Binaural Fusion by ReSound: Technology Optimized as Nature Intended

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Abstract

Binaural Fusion is a new, revolutionary approach to hearing instrument signal processing. Taking advantage of wireless information exchange between the hearing instruments, it optimizes the signal while allowing for user intent of the signal of interest. Binaural Fusion is characterized by two new features, introduced with the ReSound Verso product line: Binaural Directionality and Binaural Environmental Optimizer II.

The human body is marvelous in its design. Two eyes send visual inputs about the surroundings to the brain to create a three-dimensional representation of the environment. In a similar fashion, two ears send distinct information to the auditory cortex of the brain to create a complete, rich and accurate portrayal of the auditory environment. Auditory scene analysis is a method in which the brain organizes acoustic inputs from each ear to provide a mental representation of the sound environment.[1] In the theory of auditory scene analysis, individuals can choose what to pay attention to and what to ignore. Figure 1 shows this concept. The overall sound spectrum of the environment is shown at the left. The individual is able to discriminate which parts of the sound spectrum account for the person talking on the phone, the airplane flying overhead, and the automobile driving past. The individual is then able to take advantage of these cues and attune to the person talking on the phone, while ignoring the other sound inputs in the complex sound environment.

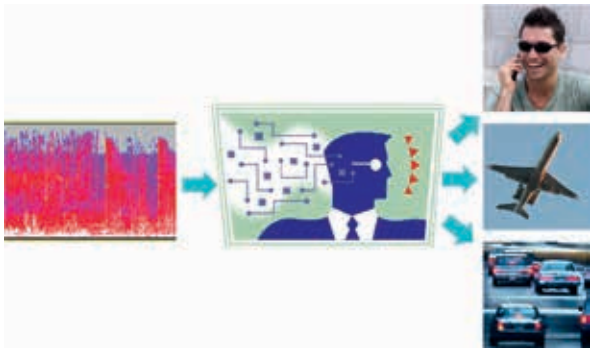

Figure 1. An illustration of auditory scene analysis. The listener is able to discriminate different sound sources in the overall sound environment and attune to the signal of interest.

But when the inputs from the two ears are altered via traditional bilateral hearing aid processing, this natural process is disturbed. The brain can only process the inputs it receives, and if the ears are receiving erroneous, incomplete or artificial information from the hearing aid processing, the final representation of the sound environment will also be unnatural or incongruous. For example, if the hearing aids are programmed to a certain setting, such as fixed directional settings for each ear, sounds arising from behind the user may be inaudible to the listener since they would be reduced by the placement of the directional null. Thus, an artificial representation of the sound environment, or auditory scene, will result – since the listener will not have the same sound awareness as the unaided, normal-hearing listener would.

The Difference between Binaural and Bilateral Signal Processing

ReSound's new Binaural Fusion technology re-establishes the synergistic relationship between human auditory processing in the brain and sensory inputs from the ears. The term "Binaural" signifies that the processing is done between the two inputs from each ear, by the brain. This is distinguished from "bilateral" processing, which is the common theme used by hearing instruments with wireless technology. Although information can be shared between hearing instruments to maximize audibility or the directional beamforming pattern, this does not necessary lead to the human, unaltered binaural processing of sound that occurs naturally. In bilateral processing schemes, hearing instruments may assume that the loudest speech signal is always the signal of interest – however, this may not always be the case. The user is then at the mercy of the signal processing, and the listening intent of the individual may be all but ignored. Figure 2 illustrates the fundamental differences between binaural and bilateral signal processing schemes. With binaural signal

processing strategies, the focus is on the user and the natural sound delivery process to the brain, whereas with bilateral processing strategies, the hearing instruments and machine processes play a central role.

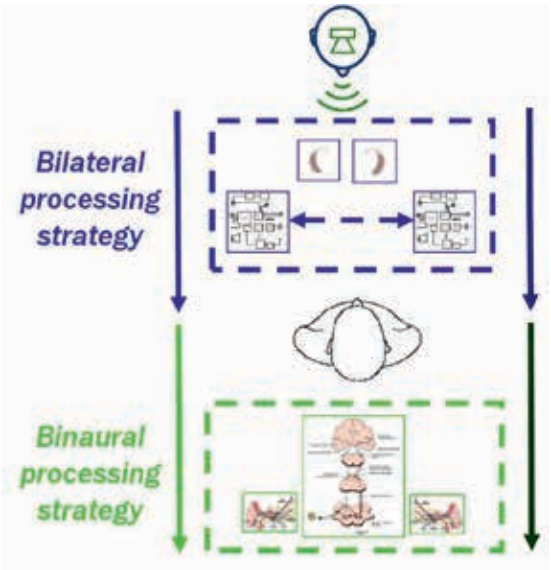

Figure 2. The fundamental difference between bilateral and binaural processing strategies is where the focus lies. The focus for bilateral processing technology is the communication between the hearing instruments, while the focus for binaural processing is the natural sound delivery and intent of the individual user.

