Advantage of Microphone Placement: A Review of Two External Trials Conducted on be by ReSound™

Introduction

As hearing-instrument technology continues to advance, decisions are often made by the signal processing, and wearers must accept the sound delivered to their ears. While signal processing schemes such as directionality and localization are intended to alleviate the negative effects of peripheral auditory system damage, they may also interfere with the well-functioning higher cortical processes of the central auditory system. For example, a bilateral directional response can improve the speech-to-noise ratio when the desired speaker of interest is in front of and near to the listener and the noise originates from behind the hearing instrument wearer. In other situations, binaural directional instruments can impede important acoustic information originating from behind the wearer. **be by ReSound™** hearing instruments introduce an innovative concept that helps to maintain natural and directional localization cues by placing the microphone within the concha cymba area of the pinna. Because certain hearing instruments, such as behind-the-ear (BTE) devices, remove the microphones from the pinna and essentially place them behind the ear, artificial decision-making often is utilized to compensate for distorted spectral cues when sound collection from the pinna are not used. **be by ReSound™,** by taking advantage of the pinna effect, preserves natural localization and directional cues. Additionally, these cues are preserved in windy listening situations without the use of a wind noise reduction algorithm. This article will review two external trials conducted on **be by ReSound™** that lend support to the rationale of microphone placement within the concha cymba.

Microphone Location

Since sound that is delivered to the ear canal of a hearing instrument wearer is picked up by the hearing instrument's microphone, it is clear that the location of the microphone determines the extent to which the pinna will modify the incoming sound. Microphone placement, for example, can have an effect on localization ability or signal-to-noise ratio (SNR). The acoustic advantages of placing the microphone in the ear as opposed to behind the ear have been well documented. For example, Griffing and Preves (1976) discussed the increased SNR provided by the outer ear and how in-the-ear (ITE) microphone position utilizes this acoustic phenomenon. Additionally, they hypothesized that this microphone placement would result in improved speech discrimination.

Westermann and Tøpholm (1985) demonstrated the significance of microphone placement for the wearer by comparing the performance on localization tasks of hearing impaired and normal hearing subjects wearing ITE and BTE hearing instruments. Subjects were asked to localize samples of speech-shaped noise under three conditions: wearing a BTE hearing instrument, wearing an ITE hearing instrument, and unaided. All subjects performed worse on this task when wearing a BTE hearing instrument. The normal hearing subjects performed equally well unaided and with an ITE, provided the subjects were allowed a short period of time to adjust to the hearing instrument. The hearing impaired subjects localized the signal most accurately when wearing the ITE hearing instruments, possibly because the hearing instruments allowed the subjects to hear acoustic cues which were inaudible in the unaided condition. These results support the notion that a microphone placement which preserves acoustic information consequent to the diffraction of sound by the pinna (i.e., within the concha or ear canal) maintains the wearer's ability to localize sounds and increases the SNR (Dillon, 2001). Also of importance to wearing comfort and maintained speech intelligibility is protection from wind noise due to microphone placement. It is known that wind can have a negative effect on the microphones of hearing instruments, particularly those with directional microphones (Kates, 2008; Thompson, 2000). Both static and impulsive noise can be generated by wind turbulence, and amplification of this noise can decrease wearing comfort and speech intelligibility in wind noise.

The aim of the first study, conducted in Milano, Italy, was to investigate microphone placement on directivity, whether or not a gain advantage occurs due to microphone placement in the concha cymba area, as opposed to a BTE or completely-in-the-canal (CIC) microphone position. Additionally, protection from wind noise by microphone placement in the concha cymba area was investigated. The aim of the second study, conducted at ExpORL, K.U. Leuven, Belgium, was to investigate whether or not microphone placement within the area of the concha cymba significantly preserves spatial awareness and localization ability.

Methods (Milan Trial)

Testing was completed utilizing new hearing instruments, including **be by ReSound™** and CICs. Head-Related Transfer Functions (HRTFs) were measured first on a manikin head, and then with the devices placed on the manikin head. The manikin head was custom made with interchangeable pinnae in order to be able to test the hearing instruments with different pinna shapes. **be by ReSound™** was measured with microphone placement within the concha cymba area, then in a simulated BTE position outside of the pinna (*figures 1 and 2*), and these results were compared to the position of a CIC, as well as to the manikin head with no hearing instrument placed on the ear.

