Abstract

The e2e wireless™ technology facilitates genuine bilateral fittings. Recent research on e2e wireless proves its positive effects on ease-of-use, speech intelligibility and localization. In addition, e2e wireless diminishes the “Stigma” effect by assuring maximum discretion through smaller housings and less manual adjustments. Binaural synchronization is an essential technological prerequisite for new and improved hearing instrument features like the Learning Volume Control, sophisticated DNR algorithms, state-of-the-art microphone technology or an intelligent classification system. Thus, e2e wireless should be used regularly for bilateral fittings.
Decades of research have substantiated that binaural hearing is superior to monaural hearing. This research has focused on areas such as sound detection, localization, speech intelligibility and sound quality (Blauert 1996). Considerable research on the advantages of bilateral hearing instrument fittings also has been conducted. In general, the benefits observed for binaural hearing and bilateral hearing instrument use are mostly the same (Byrne 1980, Byrne 1981, Ross 1980, Byrne et al. 1992).

The three major factors related to the use of bilateral hearing instruments are: elimination of the head shadow effect, binaural squelch and binaural redundancy (Dillon 2001). Due to the head shadow effect that occurs when only one hearing instrument is used, audibility is improved for signals from both sides of the head when a second hearing instrument is aided. Importantly, this has the greatest benefit for frequencies in the 1500–4000 Hz range, critical for understanding of soft speech.

As we know from psychoacoustic research, the human brain is able to extract more information from speech signals in competing noise when both ears are used. If different signals are available to left and right ear, this effect is called “Binaural squelch,” while “Binaural redundancy” implies identical signals at both ears. In combination with the head shadow effect, speech intelligibility in noise can be improved by 5 to 6 dB (Dillon 2001).

Given these advantages, it would seem that most people with a bilateral hearing loss would be candidates for bilateral fittings, and indeed this is true – approximately 85% (Dillon 2001). The prevalence of bilateral fittings, however, falls far below this number. Figure 1, from Kochkin 2003, shows the bilateral fitting rates for different countries (Kochkin 2003). Only the U.S. approaches the projected 85% value, while most other countries fall far below.

It is important to question why so many people in need of bilateral hearing instruments are only fitted unilaterally. Some possible explanations are (Dreschler 2005, Hickson 2005):

- Ease-of-use: two hearing instruments are too much to bother with.
- Speech understanding is not improved by a second hearing instrument.
- Localization does not benefit from a second hearing instrument.
- Stigma effect is more pronounced with a second hearing instrument.

<table>
<thead>
<tr>
<th>Country</th>
<th>Bilateral Fitting Rate (%)</th>
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<tr>
<td>Japan</td>
<td>12</td>
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<tr>
<td>Spain</td>
<td>20</td>
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<tr>
<td>England</td>
<td>35</td>
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<tr>
<td>Germany</td>
<td>40</td>
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<td>France</td>
<td>45</td>
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<tr>
<td>Scandinavia</td>
<td>50</td>
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<tr>
<td>Italy</td>
<td>50</td>
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<tr>
<td>Netherlands</td>
<td>60</td>
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<tr>
<td>US</td>
<td>74</td>
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Percentage of bilateral fittings in various countries (Kochkin 2003)
Examining the Advantages of e2e wireless Technology

Recently, Siemens introduced e2e wireless technology that enables the right and left hearing instruments to work together in a harmonized system (Powers, Burton 2005). The input obtained from both instruments is shared so that important decisions concerning signal processing are based on this combined intelligence. This allows for symmetrical steering of important functions such as the digital noise reduction features and the automatic directional microphone technology.

e2e processing ensures that both instruments are analyzing, interpreting and reacting together as one system enabling patients to take full advantage of the benefits of binaural hearing. e2e wireless is based on the concept of a single integrated auditory system.

In addition to the combined intelligence and the symmetrical steering of processing functions, e2e wireless enables the bilateral sharing of wearer commands (i.e. changes in gain setting or hearing program selection). An adjustment of the volume control of one hearing instrument results in a symmetrical change in gain for both instruments. Likewise, a single push of the program button on one hearing instrument simultaneously changes the program for both hearing instruments.

e2e wireless technology uses electromagnetic transmission to communicate between the two hearing instruments, and also between hearing instruments and an optional ePocket™ remote control accessory. The communication is conducted through modulation via frequency shift keying technology, employing transmission frequency shifts between 115 and 120 kHz. Transmission between instruments is enabled for distances up to 30 cm.