ReSound's Binaural Fusion approach finds the most intense speech signal in the listening environment and ensures it is audible, but goes one step further. By not making assumptions about the hearing instrument user's signal of interest, it provides the necessary auditory information to the individual to allow for user intent to manifest. The user is in the driver's seat, and can choose to attune to or ignore sounds in the environment. The sound environment is modeled at the level of the hearing instruments, and then shared between the instruments to derive a more comprehensive, complete classification of the listening setting. It is at this point that the most advantageous directional or omnidirectional patterns are applied; it is at this point that the hearing instruments mutually decide which environmental gain and noise reduction offsets are correct. The hearing instruments are doing more than providing bilateral inputs to the brain; they are providing the most accurate sound picture to the user, enabling the user to make informed decisions about the sound environment.

When an individual enters a noisy environment, two processes in the brain help to analyze the sound environment or auditory scene. "Bottom-up" processing is how all the sounds in the noisy setting are perceived. "Top-down" processing is involved in helping the person focus on the signal of interest at the time, for example the person speaking nearby. An example of these two processes at work in the real world is for a person standing at a bus stop in the rain amidst other people (Figure 3). The sounds of automobile engines and the rain are mixed with the speech of other people standing nearby at the bus stop. An acquaintance approaches the person on the sidewalk from behind and voices the person's name. All of these sound inputs would be registered in the brain by "bottom-up" processing. However, the person standing at the bus stop is most interested in the acquaintance's voice arising from behind him. Therefore, the person uses a higher-level "top-down" process to choose to attend to this signal primarily. Other signals in the environment – the engines, the rain and the other people's conversations – are suppressed in the listener's brain so that the signal of interest, the acquaintance's voice, is more audible.

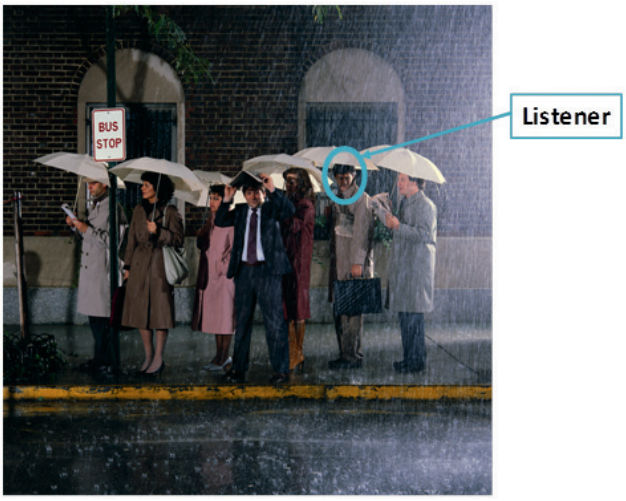

Figure 3. "Bottom-up" and "top-down" processing is involved in everyday situations. These binaural processes in the brain allow listeners to detect sounds in the environment and choose to attend to the most salient sound, or the signal of interest.

ReSound hearing instruments with Binaural Fusion also include the experience of Surround Sound by ReSound, which strives to replicate the way the ear receives and processes sounds naturally. Surround Sound by ReSound works to model, clean, balance and stabilize the sound inputs for the best representation to the brain. The modeling component preserves temporal information and restores non-linearity

through WARP and wide dynamic range compression. The signal is cleaned through NoiseTracker II, which provides seamless and comfortable noise reduction for steady-state and multi-talker babble noise sources. Balancing occurs via Directional Mix, which eliminates problems pertaining to sound quality and low-frequency audibility as a result of directionality. DFS Ultra II, a new iteration of DFS Ultra with improved scaling and input modeling, ensures the best sound quality and a stable, feedback-free listening experience.

Binaural Fusion, Implemented in Hearing Instruments

Introduced in the ReSound Verso line, the Binaural Fusion technological strategy supports binaural processing by the brain, and empowers users to hear and listen to what they want. Users can tune into what they want to hear, just as normal-hearing listeners would. This is all made possible by the hearing instruments working together as a single system to provide the best, most natural sound representation to the user. The hearing instruments independently analyze the type and level of sounds in the listening environment, determining both the location of sound sources and the signal-to-noise ratio for speech. Next, the information gathered by each hearing instrument is exchanged between them, to derive a common solution for the most appropriate sound processing. This cooperative effort between the hearing aids results in the most advantageous binaural microphone response, as well as coordinated noise reduction and gain settings for any given listening environment. The result of this Binaural Fusion technology is the creation of two new options to maximize the listening experience (Table 1).

