

EVIDENCE FOR THE **BENEFITS** OF **BINAURAL** AMPLIFICATION



The benefits of binaural hearing have been known for decades. They include, but are likely not limited to, elimination of the head shadow effect, binaural summation, binaural squelch, reduction of central auditory sensory deprivation, utilization of the unique characteristics of certain neurons to encode both arrival time and details about the shape of the acoustic input in order to enhance localization, optimization of auditory

scene analysis, improved understanding of speech in adverse acoustic environments, better management of bilateral tinnitus, and greater user satisfaction. Yet despite these advantages, a significant number of hearing health care professionals still do not, or feel they cannot, abide by the general consensus that unless a significant asymmetry exists between the ears in either sensitivity or word recognition ability, the standard should be trial with binaural amplification. Furthermore, much of this disparity in usage of binaural amplification and recommendation of two hearing aids, is geographic specific. For example, in the United States, approximately 80% of hearing aid users who have bilateral hearing loss, own two aids¹, but the same can be said for only 40–65% for western European nations² and unconfirmed data estimate binaural usage to be as low as 30% in certain Asian regions³.

In this issue of WidexPress, this perplexing matter will be confronted by 1) exploring reasons, both justifiable and unjustifiable, for not regularly utilizing binaural amplification when a bilateral hearing loss exists; 2) examining evidence supporting binaural superiority; 3) discussing whether hearing aids take advantage of binaural cues; and 4) briefly describing new strategies designed to maintain those cues for the hearing impaired listener.

REASONS WHY BINAURAL AMPLIFICATION ISN'T UNIVERSALLY ROUTINE FOR LISTENERS WITH BILATERAL HEARING LOSS

There are a number of reasons why users may not want to wear two hearing aids and why professionals may not recommend binaural amplification. These concerns range from legitimate to questionable to simply unsupportable. Among the legitimate concerns from the user perspective, is the fact that there is greater cost for two hearing aids than for one hearing aid. Yet cost alone cannot account for this reluctance. For example, in the United States where binaural usage is greatest, 3rd party payers are involved to some extent in less than 40% of hearing aids purchased, as compared to the United Kingdom where 74% of hearing aid purchases receive public funding yet the binaural rate there is only 47%². So the issue is more complex than just money.

Undoubtedly, cosmetics play a role in some rejection of binaural usage. Users have often stated the belief that wearing two hearing aids levels the perception of a more severe impairment than wearing only one device. This perception however, has never been confirmed in the literature, and it would seem logical that overt errors in communication that result from not having proper hearing in both ears may create the impression of a more significant impairment than would be made on the basis of having aids in both ears⁴. Moreover, the recent move toward less obtrusive hearing aids (such as open fit, mini BTEs) should lessen cosmetic based apprehension.

A concern that has been expressed by some hearing aid users is the sensation of a larger occlusion effect when wearing two aids. While this may indeed have been a justifiable reason for not using binaural amplification in the past, the increasing popularity and availability of open fit hearing aids should lessen this worry in a large percentage of cases.

Other reasons for preferring only one aid include fears of dependence that could arise from wearing two aids (never substantiated), and apprehension that two hearing aids will be louder than one hearing aid. This would not be the case for properly fitted devices that incorporate the concept of binaural summation (discussed below).

A legitimate concern that may impact both users and professionals is that some individuals actually do function better with monaural amplification than with binaural amplification. "Binaural interference"⁵ may occur in as many as 20% of elderly hearing impaired listeners. This may be attributable to "age-related progressive

atrophy and/or demyelination of corpus callosal fibers, resulting in delay or other loss of the efficiency of inter-hemispheric transfer of auditory information." It is important to recognize that there is a difference between "binaural interference" and lack of demonstrable binaural integration in a laboratory environment. Better testing materials and procedures are clearly needed to identify this group of listeners.

