-hearing subjects, and hearing instruments for hearing-impaired subjects were programmed according to their hearing loss. Hearing instruments that were compared to remote microphone placement included a micro-BTE, CIC, and a BTE hearing instrument that utilizes ear-to-ear communication and a directional scheme that purportedly restores front-biased directionality that is naturally present due to the pinna effect.

For left/right and up/down localization abilities, a root mean square (RMS) measure was used. For front/back localization ability, performance was expressed as a percentage of confusions (i.e., the lower the percentage of confusions, the better the performance). A test/re-test paradigm was utilized, and intra-subject and inter-subject data was collected. Broadband stimuli were utilized in the investigation. Three separate test protocols were used to refine data collection. Protocol one, using normal-hearing subjects, served to develop a meaningful test setup/environment prior to evaluating hearing impaired test subjects. The second protocol evaluated the first test setup/environment and served to improve and correct the test protocol. The third protocol was a larger scale evaluation of hearing impaired test subjects.

An objective measure of energy differences was also obtained to either measure the pinna effect or restored pinna effect of hearing instruments utilized in the study. Energy differences of a 1000Hz sound signal were measured at 0° and 180°, 30° and 150°, and 60° and 120° (figure 9).

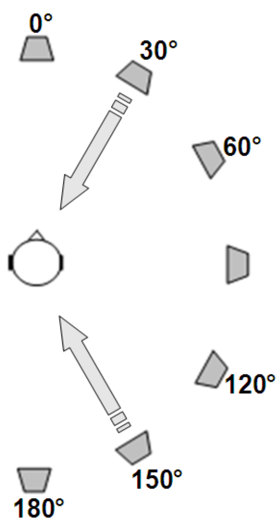

Figure 9. Schematic for front-back energy differences.

The baseline was a CORTEX manikin with open ear canals. The hearing instruments were then fitted to the manikin.

The same test set-up was used for evaluating localization with the ReSound Live BTE hearing instruments. One difference, however, was that up/down localization measures were not collected. This decision was based on results obtained in the remote microphone study, where large variability in both hearing-impaired and normal-hearing test subjects was recorded for up/down localization.

For the trial conducted utilizing ReSound remote microphone hearing instruments, no significant differences were found for left/right and up/down localization ability. For front/back confusions, remote microphone placement demonstrated a reduced percentage of confusions. Of particular interest were the differences between remote microphone performance and the ear-to-ear BTE hearing instrument with a directional scheme that restores front-biased directionality (figure 10).

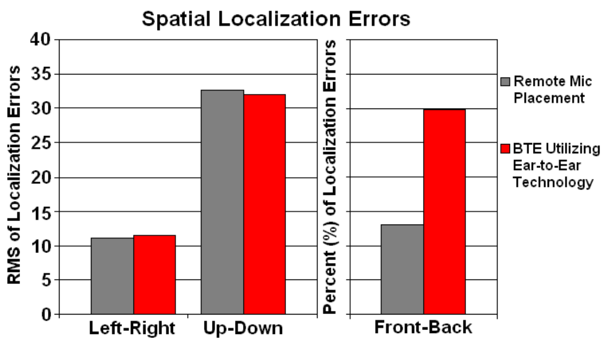

Figure 10. RMS of localization errors for left/right and up/down, and percent of errors for front-back confusions for Resound's RM position compared to competitor BTE that utilizes ear-to-ear technology (from Van den Bogaert et al, 2009).

Sound energy differences in decibels were recorded on a CORTEX manikin for 0° minus 180°, 30 minus 150°, and 60 minus 120° were plotted from 2000 to 7000Hz. For each frequency region, energy differences were plotted using a color schematic where 0dB is the lowest difference and 10dB is the highest difference (figure 11).

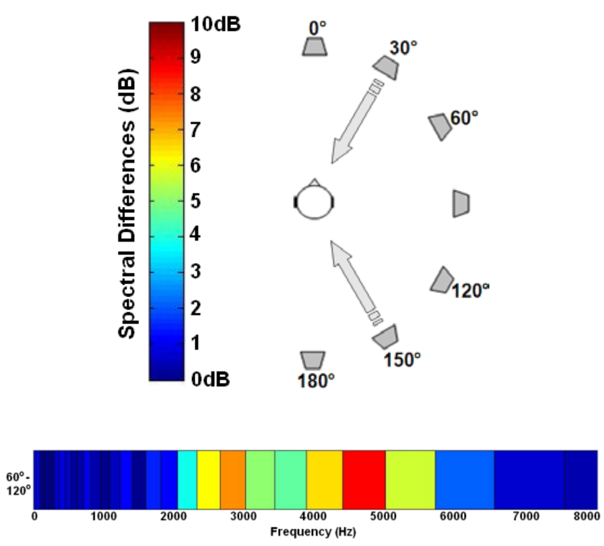

Figure 11. Example of the energy differences on CORTEX manikin at 30° versus 150°. The lowest difference is blue, and the highest difference is brown.

Figure 12 shows the energy difference recordings obtained on the CORTEX manikin head. Recordings were taken from the right ear of the CORTEX manikin.