The sum of this technology is a synergistic relationship between the hearing instruments that better approximates the natural binaural listening process in unaided, normal-hearing individuals. Through this technology, speech understanding in noise is maximized for the environment. Listening comfort is better achieved as the user moves through different listening situations throughout the day. And most importantly, the hearing instrument user is in the driver's seat, since auditory inputs surrounding the listener are preserved.

The Evolution of Directionality to Binaural Directionality

Directional microphone technology revolutionized the hearing instrument industry many years ago. Since that time there have been numerous improvements to the feature, in a never-ending quest to improve speech intelligibility in background noise. Obstacles have been overcome and solutions have been implemented, but the results have not been without problems. To illustrate the need and rationale for Binaural Directionality, it is helpful to examine the evolution of directionality to this point.

Directional microphone technology is the only proven way to increase the signal to noise ratio for hearing aid users in background noise.[2,3,4,5] Yet there are drawbacks that affect the directional benefit the user receives. In a conventional directional fitting, in which both hearing aids are set to a fixed or traditional adaptive response, there is a loss of environmental awareness to sounds from the back. Directional technology assumes that the listener is looking in the direction of the speaker, and this is true in many cases but not all.

Table 1. Binaural Fusion features in the ReSound Verso bilateral wireless-enabled product line.

Binaural Fusion Feature	Contribution of Feature to Binaural Processing
Binaural Directionality	This new directional option automatically assigns an omnidirectional or fixed directional pattern for each ear, tailored to the specific environment, to create the best possible directional response for speech while maintaining sound awareness. The user can decide whether to turn to the signal of interest, regardless of its location to the side or the rear, since the listener can detect all sound inputs in the surrounding environment.
Binaural Environmental Optimizer II	Noise reduction and gain adjustments are automatically synchronized and optimized between the hearing instruments, based on signal-to-noise ratio and overall intensity level analyses from both devices.

For example, in a noisy environment with the hearing aids set to directional responses, it is often difficult for the hearing aid user to perceive a speaker approaching from behind, since that may be directly where the null of the directional response occurs.

A solution to this problem is to include an omnidirectional response option as a separate program to the user. Traditionally, the omnidirectional program is set as the default or first program and the directional pattern is set as the second program. This is appropriate, since directional processing is beneficial to the user only about 30% of the time.[6] This means the typical hearing instrument user programmed with an omnidirectional response for the first program and a directional response for the second program would need to switch programs then about a third of the time. However, usage reports from a study by Cord et al.[7] revealed that about a third of their subjects did not switch programs appropriately for the sound environment.

Directional solutions that incorporate automatic switching attempt to resolve the issue of the user forgetting to change or not knowing how to change programs for different environments. However, this can create problems with erroneous switching if the hearing instruments change directional patterns inappropriately for the environment. In addition, user intent is ignored, as the signal of interest is determined solely by the hearing instrument, based on acoustic input alone. Noisy situations have been identified where users prefer an omnidirectional microphone response. [6] In addition, the signal of interest is not always in front of the listener. [6]

With Binaural Directionality, the brain receives all sound inputs and can choose to attend to certain signals in the auditory scene through "bottom-up" and "top-down" processing. These binaural processing principles are made available to the aided listener only when the sound environment is made completely accessible by the hearing instruments. Thus, Binaural Directionality represents a revolutionary advance in directional hearing aid processing.

Binaural Directionality Supports Natural Binaural Processing

Binaural Directionality is a binaural strategy for steering the microphone configuration of two hearing instruments to support binaural sound processing by the brain. Although competitive products are available with hearing aids that communicate and synchronize their settings between each other, ReSound is the first to introduce a truly binaural strategy that takes advantage of scientifically proven better-ear listening strategies, interaural phase differences and auditory spatial attention strategies.[8,9,10,11,12] Being able to detect a signal in the midst of similar competing sounds is made easier when the sounds are separated in the environment. A higher-level or "top-down" process of spatial attention is involved in making the signal of interest more distinguishable in a noisy situation. ReSound's Binaural Directionality provides all necessary information to the brain so this higher-level process can occur. Thus, the wireless link between hearing aids is used advantageously for bilateral steering and coordination of the directional response between ears. Binaural Directionality maximizes the signal-to-noise ratio benefits of directional processing for the listener by continually evaluating the sound environment and changing the response for each ear.

