ReSound GN

The evolution of the ReSound binaural hearing strategy: All Access Directionality and Ultra Focus

Jennifer Groth, MA, GN Hearing A/S

ABSTRACT

Adult hearing aid users wear their hearing aids in a wide range of acoustic environments, including a high proportion of time in less complex ones. Their preferences and listening goals are also variable. Therefore, it is important to provide the best possible hearing experience in all types of these real-life situations. Organic Hearing is the sound philosophy that drives ReSound to develop hearing solutions that consider how technology can be applied in a way that works with natural hearing, natural listening behavior, and daily life situations. ReSound ONE™ introduces the innovative All Access Directionality to help users hear well in all their daily life environments. All Access Directionality brings new, advanced directional technology to the evidence-based binaural approach to applying directionality that ReSound pioneered. In addition, Ultra Focus can be activated by users to hear better in one-to-one conversations in especially noisy conditions where they desire extra help.

The sound processing features of today's hearing aids are often designed to solve issues that occur in particular listening environments. For example, a noise reduction feature can make sound more comfortable in a very noisy environment such as traffic. However, the degree of noise reduction applied in traffic may not be preferred in a different environment. Sound processing technologies are beneficial, but the relative benefits and detriments of any feature can vary depending on the listening situation and the preferences and intentions of the hearing aid wearer. To help resolve this dilemma, today's hearing aids use steering algorithms to control how they apply the sound processing in different acoustic environments so that the user can benefit from the technology without having to take any action or give it much thought. An example of why automatic steering of complicated hearing aid features is a good idea comes from the recent MarkeTrak 10 survey. While hearing aids with directional microphones were associated with higher user satisfaction, only 28% of hearing aid owners actually were certain whether or not their hearing aids even had directional microphones.[1] Hearing aid users are certain not to benefit from features that they don't know they have and don't know how to access. One hearing aid feature that all premium hearing aids steer based on the acoustic environment is the directional microphone system.

Directional microphones are touted as our most effective built-in solution to helping hearing aid wearers hear better in noise, and most hearing aids today include not only directional microphone systems but also steering of the technology. A given digital hearing aid may offer levels of complexity in the processing carried out on the signal from the microphones, resulting in variations in the directional characteristics. Most often the appropriate level of complexity is selected by the hearing care professional (HCP), and automatic steering will control how the directional feature is applied in real life. In general, much attention is given to explaining how the directional signal processing works, but relatively little is paid to how the directionality is steered. This is akin to predicting the likely outcome of an automobile race by considering only the features of the car, but not the capabilities of the driver.

ORGANIC HEARING INSPIRES DESIGN CHOICES IN DIRECTIONAL SYSTEM

The conventional way that directional microphones have been implemented in hearing aids focuses on improving signal-to-noise ratio for speech in front at ear level with no regard for higher level processing in the user's brain or for the intent and preference of the person using the hearing aids. Since its beginnings, ReSound has been inspired by nature in developing hearing solutions, as embodied in our Organic Hearing philosophy. For more than a decade, ReSound has pursued a unique evidence-based, binaural strategy for applying directional microphone technology in hearing aids.[2] The term "binaural" means that this strategy acknowledges that the sophisticated processing carried out by the brain based on the sound delivered by a person's two ears cannot be duplicated or replaced. Therefore, the ReSound strategy seeks to support and leverage the brain's binaural hearing ability.

As technology has advanced, so has the binaural strategy. With ReSound ONE, a new version is introduced that stays true to the binaural nature of the strategy while incorporating advanced processing based on ear-to-ear binaural beamforming: All Access Directionality. In this paper, the rationale behind the ReSound binaural strategy is presented along with how it is realized in All Access Directionality.