A concern that has likely biased some professionals is the belief that there is a lack of outcome data supporting the superiority of binaural amplification. Some early publications^{6,7} supported this perception. However, it is now clear that the sensitivity of test materials used was clearly inadequate. For example, many of the studies unable to demonstrate binaural superiority compared monosyllabic word recognition scores in quiet under headphones or in free field environments that did not utilize a diffuse field. Thus, neither head diffraction nor binaural squelch effects were shown. Furthermore, when comparisons were made outside of the lab setting, the hearing aids available in the 1960s, 1970s, and even 1980s contained peak clippers, restricted frequency bandwidths, and even body borne devices that were void of benefit from the pinna effect. In addition, some published consumer surveys examined satisfaction with binaural hearing aids rather than comparing satisfaction between monaural and binaural fittings⁸.

One other factor that may account for reluctance in some professionals to recommend binaural hearing aids is the belief that there is extra time required for the fitting of two devices. While it is true that there is a small amount of additional time required, certainly the fitting of two hearing aids does not double the required time of fitting, and over the long run, communication problems minimized by binaural superiority may indeed reduce the amount of post-fitting time spent by the professional dealing with dissatisfied users.

EVIDENCE FOR THE ADVANTAGES OF BINAURAL HEARING

There are clearly reasons why human beings have two ears. The most important known binaural advantages are:

Elimination of the head shadow effect

The head creates both a barrier to sound (sound decreases by approximately 6.5 as it crosses from one side of the head to the other) and a diffraction effect (by providing a boost to sounds originating on that side of the head). These effects in combination range from about 3 dB for the low frequencies to as much

as 16 dB in the high frequencies⁹. Thus, wearing of binaural hearing aids minimizes the possibility that the physical location will create a significant disadvantage for receiving important speech cues. For example, if noise is present on the aided side and speech on the unaided side, the speech originating from the unaided side will not be perceived in either ear because of the hearing loss on the unaided side and the masking from the noise on the aided side. Moreover, one should consider the fact that even in a room surrounded by sound, binaural usage would allow the user the option of turning off one hearing aid (if, for example it is on the side of predominant noise and no speech).

Binaural summation

The very fact that sounds may be audible in each ear provides an advantage of approximately 2-3 dB by virtue of binaural redundancy or diotic summation. In addition, the loudness of a sound is greater when presented to both ears than when presented to one ear. Binaural loudness summation ranges from approximately 3 dB at threshold to 6 dB at suprathreshold where presumably amplified speech occurs¹⁰. Therefore, each hearing aid used in the binaural mode requires less to achieve the same effect. This would likely have a number of beneficial effects including lower distortion, less feedback and thus the possibility of larger vents. This in turn, may account, at least in part, for the findings of several studies showing better sound quality and speech understanding¹¹⁻¹³ for binaural amplification.

Binaural squelch

There is a significant binaural advantage that occurs in the form of release from masking for the low frequencies as a result of the brain receiving dichotic signals differing in time of arrival and phase. The magnitude of this effect of extracting a speech signal from noise has been shown to be as high as 13 dB¹⁴.

Reduction of central auditory sensory deprivation

While it is debatable whether disuse of an ear will necessarily produce a further reduction in peripheral loss (i.e. on pure tones), there is ample evidence of neurological degeneration. Several studies have demonstrated individuals who were fitted monaurally suffered a greater loss of speech recognition ability in the unaided ear than in the aided ear¹⁵⁻¹⁷.

Enhanced localization

The ability to identify the direction and distance of a moving or stationary sound source outside the head is known as localization. There are some obvious important implications of this ability relative to both safety and sound enjoyment. To accurately locate the source of a sound, it is necessary to determine the horizontal and vertical planes, as well as the front to back site of origin.