Binaural Directionality uses ReSound's 2.4 GHz wireless technology to coordinate the microphone modes between both ears for an optimal binaural response. Front and rear speech detectors on each hearing instrument estimate the location of speech with respect to the listener. The environment is also analyzed for the presence or absence of noise. Through wireless transmission, the decision to switch the microphone mode for one or both of the hearing aids is made based on the inputs received by the four speech detectors in the binaural set of devices. The possible outcomes were derived from external research regarding the optimal microphone responses of two hearing instruments in different sound environments. Table 2 provides the justification for each possible binaural microphone response.

Binaural Directionality Pattern	Research finding
Bilateral Omnidirectional	In quiet environments, a bilateral omnidirectional response is strongly preferred by users.[6,13]
Bilateral Directional	A bilateral directional response provides the greatest benefit when the speech signal is the predominantly in front of the listener.[14]
Bilateral Omnidirectional and Directional	A directional response for one hearing instrument and an omnidirectional response for the other hearing instrument can improve ease of listening and awareness of surroundings as compared to bilateral fixed directional fittings,[15] without significantly degrading directional benefit.[15,16] Further, when speech is to the side of the listener in a noisy environment, the best intelligibility can be achieved if the hearing instrument on the same side as the speech is in an omnidirectional mode and the opposite hearing aid is in a directional mode.[17,18]

Table 2. Research study findings on optimal binaural microphone response were instrumental in developing the four bilateral microphone responses of Binaural Directionality.

Microphone response transitions between omnidirectional and directional processing occur gradually, over 10-20 seconds. This allows for a seamless listening experience, which prevents switching due to instantaneous sound events in the environment as well as perceptual changes in sound quality.

As with all of ReSound's directional options, Binaural Directionality incorporates band-split directionality for its directional conditions, such that frequencies below a blending point frequency are processed as omnidirectional and frequencies above the blending point frequency are processed as fixed directional. The benefit of this frequency-differentiated microphone response is the elimination of the low-frequency equalization amplification, or bass boost, to overcome the inherent low-frequency roll-off in directional processing. The synchronized time constants for the low-frequency omnidirectional processing can improve the overall sound quality of the directional program while restoring audibility for low frequency sounds.

Putting Binaural Directionality to the Test

Research trial testing was conducted with ReSound Verso devices programmed with Binaural Directionality, in part to ascertain the percentage of time the devices were in each of the bilateral microphone modes (Bilateral Omnidirectional, Bilateral Directional and Bilateral Omnidirectional and Directional). Data logging results were obtained from 29 subjects fitted with ReSound Verso devices over a four-week period. The results, shown in Figure 4, indicated that the hearing instruments were in the Bilateral Omnidirectional mode 78% of the time, and were in some form of directional mode (Bilateral Directional or Bilateral Omnidirectional and Directional) 22% of the use time. This is roughly in agreement with published research stating that omnidirectional processing is appropriate roughly 70% of the time and directional processing is beneficial the remaining 30% of the time.[6]

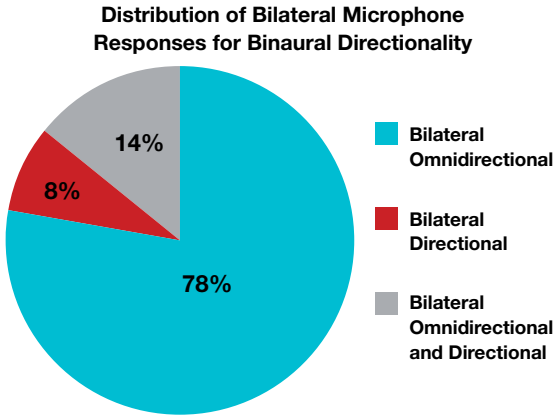

Figure 4. Results of data logging for users fitted with ReSound Verso hearing instruments programmed with Binaural Directionality.

Environmental Steering Enhanced through Binaural Environmental Optimizer II

Environmental Optimizer II is taken one step further with the incorporation of wireless information exchange between the hearing instruments. Binaural Environmental Optimizer II promotes better agreement and congruence in the sound environment information for the user, as the environment is classified based on

inputs from both hearing instruments (Figure 5). As before, classification occurs based on the environment's overall intensity level and the signal-to-noise ratio. Noise reduction and gain adjustments are made based on this classification, but are also synchronized and optimized between the two hearing instruments. This synchronization allows for a more accurate depiction of the sound environment, more tailored gain and noise reduction adjustments and a better, more cohesive sound quality experience.