BINAURAL BEAMFORMING BENEFITS AND ISSUES

ReSound ONE is built on a dramatically upgraded platform that adds the ability to wirelessly stream sound from ear-to-ear. This makes it possible to create strong directionality via binaural beamforming. Binaural beamformers are well-known in the hearing aid industry. They work by using the signal from all 4 microphones on a bilaterally worn pair of hearing aids to form one monaural, highly directional signal. This monaural signal is then delivered to both ears. With binaural beamforming, improvement in speech recognition in noise under simple laboratory conditions has been reported to be higher than what is typical with independently operating directional hearing aids.[3] However, testing in more complex conditions has shown the advantage to be more modest.[4,5] This is thought to be due to the lack of binaural spatial cues with binaural beamformers. Binaural spatial cues help listeners locate and separate competing sound streams in complex and realistic listening situations. Low frequency interaural time difference (ITD) cues appear to be critical to helping listeners in realistic conditions with competing talkers. For example, Best et al[6] tested a high pass binaural beamformer where the crossover frequency was varied so that low frequency spatial cues were preserved to some degree. When modulated noise was used as the masker, listeners with and without hearing loss showed a robust benefit regardless of crossover frequency. In more challenging conditions with speech maskers, overall benefit was less, and average benefit was only shown for crossover frequencies of 800 Hz and above. These results support that the ITD cues contained in the low frequencies were useful for listeners in segregating and processing speech in the more realistic condition.

A closely related issue with binaural beamformers that can impede a listener's ability to follow conversations in real-life situations is audibility of sounds that are not in the look direction of the listener. In many real-life situations in which hearing aid users desire to hear better, following a conversation involves following quick shifts in talkers and topics, as well as separating out the voices of overlapping talkers. Listeners must constantly re-orient to a new talker of interest in such conditions. In contrast, laboratory tests of hearing aid directionality are often carried out with an unvarying location of the target speech. This makes the task easier. Listeners do not need to expend effort in finding the target speech, because they know it will always be in the direction they are looking. Multiple investigations where binaural beamformers were tested have shown how an unpredictable location of the target speech impedes speech recognition in noise performance.[4,5] Some studies have used head tracking devices to investigate how behavior in orienting to new locations of target sounds interact with directionality in hearing aids. Stronger directionality interferes with the ability of listeners to keep up with target sounds when they shift position.[7,8] It has been estimated that attenuation of off-axis sounds of more than 12 dB would render directional microphones unusable in moving conversations, as is typical in group conversations.[8]

Another potential issue with most binaural beamformers is that they are adaptive. This is intended to be advantageous, as it means they change their directional patterns to cancel the most dominant noise source in the rear hemifield. However, at poorer SNRs, adaptive directional microphone systems have been shown to interfere with localization.[9] One theory is that this could be due to the directional system rapidly changing its characteristics as the background noise becomes more diffuse. This might distort interaural level differences (ILD) in unpredictable ways, thereby disrupting localization ability.

RESOUND BINAURAL BEAMFORMING WITH SPATIAL CUE PRESERVATION

The ReSound binaural beamformer used in All Access Directionality strikes a balance between maximizing SNR for speech in front of the listener, preserving access to off-axis sound, and preserving spatial hearing cues to allow re-orienting to new or moving target speech. A multiband system allows processing to be applied differentially to meet these goals. In addition, an adaptive weighting of the sound from the less noisy ear can further enhance the benefit of the binaural beamformer when the noise surrounding the listener is unequal.

MULTI-BAND SYSTEM

Figures 1 and 2 conceptualize the multi-band binaural beamformer. Figure 1 illustrates how sound is separated into bands with the output of each dual microphone directional system streamed to the other side and added to its output. In the lower band, an omnidirectional response is applied. This is consistent with the split-band approach to directionality that preserves low frequency ITD cues that ReSound has used for more than 10 years. This approach has been shown to be preferred over full band directionality for sound quality[10,11] and to allow better overall localization compared to full band directionality.[12] Speech recognition in noise performance is equivalent for this approach versus full bandwidth directionality for open fittings but increases with increased directional bandwidth for occluding fittings.[13]

The middle band covers the frequency range with high speech importance.[14] Binaural beamforming is applied only in this band. Depending on the audiogram, the crossover frequency between the low and middle band is prescribed. People with more severe hearing losses are more likely to have an occluded hearing aid fitting and there is likely to be more benefit of directionality across a wider frequency range.[11] Thus, they are prescribed a lower crossover frequency than people with mild or moderate hearing losses. Above 5000 Hz, monaural fixed directionality is applied in order to approximate high frequency monaural spectral cues from the pinna as well as minimize the potential impact of adaptive directional patterns on ILD.