Accurate identification of the horizontal location of a sound is based on the comparison of interaural time difference (ITD) of arrival and thus the phase of the sound at each ear (because any delay in time results in a phase shift), and the interaural intensity level difference (ILD) at the two ears. For example, a sound originating directly in front of a listener (0 degree azimuth) would have an ITD of 0 at the two ears, whereas a sound originating at a 90 degree azimuth would have an ITD of about 0.7 msec. The duplex theory hypothesized by Lord Rayleigh in 1907 is still largely accepted today (at least with regard to horizontal location)¹⁸. It states that high frequency (>1600 Hz) location is determined by ILD, and low frequency (<800 Hz) location is determined by ITD and phase differences. Thus, low frequency sounds would be localized in the horizontal plane toward the ear that receives the sound first and high frequency sounds would be localized in the horizontal plane toward the ear which receives the higher intensity level. However, interaural time differences also are present in the envelope of sounds and thus can be conveyed across the entire frequency range¹⁹.

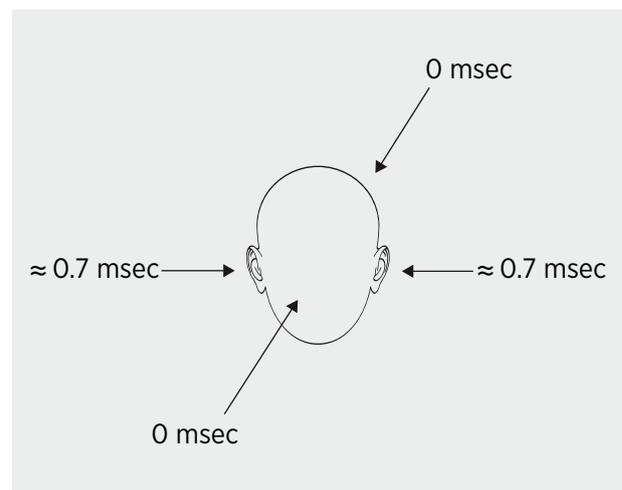


Fig 1: The Interaural Time Difference: a sound originating at a 90 degree azimuth would have an ITD of about 0.7 msec, whereas a sound originating directly in front of a listener will have an ITD of 0.

In addition to these long known facts, more recent discoveries have demonstrated that certain neurons encode both arrival time and details about the shape of the acoustic input in order to enhance localization²⁰. For example, while ITD was believed to be perceived with identical processing at the two ears based on the rise time of the input signals, it has now been shown that the rise time of ipsilateral signals is faster than that of contralateral signals. In addition, neurons not only encode coincidence in arrival time, but they also detect details about the input's shape. Neurons located in the medial superior olive that respond to the rise time of the summed input are differentiators while neurons that respond to the net amplitude and width of summed inputs are integrators. These neurons are tuned to a particular frequency (CF) and are tuned to a particular ITD by acting as interaural "coincidence detectors" so different neurons have different "best" ITD values equal to the ITD that compensates for differences in ipsi- and contra- transmission delays. The ability to detect "group delay" is especially important in reverberant environments²¹.

Vertical localization is based on the high frequency (above 4-5 kHz) reflections, echos, and resonances of the pinna, head, and upper torso⁹. Listeners can detect vertical differences as slight as 3 degrees²². The ability to localize in the front-back dimension is also based on high frequency cues provided by the pinna. Specifically, the pinna provides a 3-5 dB boost between 2-5 kHz for sounds originating in front of the listener and further attenuates sounds originating from behind the listener²³.

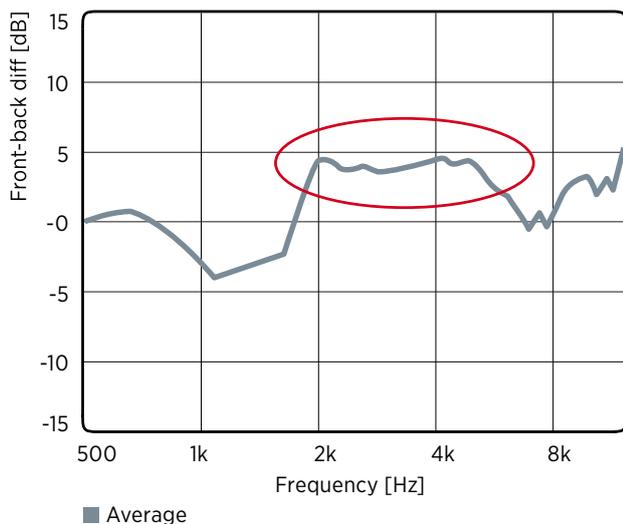


Fig 2: The average Pinna Effect of 45 different heads (CIPIC database)

