Savia™

Digital Bionics

Real Ear Sound

Summary

Precise localization of sounds is needed to feel comfortable and secure in all acoustic environments. It also contributes to better speech understanding in noise. Unfortunately, the microphone placement in BTE hearing instruments destroys pinna cues which contribute to sound localization. Savia Real Ear Sound restores pinna cues by utilizing advanced signal processing schemes. This results in improved localization ability of the hearing impaired. In particular, front-back confusions are reduced significantly.

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hearing systems

How do we localize sounds?

Accurate localization of sounds is obviously beneficial in daily life. A precise localization of sounds is the prerequisite for "mapping" the environment and feeling comfortable and secure. Furthermore, the intelligibility of a speech signal is enhanced when its spatial position is perceived separately from competing noise sources (Plomp, 1976).

Our ability to determine the direction that sounds are coming from is based on several acoustic cues. A sound coming from the left side of the head reaches the left ear prior to the right ear. This time difference is referred as the interaural time difference (ITD) and ranges from 0 (for a sound from straight ahead) to about 650 µs (for a sound from the side at 90°). In addition, the sound level will be less at the right ear due to the head shadow effect. Frequencies above 1.5 kHz have a wavelength smaller than the diameter of the head, and are substantially attenuated. For example, the interaural level difference (ILD) at 5 kHz is up to 20 dB. For low frequencies around 500 Hz, the interaural level difference is about 5 dB.

Interaural cues are important for determining the direction of incoming sound, which strongly supports bilateral hearing instrument fittings. However, ITD and ILD alone are not sufficient for accurate sound localization. A sound coming from the front results in the same ITD and ILD as a sound coming from behind (namely, zero). Thus, ITD and ILD do not provide any cues to distinguish between these sound directions. Accordingly, a sound from 30° results in the same ITD and ILD as a sound from 150° (see Figure 1). ITDs and ILDs are identical and result in localization errors.

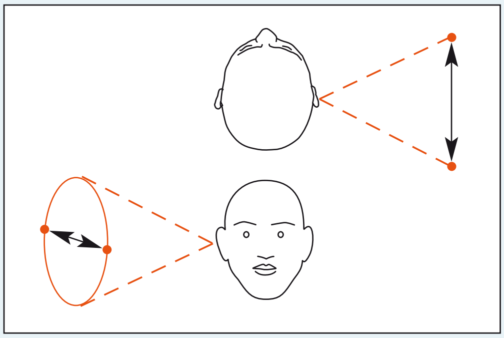


Figure 1
In the "cone of confusion", different spatial locations result in identical ITDs and ILDs.

Additional important localization information to overcome these difficulties is provided by the pinna. Some of the sound reaching the ear enters the outer ear canal directly, and some only after reflection from one or more folds of the pinna (see Figure 2). Direct sound and reflections sum up before they reach the eardrum. This changes the spectral shape of the added signal systematically with the direction of the sound (Blauert, 1996). In addition, the bulge of the pinna provides directivity at high frequencies which serves as a further localization cue. Thus, the pinna provides important monaural spectral information, in particular in the high frequencies, which is necessary to avoid front-back confusions, and also for vertical localization.

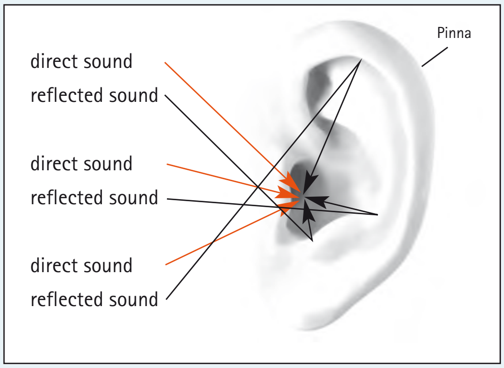
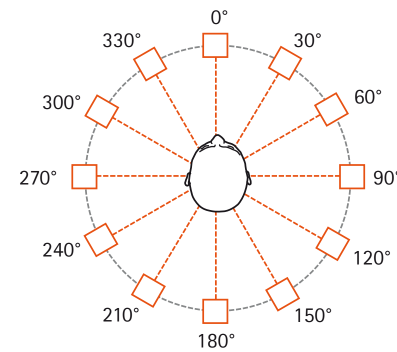


Figure 2
Pinna reflections of incoming sound.