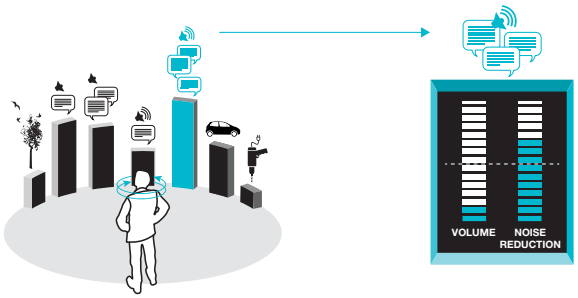

Figure 5. Binaural Environmental Optimizer II chooses the correct gain and noise reduction settings for each distinct listening environment, and ensures they are symmetrical between hearing instruments in the binaural fitting.

A Real-World Example of Binaural Fusion's Benefits

ReSound Verso hearing instruments programmed with Binaural Directionality and Binaural Environmental Optimizer II will provide a more advantageous bilateral microphone response than other hearing instruments that use bilateral wireless communication. An example of a family dinner illustrates these differences (Figure 6).

Figure 6. ReSound's Binaural Fusion technology affords unparalleled advantages in complex yet common listening situations.

The woman in black holding the fork is the hearing instrument user. Everyone is talking and laughing. The voice of the woman holding the baby behind the user is the loudest signal to the hearing instrument on the right side, but the user would actually like to continue listening to a story being told by the man at the end of the table.

Other bilateral wireless hearing instruments work differently, but none other than ReSound's provides this user with the correct input for her signal of interest (the man's story). Competitor A's hearing instruments will attempt to increase audibility of the voice of the woman holding the baby by reducing gain and increasing noise reduction for the user's left hearing instrument, and increasing gain and reducing noise reduction for the right. Competitor B's hearing instruments will attempt to improve both the signal-to-noise ratio for and audibility of the voice of the woman with the baby. It will most likely switch to backward-facing directionality, or it may drastically reduce gain for the microphone input on the left, and stream the signal picked up by the right ear over to the left. In both cases, the user's signal of interest will be reduced, and other non-salient sound inputs will be enhanced.

ReSound Verso hearing instruments programmed with Binaural Directionality and Binaural Environmental Optimizer II handle the situation very differently, and allow for user intent. Although the voice of the woman with the baby is detected as the loudest signal, the hearing instruments do not presume this signal is what the user wants to hear. Therefore, the hearing instruments will optimize the listening environment so the user can choose the signal she would prefer to hear most. Due to the complexity of sound sources in the environment, the Bilateral Omnidirectional and Directional microphone response will be engaged. The right hearing instrument will have an omnidirectional microphone response to ensure audibility of the woman behind the user. Since there is speech concurrently arising from the front of the user, the left hearing instrument will have a directional microphone response. The user can take advantage of the favorable signal-to-noise ratio for the speech from in front to listen more comfortably to the man telling the story. She can improve the signal-to-noise ratio even further by looking up at the speaker, as is also the most natural response people

use when they attend to a certain signal of interest. If the woman behind the hearing instrument user says something of interest, such as “Julie, would you like one of my home-baked rolls?”, Julie will still be able to detect the sound. Her most natural response when this change of events occurs will be to turn her head toward the woman to reply, “Yes, please!”

Binaural Environmental Optimizer II will also play a part in optimizing this scene for the Verso hearing instrument user. Both gain and noise reduction settings will be adjusted and synchronized between ears. The gain adjustments will help ensure audibility and comfort in this noisy situation, while the noise reduction adjustments will further promote better comfort. Since the settings will be synchronized, all adjustments will be made seamlessly to provide the best possible sound quality.

Summary

The brain can only process and analyze the sound environment based on the inputs received from the ears. Traditional wireless solutions for transmission between two hearing instruments can optimize the audibility and beamforming characteristics of a fitting, but do not necessary lead to a natural, binaural processing of sound. ReSound’s new Binaural Fusion technologies allow for the brain to receive the best possible representation of the sound, by focusing on the user and natural sound processing as opposed to the hearing instruments and their prescribed “signal of interest.” It is distinguished from other wireless-enabled sound processing schemes on the market by its allowance for the user to determine the signal of interest. In addition, Binaural Fusion technologies are incorporated into the Surround Sound by ReSound experience that assures the best possible sound quality for the user. Hearing instruments are no true substitute for the normal-hearing, unaided ear – but with ReSound’s Binaural Fusion technology, sound inputs are delivered to the brain and optimized as nature intended.

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