Optimization of auditory scene analysis

Perhaps of even greater importance to hearing impaired individuals is that the ability to localize allows listeners to not only identify the location of a sound or speaker of interest (particularly in multi-talker environments) but to also group together elements from one direction and assign a separate identity to sounds originating from different directions. Auditory scene analysis enables one to recognize the environment and identify objects through sound. It is defined as "the organization of sound scenes according to their inferred sources"²⁴. Without this, simultaneously presented sounds blend together to form a confusing background rather than a collection of individual signals having different perceived qualities (such as pitch or timbre) which can be perceived or ignored. In addition, errors in sequential grouping can lead to perceiving a single word created out of syllables originating from two different voices.

Among the many complex features employed in this process of tagging and grouping to allow for better understanding of speech in noise are the use of fundamental frequency information, harmonicity, common onsets/offsets, common amplitude modulations, common frequency modulations, and timbre.

Better management of bilateral tinnitus

Binaural hearing aids are commonly used in the management of patients with bilateral tinnitus²⁵ (and some even believe for unilateral tinnitus), because of the wide representation of tinnitus throughout the central auditory nervous system. With two hearing aids, tinnitus awareness is often reduced, but if only one hearing aid is worn, the tinnitus sufferer may find that there is increased awareness of the tinnitus in the unaided ear.

Greater user satisfaction: Improved sound quality

Last, but certainly not least, among the advantages of binaural amplification are the abundance of surveys demonstrating greater user satisfaction and enhanced sound quality, even in reverberant situations^{8, 11, 13, 26, 27}, more convenience when one hearing aid breaks down, and decreased listening effort for binaural hearing^{28, 29}. These advantages are particularly important for older listeners.

HAVE HEARING AIDS TAKEN ADVANTAGE OF BINAURAL CUES?

In order to capture the true binaural experience, it is necessary to preserve the auditory cues discussed above. Most of these binaural cues are captured simply by virtue of making sounds audible in each ear, and by having a distinct input to both ears. For example, the binaural advantages of minimization of head shadow, binaural summation, reduction of central auditory sensory deprivation, better management of bilateral tinnitus, and greater user satisfaction are maintained. However, a number of binaural cues can be obscured or distorted by wearable amplification. For example, several studies have shown that localization may actually be better with no hearing aid than it is with hearing aids^{30, 32, 33}. This happens as a consequence of both the presence of a hearing impairment (and therefore the loss of certain spectral cues) as well as processing and physical characteristics of hearing aids. For example, if the ILD is to be maintained, the relative volume has to be unaltered, however, this can be changed in a number of ways. Some types of compression could reduce ILD. For example, if sound is originated from one side, compression can reduce the gain for that hearing aid while simultaneously increasing the gain on the other hearing aid. This would change the relative ILD. Also consider that if the hearing aid user changes the volume in only one ear, the relative ILD is altered. Similarly, the ILD can be modified if the hearing aid user chooses to have different programs or two different microphone arrays in each hearing aid.

In addition, interaural phase and time differences (ITD) can be obscured or altered by the combinations of processing delays, compression characteristics, and vent sizes. For instance, there may be differences in the time constants for hearing aids worn in each ear, the two aids may have different vent characteristics thereby modifying transmission times, and there is a processing delay in hearing aids of approximately 3-6 ms in speech frequencies, yet the brain can take advantage of much shorter ITDs (recall that the maximum ITD is about 0.70 ms). Moreover, the processing delay varies depending on the number of channels in the hearing aid and can be nearly 10 msec in the low frequencies for 16 channel devices (see Figure 3), and even more if the hearing aid has other processing features such as noise reduction. Given the fact that most digital hearing aids contain multiple channels and noise reduction, this can be an important factor.