BTE hearing aids and pinna cues

In BTE hearing instruments, the microphones are located above and/or slightly behind the auricle. Thus, natural pinna cues get lost. Figure 3 shows the effect of the microphone location on the natural directivity of the pinna. While there is directivity between about 2-4 kHz when the signal is picked up in the ear canal (as measured with KEMAR), directivity is completely lost when the signal is picked up by the microphone in a BTE hearing instrument in omnidirectional mode. It would be expected that hearing instruments which degrade pinna cues, actually worsen localization. In fact, aided BTE localization tends to be poorer than unaided localization of audible sounds. This was found for both vertical (Noble and Byrne, 1990) and horizontal localization (Orton and Preves, 1979; Noble and Byrne, 1990; Keidser et al., 2004). This degradation of performance with hearing instruments was present in experienced hearing impaired listeners who used their own instruments, but also normal hearing subjects in control groups. In the hearing impaired group, localization performance further decreased when using a different hearing aid style (i.e., ITEs for BTE users and vice versa).



Setup for localization experiments

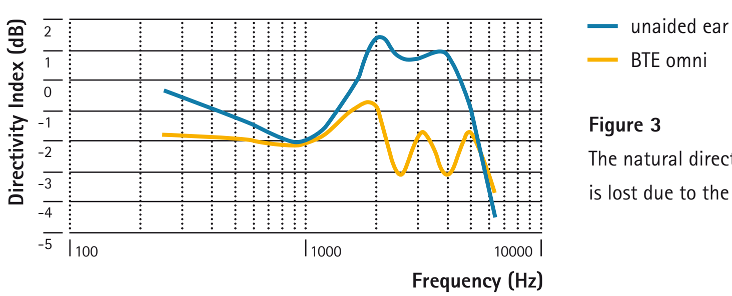


Figure 3
The natural directivity between 2-4 kHz provided by the pinna is lost due to the microphone location in BTE instruments.

Figure 4 illustrates the results of BTE localization experiments in the horizontal plane. Speech shaped noise (500 ms duration) was presented from one of twelve loudspeakers which were located around the subject. From each direction, test signals were presented three times in randomized order. Shown are the localization errors from 9 normal hearing subjects without and with BTE instruments (omnidirectional mode, programmed for a flat 20 dB loss).

It can be seen that the use of BTEs clearly degrades localization performance. In general, the highest localization accuracy was measured with signals coming from the sides. Signals coming from the front or from behind, in contrast, were not located properly in the hearing aid condition, and many front-back confusions could be observed. Front-back confusions can be explained by missing pinna cues. The interaural time and level differences are zero for signals coming from front or behind, respectively. In contrast, the spectral shaping of the signal due to the pinna differs for both directions and serves as a cue for resolving confusions between front and back. With absent pinna cues due to microphone position in BTE hearing instruments, an accurate localization is no longer possible.

