

Figure 5: One Two Epoq. Results from ratings on selected items from the Speech, Spatial and Qualities of hearing scale of unaided subjects, as well as subjects fitted unilaterally, bilaterally and with two Epoq hearing aids. Based on data from (Noble & Gatehouse 2006) and (Hansen, 2008)

A recent study by Neher et al. (2007) indicates that elderly hearing aid users can have significant residual abilities in this domain, provided that the different talkers differ clearly in terms of their spatial cues.

**Conclusion**

The three features in Epoq designed to improve spatial hearing; binaural compression, increase in bandwidth, and

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**References:**

- Gatehouse S., Noble W., "The Speech, Spatial and Qualities of Hearing Scale (SSQ)", International Journal of Audiology, 2004, Vol. 43, No. 2, pp. 85 – 99
- Hansen L.B., "Success in the pursuit of meeting users' expectations", Hearing Journal, In press, 2008
- Neher T., Behrens T., Kragelund L., Petersen A. S., "Spatial unmasking in aided hearing impaired listeners and the need for training", Proceedings of the International Symposium on Auditory and Audiological Research, Elsinore, Denmark, 2007, In press

improved hearing instrument acoustics with the RITE, can help improve access to the acoustical cues used for navigating spatially complexity. Improvements observed with Epoq, are obtained in a number of dimensions relating to listening in complex environments. These range from social settings indoors, where there is little or no change in the physical layout of the situation, to orientating outdoors in a rapidly changing environment.

- Noble W., Gatehouse S., "Effects of bilateral versus unilateral hearing aid fitting on abilities measured by the Speech, Spatial, and Qualities of Hearing scale (SSQ)", International Journal of Audiology, 2006, Vol. 45, No. 3, pp. 172 – 181
- Singh G., Pichora-Fuller, M. K., & Schneider, B.A. "The Effect of Interaural Intensity Cues and Expectations of Target Location on Word Identification in Multi-talker Scenes for Younger and Older Adults", Proceedings of the International Symposium on Auditory and Audiological Research, Elsinore, Denmark, 2007, In press
- Sivonen V. P., Ellermeier W., "Directional loudness in an anechoic sound field, head-related transfer functions, and binaural summation", J. Acoust. Soc. Am., 2006, Vol. 119, No. 5, pp. 2965 – 29

# Spatial hearing in complex sound environments

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**Summary**

Enabling two hearing instruments to wirelessly exchange information and using this for coordinating compression binaurally is a key feature of the Epoq hearing instrument. When it is combined with an extended frequency bandwidth and better output acoustics with the new RITE hearing instrument style, vital cues for spatial hearing in complex sound environments are rendered more accessible for the user. With Epoq sound sources can be perceived more distinctly, resulting in a number of improvements in performance in challenging listening situations. Amongst these are better speech intelligibility, improved ability to suppress competing voices and interfering sounds, and increased ability to locate moving objects. Thus, improvements observed with Epoq are found in complex and changing sound environments, where the use of spatial hearing abilities is crucial to be able to perform well.

**The challenge**

Being able to understand speech in a complex, dynamic and often also noisy environment, such as a dinner with friends or colleagues is taken for granted by normal hearing people. A normal hearing person is able to find all sound sources in the environment, focus on what is judged as the most important sound source and ignore competing sounds. Mental resources can be focused on the information conveyed by a foreground speaker, whilst only spending limited resources on surveying speakers and noises which have been put in the background.

For the hearing impaired listener, such tasks are typically quite challenging. The organization of a complex sound environment takes a lot of mental capacity, leaving less to focus on the information contained in what is being said by the foreground speaker. However, hearing aids have been shown to be quite effective in helping the hearing impaired improve performance in complex environments (Noble & Gatehouse, 2006). Still, the hearing aid user is left with a number of challenges associated with speech perception and organization of sounds in dynamic and complex daily life situations.

Enabling people with hearing loss to be able to better organize the spatial complexity of typical daily life environments has been a key goal in the development of the Epoq hearing instrument. In the following we will show that users of Epoq have found the experience to enrich their interaction in groups and when orientating outdoors.