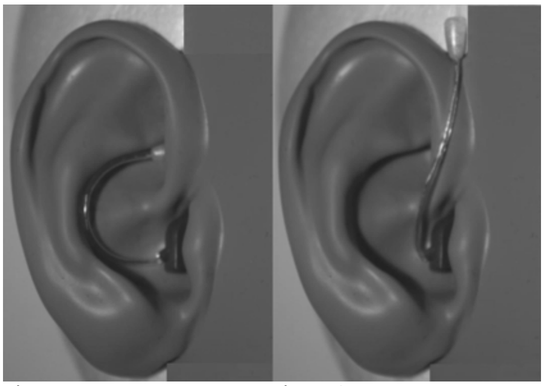

Figure 1.
Microphone in concha cymba area.

Figure 2.
Microphone in simulated BTE position.

The decision to compare **be by ReSound™** in the concha cymba area to a simulated BTE position rather than to BTE hearing instruments was because the goal of testing was to compare the differences in placement of the microphone inside versus outside of the pinna. For assessment of wind effect on **be by ReSound™,** again microphone placement was compared between the concha cymba area and simulated BTE positioning. Wind was produced in various directions at 12 Km/h. In order to be able to have a reference, during wind noise recordings, a speech signal was utilized in the frontal position. Wind was place at various angles, as shown in figure 3.

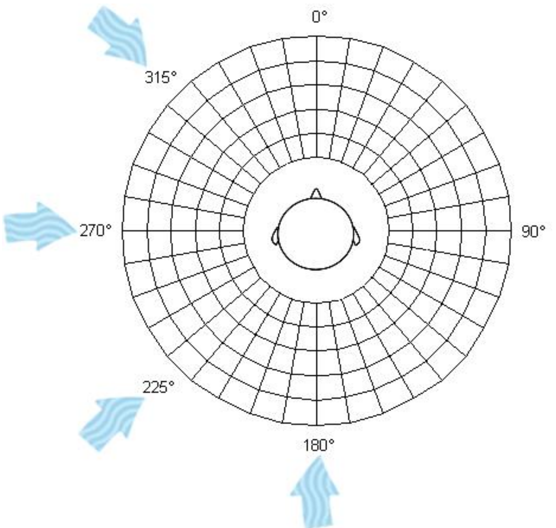

Figure 3. Wind stimulus introduced at 180°, 225°, 270°, and 315°.

Methods (Leuven Trial)

Testing was completed on 14 test subjects with sensorineural hearing loss, as well normal hearing test subjects that served as a baseline. Hearing instruments included **be by ReSound™,** a micro-BTE, CIC, and a recent BTE hearing instrument which utilizes state of art ear-to-ear communication and a directional scheme that restores front biased directionality that is created by the pinna effect. All hearing instruments were programmed with similar settings. Left-Right and front-back performance was measured, as well as elevation performance (figures 4, 5, 6, and 7).

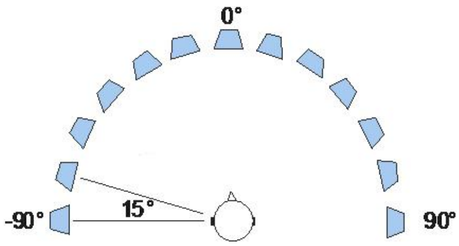

Figure 4.
Left-Right measurement scheme.

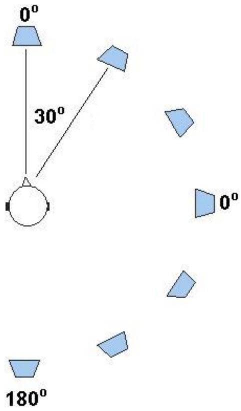

Figure 5.
Front-Back measurement scheme.

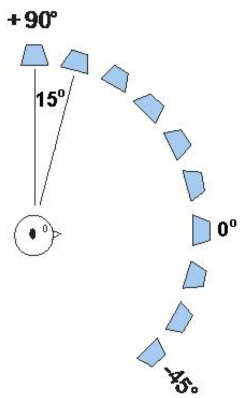

Figure 6.
Elevation measurement scheme.