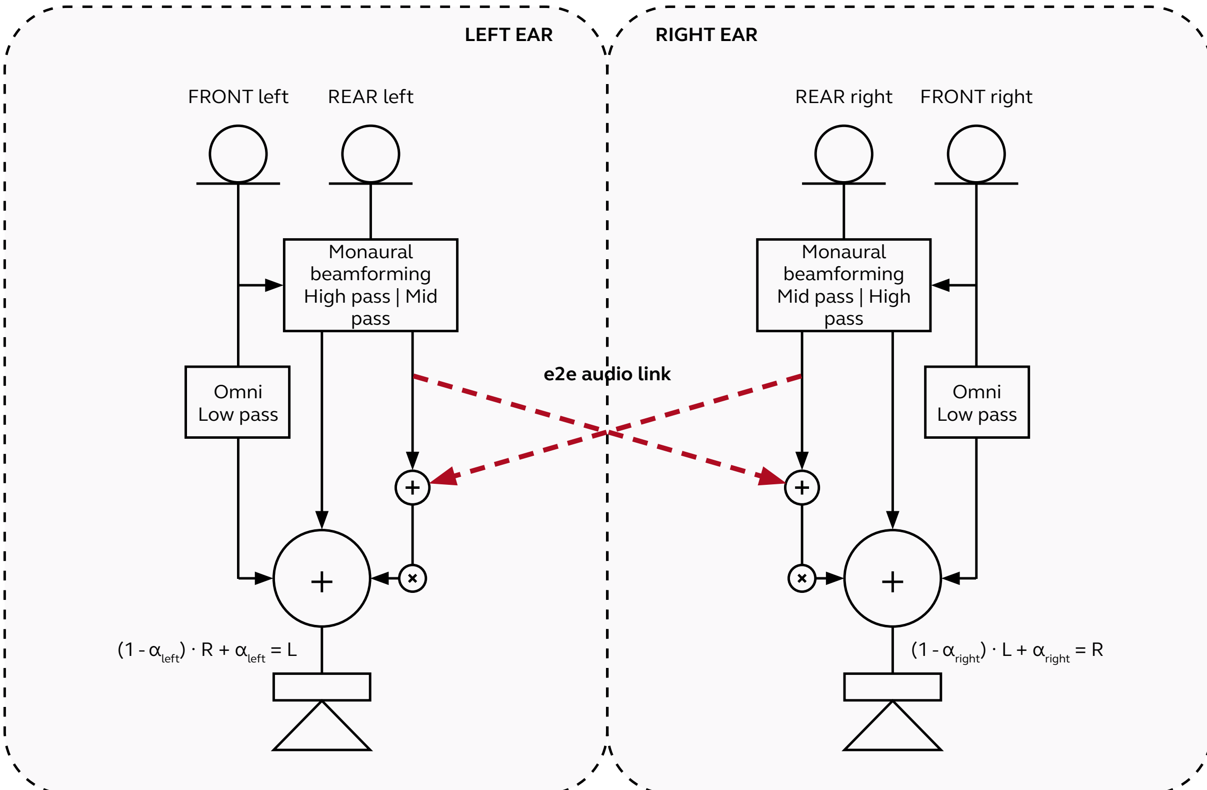

Figure 1. ReSound binaural beamformer design. The red arrows indicate that the sound from the dual microphone directional system of each hearing aid is streamed and added to the output of the other to form a stronger directional beam. This occurs only in the speech important frequency band, while processing that preserves spatial hearing cues is applied in the other bands.