**Spatial complexity**

Environments with spatial complexity are common in the world of today. Imagine sitting at home watching TV. When only the TV is heard, the situation is simple. But when a car passes by outside our attention is attracted to it and we can deduce a lot about the car even though we cannot see it. What direction is it driving in? Is it headed for my driveway? As we start noticing other things than the TV, the environment becomes complex.

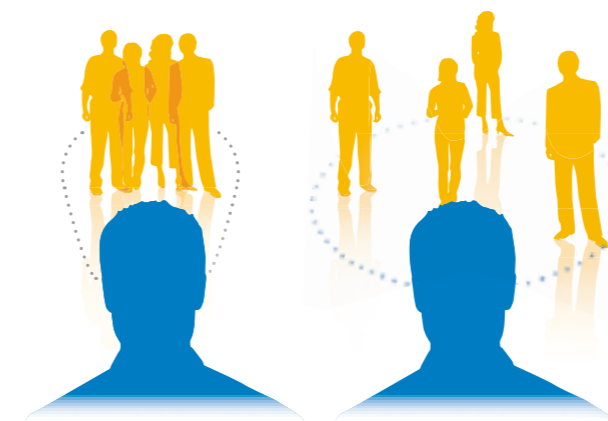


Figure 1: Illustration of how Epoq makes it easier to perceive talkers as distinct and thus enables the user to focus attention to the most important message while suppressing the rest.



From the sounds of the car we are able to deduce the location of the car every instant and from that we determine the direction of it and whether it is something we need to pay attention to.

**Perceiving spatial complexity**

When we perceive sound in a spatially complex environment, the key components of the sound that enables our brain to decode the spatial complexity are differences in time and level of the sounds reaching our two ears. These are known as interaural time and level differences.

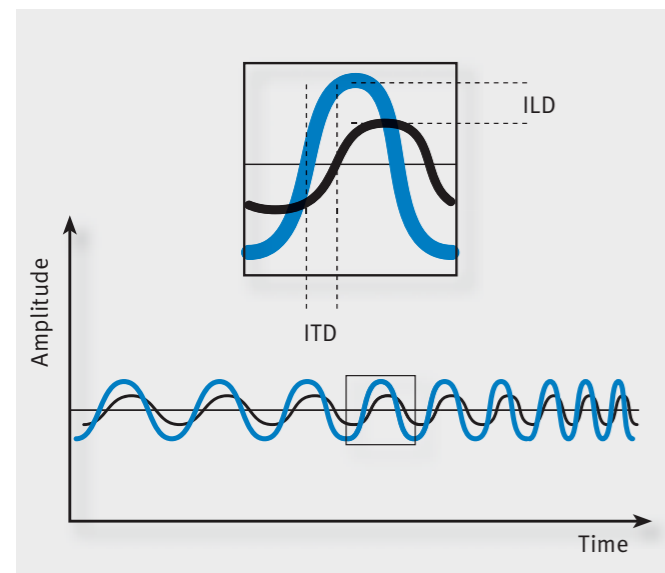


Figure 2: Illustration of Interaural Level Differences, ILD, and Interaural Time Differences, ITD.

It has long been widely accepted that the interaural time differences, ITDs, are the key for locating sources in the horizontal plane. This still holds for very well determined situations in which the listeners' expectations completely match the actual course of events. But when there is uncertainty in the environment, which occurs in many daily life situations, the interaural level differences, ILDs, seem to play an important role (Singh et al., 2007). In Singh et al., 2007 it was shown that in a situation where only ITDs were present, and the location of the target talker was uncertain, meaning that the subject had to listen for a specific cue to find the correct response, average speech recognition was around 20%. When both ITDs and ILDs were present the performance rose to 50%.

That the ILDs may play such a large role is an important finding for the design of compression systems in hearing aids. In Epoq, compression is coordinated between the two hearing instruments in a way that better preserves the ILDs, whilst still allowing dynamic range reduction.