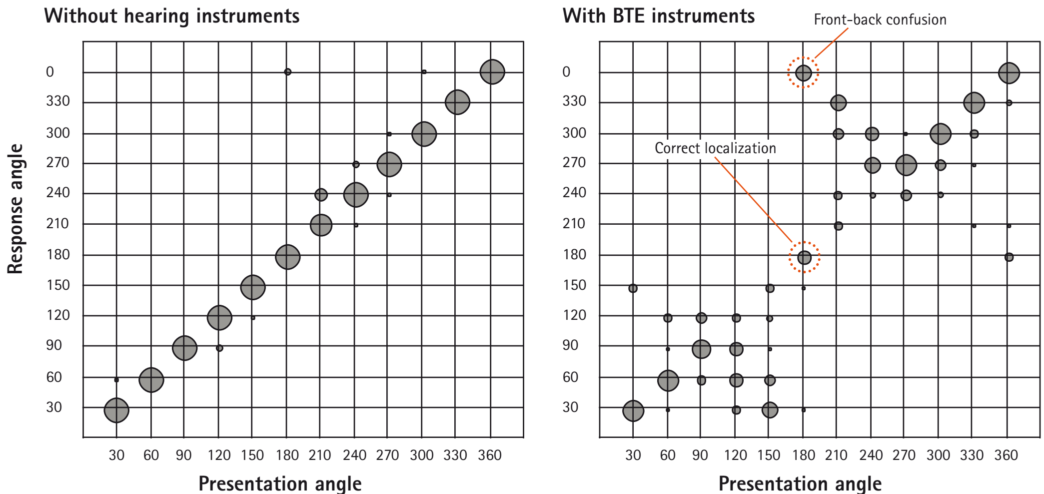


Figure 4

Localization errors for normal hearing subjects for different presentation angles (degree azimuth). Without hearing instruments (left), presentation angle and response angle correspond very well; the localization is almost perfect. Frequent errors, especially front-back confusions, occurred with BTEs in omnidirectional mode (right). (Phonak internal research).

Savia Real Ear Sound

Savia with Real Ear Sound is the first hearing instrument to actually simulate the spectral shaping effects of the pinna.

Figure 5 illustrates how Real Ear Sound restores pinna effects. The picture shows the directivity index across frequency in two conditions: i) measured inside the unaided ear (i.e., the natural directivity pattern), and ii) with Real Ear Sound. It can be seen that the natural directivity in the high frequencies above 1.5 kHz, which is lost in conventional BTEs, is restored with Real-Ear Sound. Thus, Savia meets the prerequisite for precise localization and natural sound impression.

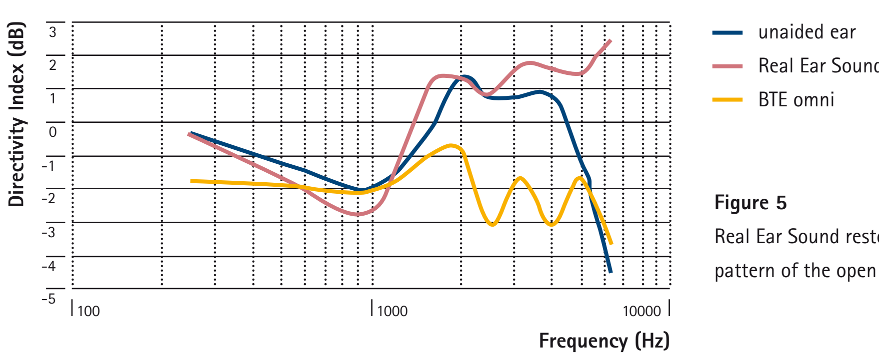


Figure 5

Real Ear Sound restores the natural directivity pattern of the open ear.

Localization Experiments

To evaluate the effect of Real Ear Sound on localization performance, clinical trials have been conducted. In total, eighteen hearing impaired subjects participated. Their age ranged from 25 to 80 years (average: 61 years), and they had a hearing loss (pure-tone average) of 43 dB. They were experienced BTE users and were fitted with Savia 211 BTEs using their own earmolds with vents according to their individual hearing loss. Speech shaped noise (500 ms duration) was presented from one of twelve loudspeakers which were located around the subject, as shown on page 3. From each direction, test signals were presented three times in randomized order. Two test conditions were accomplished: i) with microphones in omnidirectional mode, and ii) with Real Ear Sound. A training run was conducted prior to each test condition. The results of the localization experiments show a clear reduction of front-back confusions (Figure 7). On average, the rate of confusions was reduced by 38%.

The individual effect of Real Ear Sound on localization performance varied between subjects. While some hearing impaired subjects showed moderate improvements, others experienced a dramatic increase in performance with almost perfect localization when using Real Ear Sound (Figure 6).