Figure 7. View of the test setup for left/right, elevation, and front/back localizations.

Left/Right and elevation localization performance was a root mean square measure, and the performance measure for front/back localizations was based on percentage of confusions.

A test re-test paradigm was used, and inter-subject as well as intra-subject statistics were gathered. Stimuli utilized were of limited duration, including 500Hz one third octave band noise, 3150Hz one third octave band noise, telephone signal, broadband speech spectrum of a male talker, and white noise. Acoustic environments included an almost anechoic condition and a "real" living room condition.

Testing entailed three separate protocols. Normal hearing test subjects were used for protocol one. The aim of protocol one was to develop a meaningful test setup/environment and test protocol before evaluating hearing impaired test subjects, as well as to develop a reference framework for testing. Protocol two was a pilot study to evaluate protocol one test subjects with hearing impaired test subjects. The aim or protocol two was to develop a more improved and scientifically correct test protocol. Through protocols one and two, the two stimuli that yielded the most accurate localization ability were broadband speech spectrum of a male talker and white noise. No large influence of reverberation was found (living room condition), and many repetitions were needed due to training effects. For hearing impaired test subjects, hearing loss was compensated with amplification. Protocol three was a larger scale evaluation of hearing impaired test subjects.

Lastly, to objectively measure the pinna effect, objective measures were taken of the energy difference of a 1000Hz sound signal launched at 0° and 180°, 30° and 150°, and 60° and 120°. The baseline was a CORTEX manikin with open ear canals. The CORTEX manikin was then fitted with all hearing instruments utilizing settings from two of the test subjects.

Results

For the Milano trial, comparing the microphone position of **be by ReSound™** in the concha cymba area to a simulated BTE position, there is a clear enhancement in the high frequencies for a speech signal (figure 8).

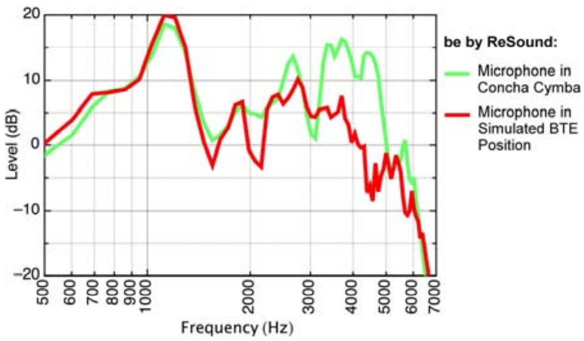

Figure 8. High frequency advantage primarily from 3000-5000Hz due to microphone placement.

Comparing both microphone positions to an open ear, **be by ReSound™** microphone placement maintains a curve that is more closely related to the HRTF. Note the peak-notch-peak pattern between 2500 and 3500Hz, which is frequently reported in HRTF characterization studies (Blauert, 1996). This pattern, which does not appear with microphone in the simulated BTE position, is often linked with front-back confusions.

Comparing **be by ReSound™** with proper microphone placement within the concha cymba to a CIC, both microphone placements follow the manikin's HRTF nicely (figure 9). However, microphone placement in the concha cymba allows for a high frequency advantage from 3500 to 5000Hz.

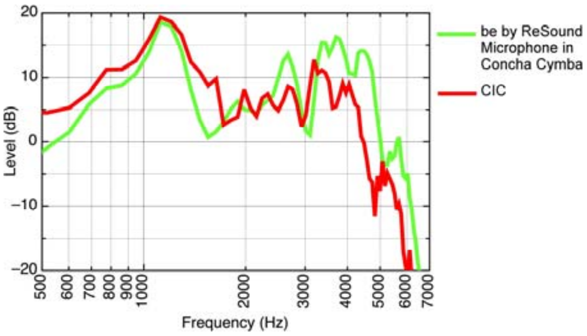

Figure 9. Recorded high frequency advantage for **be by ReSound™** over CIC from 3500 to 6000Hz due to microphone placement.

HRTF comparisons from 0° to 180°, manikin measurements were compared to **be by ReSound™** microphone placement in the concha cymba and in the simulated BTE microphone position (figure 10).