**Bandwidth**

Bandwidth is another important aspect of spatial hearing. The ITDs are predominately a low-frequency phenomenon, being effective only below 1500 Hz and thus quite robust to most types of hearing loss. However, ILDs first start reaching a magnitude of 5 dB at frequencies higher than about 1 kHz; above approx. 6 kHz they can reach 20 dB or more. This is shown in figure 3.

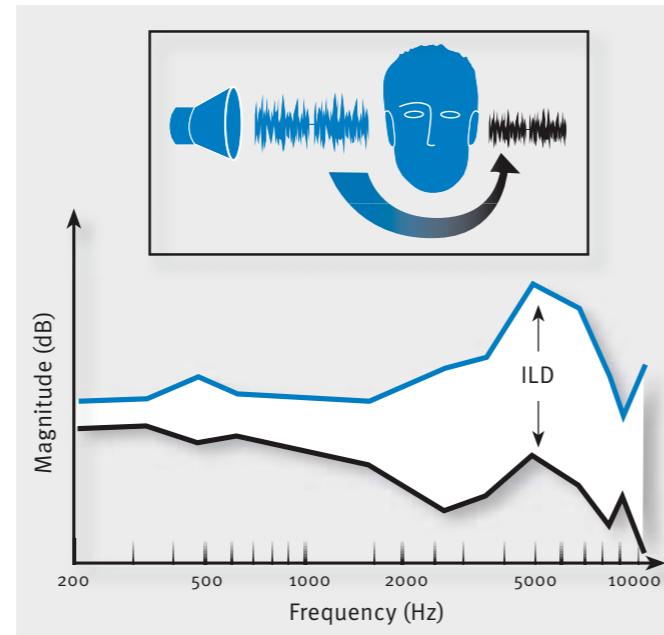


Figure 3: Magnitude of the interaural level difference, ILD, versus frequency. Based on data from Sivonen and Ellermeier, 2006.

Consider a situation where a noise source is placed to on a listener's left side and a speech source is placed to the right. The speech reaching the right eardrum is amplified by the blue curve on figure 3, whereas the noise reaching the right eardrum is amplified by the black curve, creating the so-called "better-ear" effect on the right ear. Therefore, the more audibility is provided at higher frequencies, the more access is provided to locally favourable signal-to-noise ratios at high frequencies. To take advantage of this, Epoq has an extended bandwidth to allow access to such high frequency information.

**Frequency response of the RITE**

Spatial cues are mediated by the sound sources which are active at any moment in time. Each sound source has its own unique characteristics, amongst those, how much energy is present at different frequencies. The frequency response of the hearing aid contributes to determining how we perceive the source. Hearing aid acoustics change the way sound is perceived. One aspect of this is the output stages of the device, which notably in the case of a thin tube BTE solution imposes peaks and notches on the frequency response of the device. Such peaks and notches can be mistaken for or can partly

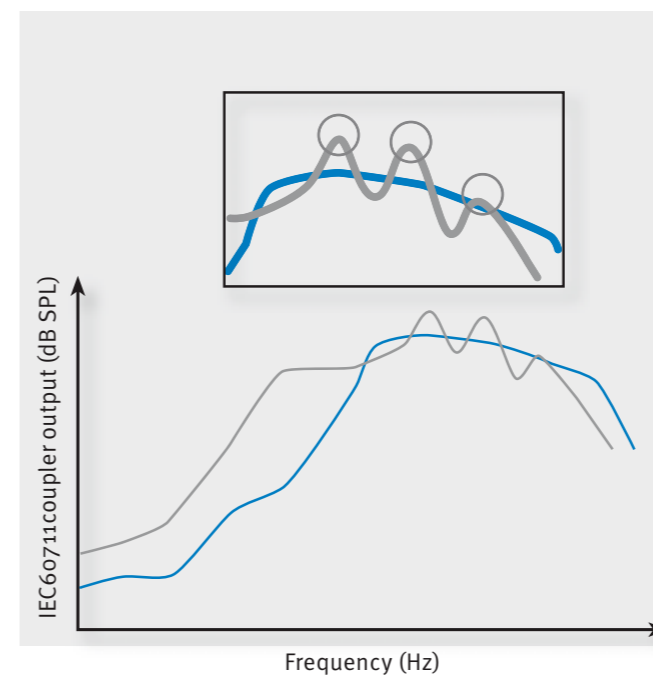


Figure 4: Frequency response of EPOQ RITE (blue) versus a typical thin tube solution (grey)