The real world customer benefit of e2e wireless has been the subject of many recent studies. Since e2e wireless was specifically designed to support bilateral hearing instrument fitting, it is of particular interest to see how e2e wireless addresses the potential reasons for rejecting bilateral fittings discussed in the introduction.

Ease-of-Use

It is well-known that many elderly patients have a reduced manual dexterity or a limited range of arm/hand motion. For many of them, it is already a great challenge to handle the program switch or the volume control of a single hearing instrument. Moreover, being able to manage one hearing instrument does not necessarily imply to be able to manage two hearing instruments (Hickson 2005). Thus, simplifying the usability of hearing instrument controls is highly important, especially for bilateral fittings. With e2e wireless, changes of volume or program made on one side are simultaneously applied to the opposite side – managing two hearing instruments therefore becomes as easy as managing one! e2e wireless also offers "split controls": a VC on the one instrument and a push button for program change on the other. Then, there is no longer the need for two controls on one instrument. Thereby, ease-of-use is significantly improved and handling of two hearing instruments becomes even easier than one. Even patients with normal dexterity may prefer hearing instruments with e2e wireless as it allows them to make changes more precisely.
A study at the Hörzentrum Oldenburg, Germany, examined the advantages of e2e wireless with regards to usability. Twenty subjects with mild-to-moderate hearing loss were bilaterally fitted with ACURIS S BTE instruments and 20 subjects with moderate-to-severe hearing loss with ACURIS P BTE instruments. Both groups wore the instruments in daily life for two weeks. All subjects were experienced hearing instrument wearers who reported no problems in changing programs or adjusting the volume on their current hearing instruments. Ninety-five percent of the subjects in Group 1 reported that controlling both instruments with one push button was useful to them. Only one participant disagreed with this statement (see Figure 2). The group with the moderate-to-severe hearing loss was asked to rate the binaural volume control. The binaural volume control was considered as useful by 70% of the subjects (see Figure 3).

When subjects who disagreed with this statement were asked why, they most frequently mentioned:
1) The effort for managing two controls simultaneously is already negligible and (often in combination)
2) they used VC controls very rarely.
Interestingly, these results are in close agreement with a simultaneously conducted four-site field trial (Powers & Burton 2005). Combined results clearly indicate that improved ease-of-use is reported by patients and that e2e wireless strongly supports bilateral hearing instrument fitting.
Advanced Real-Life Fitting Techniques

With CENTRA, Siemens introduced the first trainable hearing system, as well as a data logging feature for fine tuning and counseling.

To determine the effect of coupling on these features, a group of ten hearing-impaired individuals participated in a crossover design study. The two conditions of this study were: Using the Learning Volume Control (LVC) for a bilateral custom CENTRA ITE fitting with the two hearing instruments either in a coupled or uncoupled condition. The hearing instruments were fitted according to the Siemens CENTRA First Fit protocol with three different programs. Minor adjustments after First Fit were performed to assure that the two hearing instruments were “balanced.” The participants used each of the two counterbalanced fitting arrangements (coupled vs. uncoupled) for a one-week trial in their everyday environment.

After the one-week trial, the hearing instruments were read out and the individual, program-specific volume changes were analyzed via CENTRA’s DataLearning™ feature. As shown in Figure 4, with uncoupled controls patients’ different settings for left and right instruments resulted. Note that loudness balance was adjusted after First Fit and – more importantly – after the trial, subjects frequently reported undesired loudness differences between both ears for instruments worn in the uncoupled condition. As expected, no volume difference was revealed for instruments worn in the coupled condition, nor loudness differences were perceived by the subjects. Examining individual data reveals an average mismatch for the left and right instruments in the uncoupled condition of 6 dB, with one participant having a mismatch as large as 13 dB between instruments. These large gain mismatch values are in agreement with the gain matching research of Hornsby and Ricketts (Hornsby & Ricketts 2005). In addition, nonsynchronized program change also may have contributed to the large gain mismatch in the uncoupled condition. These overall findings clearly show that e2e wireless is a mandatory prerequisite for trainable hearing instruments and for changes made based on the traditional data logging information.