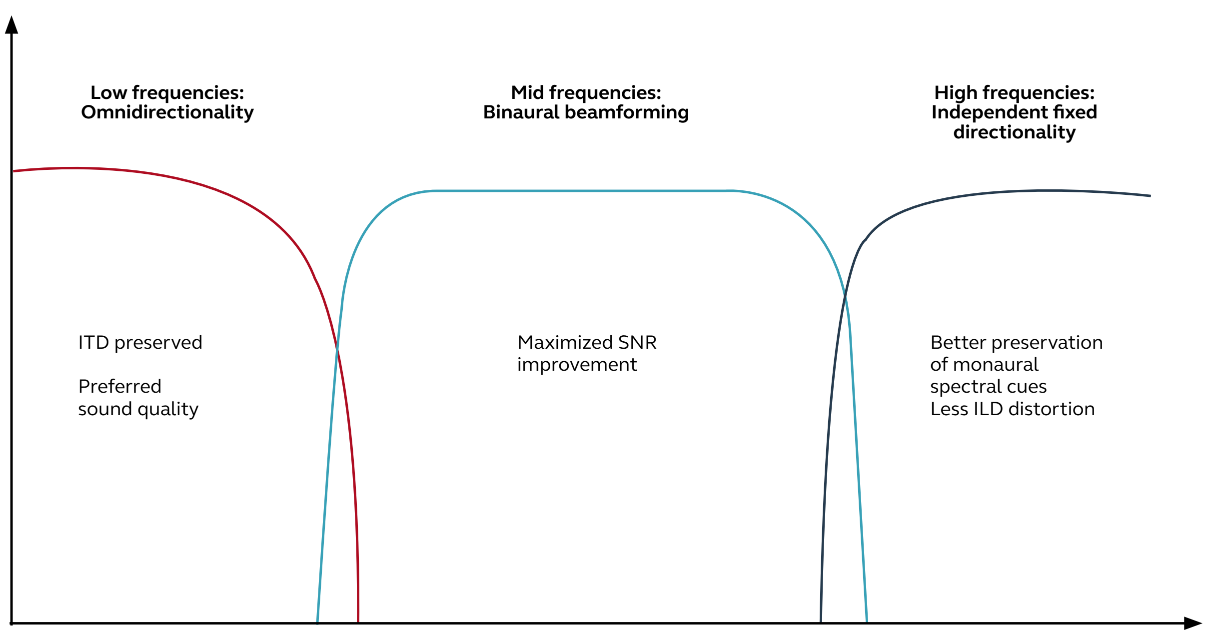

Figure 2. The ReSound binaural beamformer applies strong directionality in the mid-frequency range, while preserving spatial hearing cues in the low and high frequency bands.

Compared to legacy ReSound directional technology, the binaural beamformer has the potential to improve articulation index-weighted directivity index (AI-DI)[15] by approximately 2 dB. Figure 3 compares the improvement in AI-DI compared to omnidirectionality for four crossover frequency settings for the new binaural beamformer and the previous ReSound split-band directional technology.

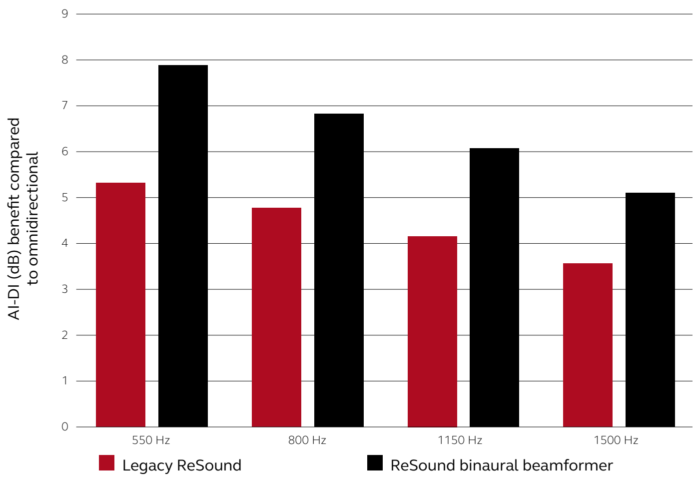

Figure 3. AI-DI improvement compared to omnidirectional for ReSound split-band directionality and the new ReSound binaural beamformer. Benefit is greater for the binaural beamformer regardless of crossover frequency.