conceal spatial cues. These are used to determine whether a sound source is located directly in front or directly behind. However, a receiver in the ear (RITE) type solution, as offered by Epoq, will not create peaks and notches of a nature that will distort monaural spatial cues.

**Assessing performance in complex environments**

A relatively new, but well documented tool which can be used for assessing user performance in complex environments is the Speech, Spatial and Qualities questionnaire (Gatehouse and Noble, 2004), also known as the SSQ.

The SSQ has recently been used to assess the effects of bilateral versus unilateral hearing aid fitting (Noble and Gatehouse, 2006). In this study, it was demonstrated that the extra benefit of two hearing aids relative to one hearing aid is especially apparent in complex environments, in which divided or rapid switching of attention is necessary, and in situations that involved discrimination of distance and movement.

**The Epoq clinical study**

As part of evaluating Epoq, a clinical study at Oticon Denmark used an abbreviated version of the SSQ for assessing performance in typical daily life situations with spatial complexity. The 58 adults taking part in the study were experienced and satisfied hearing instrument users, with a relatively active lifestyle and a moderate hearing impairment. None of them were trained listeners. All test persons wore Epoq (no-name shell) for a test period of at least 4 weeks. Details of the study can be found in (Hansen, 2008). Interview administered ratings

from the abbreviated SSQ were obtained both for the subjects own hearing aid and Epoq.

**One Two Epoq**

The results of the Epoq clinical studies are presented below along with results from the Noble and Gatehouse 2006 study. In order to be able to compare the results of the two studies some adjustment of the ratings was necessary. Epoq was compared to subjects own aid, which was typically Oticon Syncro. The bilateral and unilateral data from Noble and Gatehouse 2006, were based on other older technology, so it was necessary to adjust the ratings to account for differences in technology.

The only comparable data was bilateral data obtained on both the devices used in the Noble and Gatehouse, 2006 and in the Epoq clinical studies. First a technology level difference was computed as the difference between the bilateral ratings obtained on the Syncro hearing aids in the Oticon clinical study and the bilateral ratings obtained in the Noble & Gatehouse, 2006 study. This technology level difference was then added to the unilateral ratings of the Noble & Gatehouse, 2006 study, to obtain a unilateral rating corresponding to what one would likely have obtained from hearing aid users wearing one Syncro device. The net result of this was that the unilateral ratings shown in the figure are higher than those presented in (Noble & Gatehouse, 2006).

In summary, the unaided ratings are directly reproduced from Noble & Gatehouse 2006, the unilateral ratings have been adjusted as described above and the bilateral and Epoq ratings have been reproduced directly from the Epoq clinical study. In Figure 5 it is seen how hearing aid users rate their ability to hear in seven different situations. From the unaided ratings it can be observed that in quiet, performance is judged to be much better than in the group and outdoor situations. A unilateral hearing aid fitting increases average ratings by about 2 scale points of 10. Relative to the unilateral ratings, ratings obtained from a bilateral fitting are higher by about 1 scale point in the group and outdoor situations. Finally, it can be seen that the ratings based on Epoq fittings are on average almost 1 scale point higher than the bilateral ratings. Thus the improvements observed with Epoq relative to bilateral ratings are approaching the magnitude of the improvements found with bilateral ratings over unilateral ratings.

The improved performance observed in group settings is indicative of Epoq users being better able to spatially separate different talkers. This, in turn, could allow them to focus on one particular talker and thereby to ignore the other interfering talkers – a process known as auditory selective attention. Auditory selective attention or the ability to ignore interfering sounds and voices at will is for instance used whenever communication is taking place in a competing background.