“…e2e wireless is a mandatory prerequisite for trainable hearing instruments and data logging.”
Localization

Sounds originating from a source not directly located in front of, or behind a listener will arrive at the two ears at slightly different times, and have different intensity levels and spectral shapes. Specifically, as shown in Figure 5, sounds from the right will arrive later and softer at the left ear than at the right. These differences in time and intensity are called interaural time and level differences (ITD and ILD) and are caused by the distance traveled and the diffraction of the sound by the head and pinna. ITD and ILD are the dominating cues for left/right discrimination in the horizontal plane whereas monaural spectral differences are predominant for front/rear discrimination (Blauert 1996). Time differences are dominant as long as the signal has audible components at frequencies below 1500 Hz, whereas intensity differences are more pronounced at frequencies above 1500 Hz (e.g. Wightman and Kistler 1992). Spectral cues for front/rear discrimination are located mainly above 4 kHz.

To ensure that binaural hearing is not adversely affected by hearing instruments, interaural time and intensity differences must not be altered by hearing instruments’ signal processing. If gain is different in the left and right hearing instruments, ILDs become distorted, while different delays on each side will affect ITDs. Since different time delays are used to implement different polar patterns, nonsynchronized microphone modes (e.g. omni left, directional right) will also affect the ITD cues.

“Interaural time and intensity differences must not be altered by hearing instruments’ signal processing.”
Figure 6 shows the effect of nonsynchronized microphones on localization for 12 hearing-impaired listeners (Keidser et al. 2006). Since interaural time and intensity distortions only affect the left/right discrimination, the front/back confusions have been ignored in the analysis of the data. The localization error is largest when an omnidirectional microphone mode is used on one side and a directional (cardioid pattern) on the other. If the microphones are matched – no matter whether they are both omni or both directional – the localization error decreases by approx. 40%.

In a multimemory hearing instrument fitting whereby the instruments are equipped with a volume control and featuring digital noise reduction (DNR) and directional microphones, ITDs and/or ILDs are likely to be distorted in the following cases:
1. Unbalanced volume setting left instrument vs. right \( \uparrow \) ILD distorted
2. Different microphone modes left instrument vs. right \( \uparrow \) ITD distorted
3. Different programs active on the left and the right hearing instrument \( \uparrow \) ILD and ITD distorted
4. Different settings for digital noise reduction left instrument vs. right \( \uparrow \) ILD distorted

\( \text{e2e wireless provides a solution for cases 1 and 3 by coupling the volume control and the hearing programs. Case 2 and 4 are addressed by the binaural classification system in instruments with e2e. The binaural classification system enables bilaterally synchronized directional microphones and DNR. Hence, only with binaural synchronization are the binaural cues for localization preserved. These considerations clearly emphasize that e2e wireless improves localization for bilateral fittings.} \)
Speech Intelligibility

The effect of synchronized directional microphones on speech intelligibility was investigated in a study conducted at Vanderbilt University (Hornsby and Ricketts 2005). Aided speech intelligibility in noise was assessed using the Hearing in Noise Test (HINT; Nilsson, Soli & Sullivan 1994) with sixteen participants with mild-to-severe flat or sloping sensorineural hearing losses. The result of a HINT is the speech reception threshold (SRT) which is defined as the signal-to-noise ratio required for 50% correct word recognition. As shown in Figure 7, speech was presented from front, whereas noise was played from four loudspeakers located around the listeners, creating a diffuse sound field which exists in many everyday listening situations.

The most important finding of this study was the fact that matched directional microphone modes in both instruments significantly increase speech understanding in noise when compared to mismatched microphone settings. In this test setup, which was similar to everyday listening (talker in front, noise surrounding) a signal-to-noise benefit of 1.5 dB was found. In other listening situations the benefit of matched processing may be as high as 4.5 dB (Mackenzie et al. 2005). Note that the percentage of correct words in sentence intelligibility tests increases by 10% to 20% per dB in SRT. Thus, an improvement of 1.5 dB to 4.5 dB in SRT corresponds to an increase in sentence intelligibility between 20% and 40%. The e2e wireless technology found in CENTRA ensures matched directional microphone modes at all times.

Speech reception threshold in babble noise is improved by 1.5 dB for matched directional microphones. Study conducted at Vanderbilt University, USA (Hornsby & Ricketts 2006).
Stigma