An additional feature of the binaural beamformer can add to the benefit in some real-life situations where noise is not evenly distributed. For example, when seated in a moderately noisy restaurant, there might be a table located to one side of the listener that is noisier than other tables. In this type of situation, the binaural beamformer is designed to exploit the head shadow effect by adaptively weighting the signal from the less noisy side in creating the strong directional beam, effectively removing part of the noise. The greater the difference there is in noise level between the two hearing aids, the more weight will be applied to the signal from the less noisy side. This has the potential to improve the SNR in asymmetric noise environments compared to beamforming with an equal blending of the signals from the hearing aids on both sides.

The effect of this weighting was tested with 10 listeners with hearing thresholds within normal limits. They participated in a speech in noise recognition task[16] in four conditions with cafeteria noise as the masker. Noise was primarily presented either from the right or left, as illustrated in Figure 4. For each noise configuration, testing was completed with and without the weighting of the less noisy side in the binaural beamforming. Performance was slightly, but not significantly, better for both weighted and unweighted beamforming with the noise on the left than with noise on the right as shown in Figure 5. On average, performance improved by just over 2 dB when weighting was applied to the less noisy side.

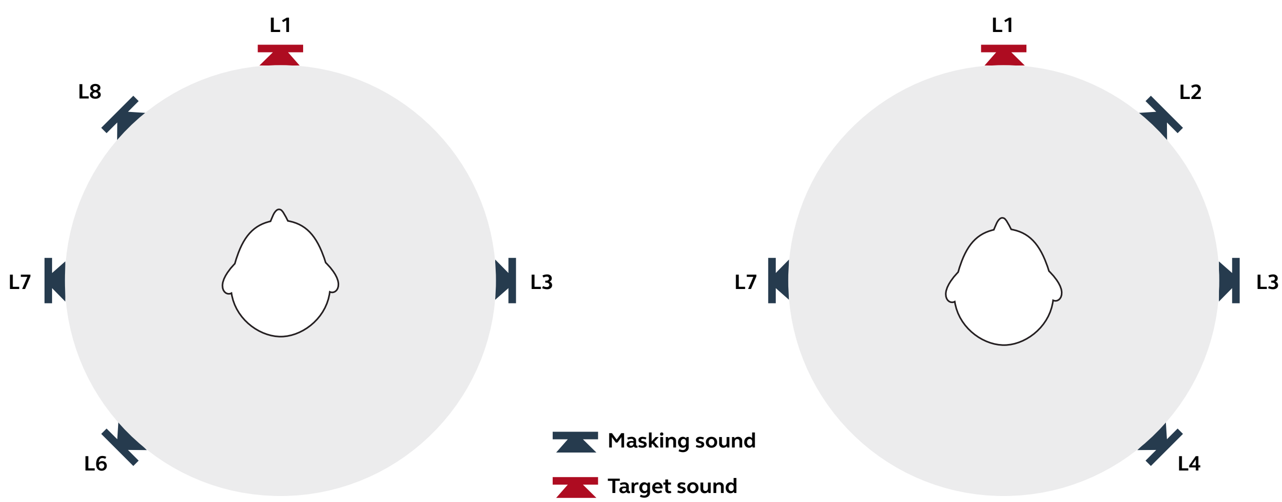

Figure 4. Setup for testing the weighting of the binaural beamformer. Cafeteria noise was presented mostly from the right or from the left, with speech presented from in front.