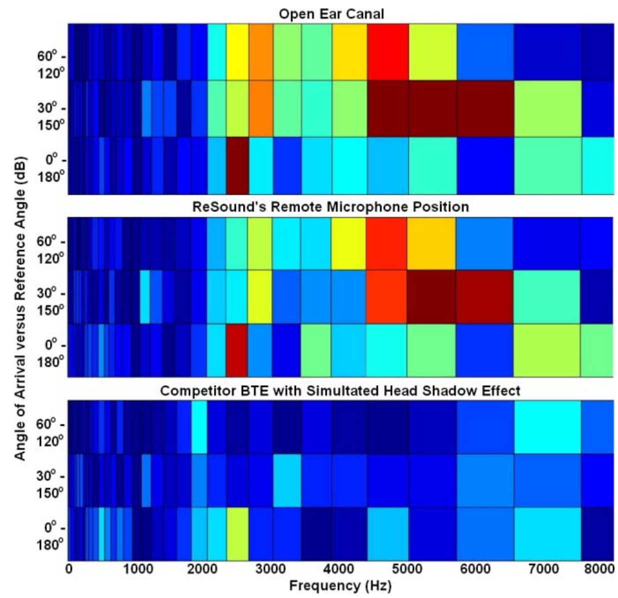

Figure 12. Energy differences for 60-120°, 30-150°, and 0-180° (from top to bottom, CORTEX manikin with open ear canals, Resound's RM position, and competitor BTE). From Van den Bogaert et al, 2009.

Results for remote microphone placement allow for energy differences that are similar to the CORTEX manikin with an open ear. These results indicated that the remote microphone position is effective at preserving the pinna effect. In contrast, results for the tested competitor BTE were primarily blue in coloration. The blue coloration indicates that virtually no energy differences were recorded, and results are dissimilar to both the CORTEX manikin with an open ear canal and the remote microphone device. These results indicate that the BTE hearing instrument measured is not effectively replicating the pinna effect.

For the trial conducted utilizing ReSound Live hearing instruments, no significant differences were found for left/right localization ability. For front/back confusions, remote microphone placement demonstrated a reduced percentage of localization errors. Significant differences were measured between ReSound Live BTEs and the ear-to-ear BTE hearing instrument with a directional scheme that restores front-biased directionality (Figure 13).

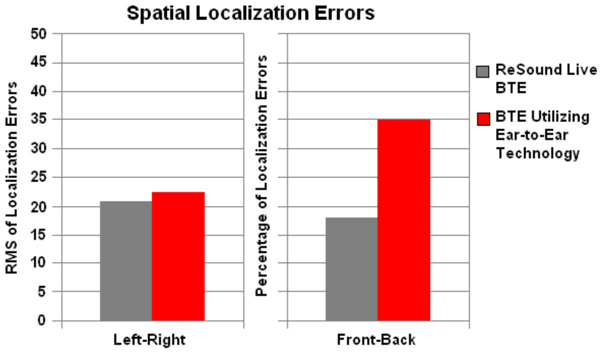

Figure 13. RMS of localization errors for left-right localization, and percent of errors for front-back confusions for the Resound BTE compared to competitor BTE that utilizes ear-to-ear technology (from Van den Bogaert et al, 2009).

Discussion

It has been demonstrated that enhancement of high frequency speech input and localization ability will occur as a result of microphone placement within the concha cymba of the pinna (Picanali et al, 2008). This is likely due to the boost given by the pinna effect in the 3500 to 5000Hz frequency range. Remote microphone placement was also shown to significantly minimize wind noise interference while simultaneously maintaining speech intelligibility in such conditions. Remote microphone placement was additionally shown to be effective at preserving localization cues (Van den Bogaert et al, 2008, 2009a, 2009b). Comparing front-back localization performance, notably with tested ear-to-ear BTE hearing instruments, remote microphone placement significantly contributes to preserving auditory cues due to the pinna effect. As the pinna effect is significantly reduced with microphone placement in the BTE position, compensatory measures must be used to attempt restoration of auditory cues. Comparing front-back performance with the tested ear-to-ear BTE hearing instruments, ReSound Live BTEs effectively restore auditory cues and mimic the pinna effect to preserve auditory cues.

Summary

Remote microphone placement takes advantage of the natural resonances of the human ear through the pinna effect. Research conducted on remote microphone devices has served to legitimize the remote microphone concept and validate the benefits of microphone placement within the concha cymba. Natural spectral cues are maintained, which enhances localization ability and spatial awareness. Further, a microphone tucked into the concha cymba area is effectively protected from wind noise. In order to enrich the listening experience, ReSound Live BTE hearing instruments attempt to mimic the pinna effect. As an extension of the remote microphone study conducted in Leuven, Belgium, ReSound Live BTE hearing instruments have been shown to effectively mimic the pinna effect, which restores important acoustic cues for spatial awareness and localization.

References

Blauert, J. (1996). Spatial Hearing: The Psychophysics of Human Sound Localisation (revised and extended edition). Cambridge (MA): MIT Press.

Dillon, H. (Ed.) (2001). Hearing Aids. Sydney: Boomerang Press.

Griffing, T.S. & Preves, D.P. (1976). In-the-ear aids, Part I. Hearing Instruments, 27, 22-24.

Hawkins, D.B., & Haskell, G.B. (1982). A comparison of functional gain and 2 cm3 coupler gain. Journal of Speech and Hearing Disorders, 47, 71-76.

Kates, J. Digital Hearing Aids. San Diego: Plural Publishing: 2008.

Picinali, L., Mancuso, A., Giancarlo, V. & Pulga, M. (2008). ReSound be: Quality Assessment. A study conducted in Milano, Italy.

Thompson, S.C. Directional microphone patterns: They also have disadvantages. Audiology Online, 2000.

Van den Bogaert, T., Wouters, J., Carette, E. (2008). The influence of helix on sound localization. A study conducted at ExpORL, K.U. Leuven, Belgium.

Van den Bogaert, T., Carette, E. and Wouters, J. (2009a). The effect of using a microphone behind-the-ear, in-the-ear or in-the-pinna on sound source localization by hearing aid users. In preparation.

Van den Bogaert, T., Carette, E. and Wouters, J. (2009b). A comparison of different directional algorithms on left-right and front-back localization. In preparation.

Westmann, S. & Toepholm, J. (1985). Comparing BTEs and ITEs for localizing speech. Hearing Instruments, 36, 20-24.