It is generally accepted that the stigma effect is one of the leading reasons for rejection of hearing instruments (Kochkin 2001). Two hearing instruments are often regarded to make one’s hearing impairment needlessly obvious and visible to others (“I was not happy about two – I didn’t think my hearing was that bad,” Hickson 2005). Solutions to overcome the stigma effect can be classified into long-term, mid-term and short-term approaches. By far the most efficient approach would be, to simply turn the negative “image” of hearing instruments into a positive: hearing instruments are fashionable, just like eyeglasses. If possible, this approach is likely to take some years to accomplish, and must be regarded as a long-term solution. A mid-term solution would be to avoid hearing instruments from being classified as “prostheses.” This might be achieved in the future by offering hearing instruments in a look similar to modern communication devices. The most straightforward method against stigma, however, is still cosmetic appeal and discretion. The key factors to support this goal are miniaturization of components and instruments in addition to discrete handling. Both are supported by e2e wireless: e2e wireless easily fits into micro-CICs and open fitting Life products. Moreover, due to its efficient implementation, power consumption is not an issue – in contrast to other wireless technologies. Also, e2e wireless allows the manufacture of smaller-sized custom instruments as split controls are possible (i.e. push button on right instrument, volume control on left). Finally, since e2e wireless reduces the amount of bilateral wearer adjustments and offers a remote control (ePocket™), discrete handling is guaranteed. Thus, e2e wireless supports bilateral hearing instrument fitting by reducing the stigma effect to a minimum.

Real-World Benefit of e2e wireless

Do the above named advantages of e2e wireless (better localization, improved speech intelligibility, ease-of-use, higher discretion) have a positive impact on the perceived performance of hearing instruments in real life?

A retrospective analysis of five field trials was conducted to examine these topics. In these studies (conducted at Hörzentrum Oldenburg and ENT department of the University Munich, Germany) hearing-impaired subjects wore different types of ACURIS (ITE, P, S, CIC) for two weeks with e2e wireless switched off and for two weeks with e2e wireless activated. The subjects rated the performance of the hearing instruments on an 11-point scale ranging from “very bad” to “optimum.” The ratings for the nonwireless condition were then normalized to 100% and differences to the wireless condition were calculated as percentages. The mean benefit across all subjects and studies is 21% (see Figure 9). The benefit of e2e wireless is very similar regardless of model. It was assumed, that the benefit for CICs would be rated higher, as e2e wireless allows for program switching and volume control, whereas for BTE and larger custom models this also is possible without e2e wireless. However, e2e wireless increases the perceived performance of hearing instruments for all models, regardless of type.

Fig. 9 Perceived e2e benefit

![Graph showing perceived benefit of e2e wireless for different hearing instrument types.]

Benefit of e2e wireless in perceived performance for different hearing instrument types compared to same devices with deactivated e2e wireless. The types studied were: P=Power BTE, IT=Full shell directional ITE, S=Mini BTE, CIC. Study 1 conducted at the ENT department of the University Munich, Germany, all other data collected at the Hörzentrum Oldenburg, Germany.

“The most straightforward method against stigma, however, is still cosmetic appeal and discretion.”
Summary

At the beginning of this article the reason why bilateral fitting rates in most countries are much smaller than the percentage of hearing-impaired subjects who are likely to benefit from bilateral fitting was discussed. Suggested reasons included: a concern that two hearing instruments are too difficult or bothersome for some patients; a perception that a second hearing instrument does not improve localization nor speech understanding; and a belief that a second hearing instrument adds to the stigma associated with hearing instruments. Summarizing the data and considerations presented in this paper indicates that e2e wireless provides a solution for each of these issues and assures an optimal binaural fitting:

- **Ease-of-use**: e2e wireless reduces the effort for managing two hearing instruments by 50% as volume and program have to be selected only one time to control both instruments. Moreover, due to the option of “split controls,” adjustments are easier and more precise.

- **Advanced real-life fitting techniques**: e2e wireless is a mandatory prerequisite for DataLearning (trainable instruments) and data logging.

- **Localization**: e2e wireless preserves perceptual cues which are necessary for spatial listening and thereby improves localization over noncoupled instruments.

- **Speech understanding**: Having matched directional microphone modes on both instruments significantly increases speech understanding in noise compared to nonsynchronized systems. Depending on the test condition, improvement in SRT between 1.5 dB and 4.5 dB can be expected. This corresponds to an increase in sentence intelligibility between 20% and 40%. e2e wireless ensures that the microphone modes are matched at all times.

- **Stigma**: e2e wireless supports bilateral hearing instrument fitting by reducing the stigma effect. Due to an extremely efficient implementation of wireless technology, e2e wireless comes in extremely cosmetically appealing styles and allows for discrete handling.

- **Real-world benefit**: Better localization, improved speech intelligibility, greater ease-of-use and higher discretion have a positive impact on the perceived performance of hearing instruments in real life.
References


The information in this document contains general descriptions of the technical options available, which do not always have to be present in individual cases and are subject to change without prior notice. The required features should therefore be specified in each individual case at the time of conclusion of the respective contract.