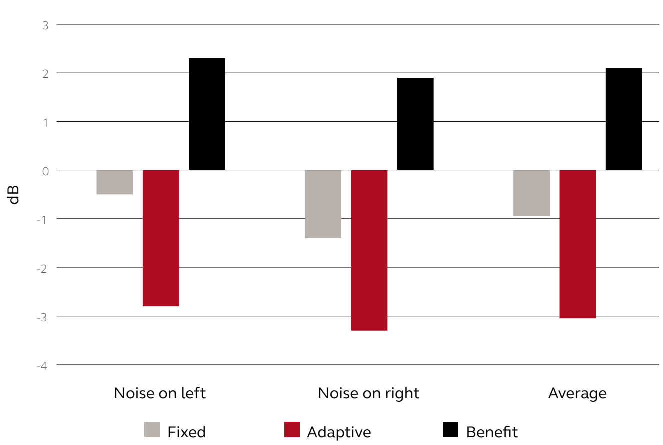

Figure 5. Speech recognition in noise scores improved by just over 2 dB with the adaptive weighting of the binaural beamformer when noise was primarily located on the left or on the right.

A BINAURAL STRATEGY FOR APPLYING DIRECTIONALITY IN REAL-LIFE

In everyday life, people naturally and unconsciously use different listening strategies depending on the characteristics of the environment and what their intentions and goals are in the given situation. For example, if you are out for a walk on a quiet street or in a park, the way you listen is different than if you are talking to someone at a party with the buzz of many people talking and music playing in the background. On the quiet street, you maintain awareness of what is going on around you. You might hear a jogger approaching from behind and you know just when to step a little to the side to give them room to pass. A neighbor might call out a greeting and you will intuitively know where to look to wave hello. You may be enjoying the sound of birdsong or leaves rustling, and the naturalness and authenticity of those sounds is therefore important. In contrast, when conversing at the noisy gathering, you look at the person you are talking with to make use of visual information. You may move closer to the person or turn your head slightly to hear their voice as well as possible. The audibility and clarity of that person's voice is the most important. Because the way you listen is different depending on the situation and your listening goals, hearing aid technology should be designed to support different ways of listening rather than imposing rigid schemes. All Access Directionality uses analysis of the acoustic environment to steer bilaterally fitted of ReSound ONE hearing aids. It selects from three different listening modes that apply the optimum settings to support the listening strategies that people naturally use. We call these modes Spatial Cue Preservation, Binaural Listening, and Speech Intelligibility.

Spatial Cue Preservation

The Spatial Cue Preservation mode of All Access Directionality emphasizes naturalness and overall sound quality. Although directional microphones help hearing in noise, they come with sound quality disadvantages that may disturb what is most important to users in certain situations. It has been found that users preferred sound quality with omnidirectional over directional processing in quiet and low complexity listening environments.[17,18,19] Since users on average wear their hearing aids more in these types of environments than others[20] it is as important to improve the listening experience in simple environments as much as in noisy ones. Furthermore, surveys such as MarkeTrak and EuroTrak consistently show that users are highly satisfied with hearing benefit in these type of environments; thus there is no need for any aggressive strategies to improve SNR or reduce noise that might distort the signal and degrade overall quality of sound.[21] A way to enhance sound quality is to preserve spatial hearing cues as much as possible so that users can segregate sounds in the environment as well as tell where sound sources are both in terms of direction and distance. Spatial Sense helps to maintain spatial hearing cues that a listener's auditory system uses to construct an auditory representation of the environment.