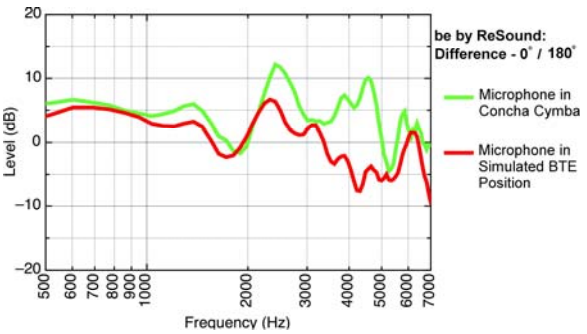

Figure 10. Measured HRTF differences by comparing 0° minus 180°.

Comparing microphone placement in the concha cymba to the manikin, the 0° to 180° difference between the two is similar to each other and very dissimilar to the simulated BTE position, suggesting that the pinna effect is not employed with the microphone in this position.

When comparing **be by ReSound™** microphone position to a simulated BTE microphone position, there clearly is protection from wind noise by microphone placement in the concha cymba area (figure 11).

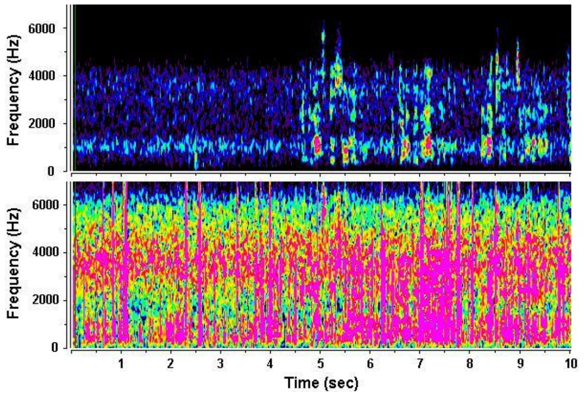

Figure 11. Spectrograph comparisons of concha cymba (top graph) and simulated BTE (bottom graph) microphone positions in the presence of wind noise.

For each spectrograph comparison, microphone placement in the concha cymba is the top graph, and the simulated BTE position is the bottom graph. The blue coloration, along with discernible peaks throughout, indicates that for microphone placement in the concha cymba, the speech signal is clearly visible. The pink coloration, along with no discernible peaks throughout the graph, indicates that in the simulated BTE microphone position, wind noise renders the speech signal unrecognizable.

For the Leuven trial, results were collected for left-right localization, elevation, and front-back confusions. For left-right localization, broadband stimuli allowed for better localization ability than for narrowband stimuli. When the hearing loss was compensated, the performance without hearing instrument was always better than with hearing instruments (although differences were small). Overall, no significant differences were found in overall performance for left-right localization. Similarly, for elevation, no significant differences were found in overall performance, and large variability in both hearing impaired and normal hearing test subjects was recorded.

Significant differences were found for front-back confusions. Of particular interest were the differences between **be by ReSound™** and the ear-to-ear BTE hearing instrument with a directional scene that restores front-biased directionality. While left-right and elevation performance was similar for the two hearing instruments, of particular interest was the difference in front-back confusions (figure 12).

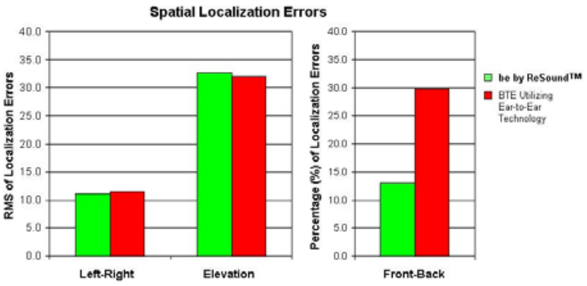

Figure 12. RMS of localization errors for left-right and elevation, and percent of errors for front-back confusions for **be by ReSound™** compared to competitor BTE that utilizes ear-to-ear technology (from Van den Bogaert et al, 2009).

For front-back confusions, **be by ReSound™** performed well compared to the compensated condition, while the tested ear-to-ear BTE hearing instruments performed poorly. This occurred in spite of the fact that the BTE hearing instruments used were supposed to mimic real ear directional performance. Evaluation of sound energy differences recorded for 0-180°, 30-150°, and 60-120° were plotted from 2000-7000Hz. For each frequency region, energy differences were plotted using a color schematic where 0dB, the lowest difference, is blue, and 10dB, the highest difference, was brown. Figure 13 shows the referent CORTEX manikin head for each difference in spectral cues on the right ear.