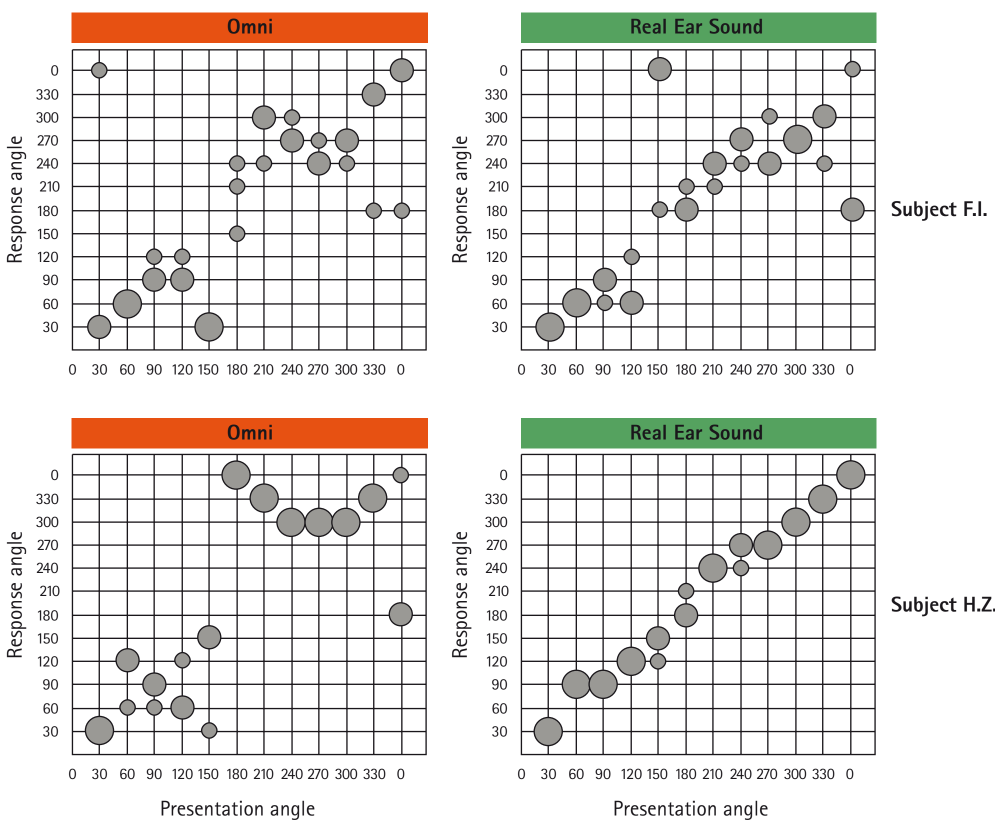


Figure 6

Individual results of localization experiments with omnidirectional microphones (left) and Real Ear Sound (right). While some subjects showed moderate improvements (top), others experienced a dramatic increase in performance (bottom).

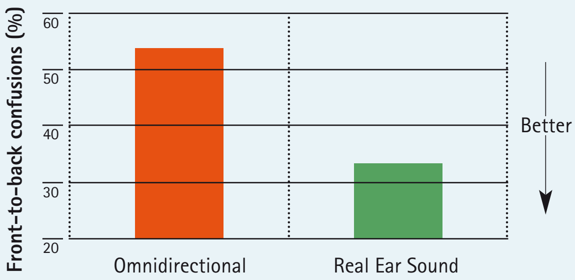


Figure 7
Real Ear Sound allows for a substantial reduction in front-back confusions in hearing impaired listeners (i.e., confusing 0° with 180°, and vice versa).

It should be noted that conventional directional microphones do also have a positive effect on localization performance (e.g., Keidser et al., 2004). However, directional microphones are only recommended for specific listening environments (e.g., for understanding speech in background noise). In other situations, they cause unwanted "shielding" from sounds that should be heard without attenuation. Thus, conventional directional microphones are not appropriate to improve localization performance in all listening situations. Real Ear Sound, in contrast, does not lead to broadband attenuation of sounds and can be activated in all listening situations to restore natural localization performance. Therefore, Real Ear Sound is activated in the Savia programs designed for all around hearing ("Quiet", "Comfort in noise" and "Music"). In the "Speech in Noise" program digital SurroundZoom is activated for maximum speech understanding.

References

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