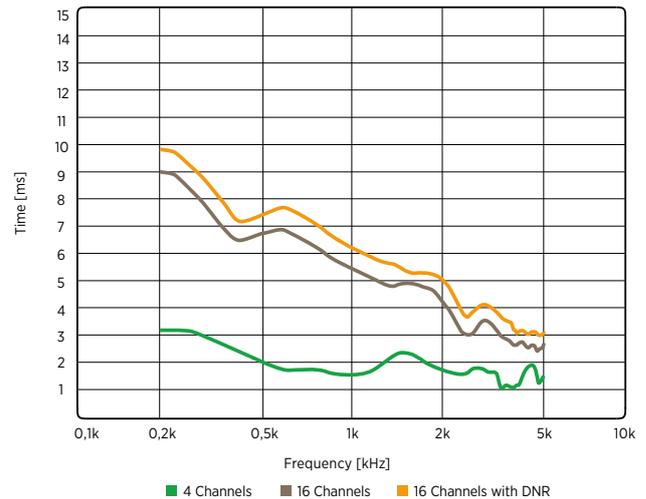


Fig 3: The processing delay varies depending on the number of channels in the hearing aid³¹.

Fortunately, while non-synchronized compression and gain mismatch can alter ILD and ITD, some studies^{32,35} suggest that horizontal localization is not appreciably impacted as long as low frequencies are more than 10 dB above threshold. However, it should be noted that not all of the potential factors that could affect low frequency ITD were accounted for, so it is still feasible that horizontal localization can be affected.

While this relative preservation of horizontal localization is welcome news, the fact that localization through hearing aids has been shown to be less than ideal leads to the conclusion that it must be errors in vertical and front to back localization that impair the aided listener. Indeed, it is these errors that appear to be most common for hearing aid users. This is because the loss of the pinna effect and restricted bandwidth limit the important high frequency spectral cues and can negatively impact overall polar localization (encompassing both vertical and front/back localization). Moreover, polar localization is most adversely affected in BTEs because of the loss of the pinna effect and concha resonance³, less affected in ITEs (despite the loss of the concha resonance) and least affected in CICs. Even so, diminished localization cues with CICs and ITEs can still exceed 7 dB above 3000 Hz relative to the open ear.

NEW STRATEGIES DESIGNED TO MAINTAIN BINAURAL ADVANTAGES

Given the significant importance of localization to auditory scene analysis, and thus to the ability to understand speech in noise and reverberation, it is important for hearing aids to do everything possible to preserve timing and spectral cues, rather than distorting them.

Recently, a number of new strategies designed to protect these cues have been implemented in Widex hearing aids.

For example, the Digital Pinna re-creates the natural attenuation of sounds coming from behind by setting the frequency bands from 2 kHz and higher (bands 10-15) in a fixed directional mode hypercardioid which picks up sound at the front and eliminates most sound from the sides and rear, while leaving the lower bands (1-9) in omni-directional mode. The Digital Pinna with adaptive locator works in the way that all the channels will still adapt to the best possible signal to noise ratio just with the limitation that the upper channels can only adapt from hypercardioid to bidirectional whereas the lower channels can go all the way from omnidirectional to bidirectional. In this way the directional system will be in full Digital Pinna setting in quiet surroundings and in full adaptive settings in very noisy situations. The rationale for this approach is that while it is important to maintain low frequency information for auditory scene analysis, it is even more important to not impair intelligibility by allowing too much noise to filter through.

As discussed earlier, different program settings, microphone arrays, volume control adjustments, and disparate time constants and compression characteristics for each ear can distort interaural cues essential for localization. Ultra-fast wireless communication between binaural hearing aids can significantly minimize, if not prevent, these misrepresentations of cues from occurring.

Also, given the importance of high frequency spectral cues (above 4 kHz) for vertical and front to back localization, Widex hearing aids offer an extremely wide bandwidth (as wide as 70 Hz to 11,200 Hz in ClearBand models) with stable high frequency gain, made possible by a unique strategy of determining true feedback via InterEar communication.

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