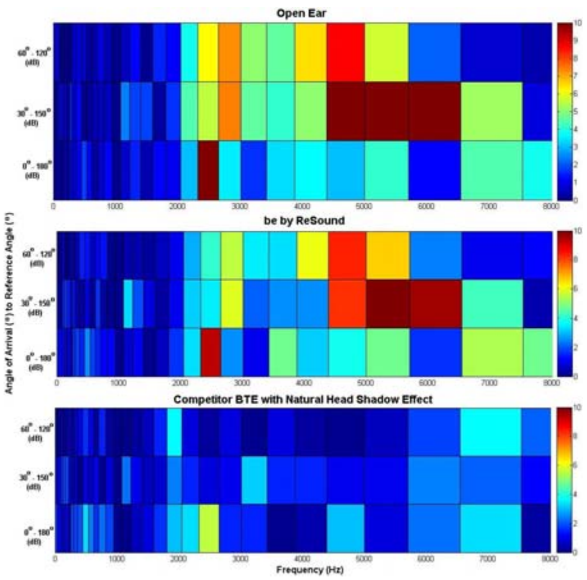

Figure13. Energy differences for 60-120°, 30-150°, and 0-180° (from top to bottom, manikin, **be by ReSound™,** and BTE). From Vanden Bogaert et al, 2009.

What is seen is that **be by ReSound™** closely allows for energy differences that are similar to the CORTEX manikin with an open ear. Results recorded for the tested ear-to-ear BTE were primarily blue in coloration. Virtually no energy differences were recorded, and results are dissimilar to both the CORTEX manikin with an open ear and **be by ReSound™.** This suggests that microphones in the BTE position do not fully utilize the natural sound enhancements due to the pinna effect.

Discussion

For the Milano trial, the enhancement of high frequency speech input due to microphone placement in the concha cymba area will result in better speech intelligibility, improving localization performance and decreasing the front-back confusion effect. For comparisons of **be by ReSound™** using the concha cymba microphone position to a CIC, both microphone positions follow the curve of the manikin's HRTF rather well. However, a slight frequency drop was noted for frequencies above 3500Hz with the CIC. This suggests that microphone placement in the concha cymba area gives a boost the frequency range from 3500 to 5000Hz. Microphone placement in the concha cymba also significantly protects the microphone of **be by ReSound™** from wind noise while speech intelligibility is well maintained.

Another important factor that needs to be considered in the comparison of **be by ReSound™** and CIC measures is that because it is an open fitting, **be by ReSound™** allows passage of frequencies into the ear canal that are out of the range of amplification but may be important for localization cues. With an occluded ear canal, such as what is typically seen with CIC hearing instruments, frequencies not within the frequency range of amplification will likely not reach the tympanic membrane. What this means is that localization cues and speech intelligibility may be decreased for complex, real world listening situations.

For the Leuven study, localization ability was found to be very complex, with many factors playing a role. Microphone placement in the concha cymba area was shown to be as effective as ITE microphone placements. Compared to front-back localization, notably with the tested ear-to-ear BTE hearing instruments, microphone placement in the concha cymba 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, perhaps the compensatory measures used in the ear-to-ear BTE hearing instrument are not adequate.

Summary

Microphone placement within the concha cymba is an entirely new concept for the hearing industry. As this microphone placement is unique, thus far there have been no direct comparisons to other established microphone positions. Results from the Milano and Leuven studies have served to validate the benefits of microphone placement within the concha cymba. This microphone placement has been shown to take advantage of the natural resonances of the human ear through the pinna effect. Natural spectral cues are maintained, leading to enhancement of localization ability and spatial awareness, which yields a more natural listening experience. Further, protection from wind noise is demonstrable, confirms that **be by ReSound™** can be worn comfortably in a variety of listening environments with speech intelligibility left in tact. When combining the proven physical benefits with an already proven non-occluding and cosmetically appealing hearing instrument, **be by ReSound™** is proving to be a unique hearing solution that works.

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