Spatial Sense accounts for three hearing aid-related issues that can interfere with spatial cues. First, placement of the microphones above the pinna in Behind-The-Ear (BTE) and Receiver-In-Ear (RIE) styles removes spectral pinna cues.[22,23] Second, placement of the microphones above the pinna distorts ILD.[24] And finally, independently functioning Wide Dynamic Range Compression in two bilaterally fit hearing instruments can distort ILD.[25] For standard RIE receivers, Spatial Sense provides a pinna compensation algorithm based on average ear characteristics, which improves front-back localization relative to omnidirectionality[26] and reduces errors in ILD estimation.[27] Spatial Sense also incorporates a binaural compression algorithm that is designed to preserve natural ILDs. The new M&RIE receiver available with ReSound ONE for mild-to-moderate hearing loss places the microphone in the user's ear canal, thus completely preserving the spectral filtering of each individual's own ear and providing preferred sound quality compared to both omnidirectionality and pinna compensation.[28]

Binaural Listening

Many real-world listening environments are moderately complex and dynamic. There may be multiple talkers as well as other noise sources and the relative locations of these change. A person with typical hearing would easily be able to pick out and focus on the sounds they want. They would also be able to shift their attention among the different background sounds, tuning in and out of what is of interest to them or following conversations among multiple talkers. In contrast, most hearing aids that steer directional microphone settings assume that the signal of interest is either speech in front of the user or the loudest detectable speech, essentially locking the hearing aid wearer into one listening mode in any situation with background noise. Clearly, these assumptions about the signal of interest will sometimes be at odds with an individual's listening goals. For example, Cord et al[29] found that the sound of interest when actively listening in everyday environments is either moving or the user is not looking at it approximately 1/3 of the time. Hearing aids that steer both hearing aids to directional microphone settings in those situations may not be helpful to users.

The Binaural Listening mode is based on the observation that listeners can take advantage of the location of the ears on each side of the head to either enhance or suppress sounds in the environments at will. When the environment is moderately complex, listeners shift away from relying primarily on spatial cues, relying instead on the ear that has the best representation of the desired sound. In other words, the "better ear" for the sound. The directivity patterns of both ears contribute to this ability to focus and the SNR at the better ear predominates.[30] This idea has been extended to hearing aid directional microphones and found to hold true. When fit with a directional microphone on one side and an omnidirectional microphone on the other, listeners perform equally well as when fit with directional microphones on both ears in the conventional speech-in-noise test setup.[31,32] The ear receiving the directional benefit dictates the perceptual benefit. For a hearing aid user, the interaction between listening intent and acoustic environment mean that the best ear is not necessarily fit with a directional microphone, because the directional response may interfere with access to the desired sound.

Creative thinking resulted in a way to apply directional technology such that it uses the brain's own ability to shift focus and avoids the main downside of directional technology, which is to limit audibility for sounds that aren't within the directional beam. The Binaural Listening mode optimizes spatial directivity patterns on the two ears to ensure there is always a "better ear" for whatever the hearing aid wearer wants to hear regardless of where that sound is in the environment. The advantages of this listening mode for identification and understanding of off-axis speech compared to sophisticated hearing aids with strong directionality were demonstrated by Jespersen et al.[5] These results showed nearly equivalent performance when the target speech was in front, but vast superiority of the binaural listening mode when speech came from the side or in back. As reviewed previously, other investigators have also demonstrated disadvantages of strong directionality in locating and following target speech.

All Access Directionality adds strong directionality with binaural beamforming technology to the binaural listening mode to improve directional benefit when the sound of interest is in front. At first glance, that might seem to conflict with the purpose of the Binaural Listening mode but in fact it does not. This is because the strong directionality is formed using the signal from both ears but delivered only to one with an optimized omnidirectional response maintained on the other ear to ensure access to sounds not in front of the wearer. The combination of these directivity patterns provides greater contrast in the inputs to the two ears, giving the user improved opportunities to rely on better ear listening.

Speech Intelligibility

Some listening environments consist of diffuse noise where individual talkers blend into the mix. In that type of environment, it is likely that a listener would employ a listening strategy where they face a conversation partner to maximize visual cues as well as the audibility of the person's voice. It has also been shown that a bilateral directional response can improve speech recognition for speech in front relative to an asymmetric response when the noise background is diffuse.[33,34] To support this listening strategy as well as possible, the Speech Intelligibility mode steers both hearing aids to a strong directional response using the binaural beamforming technology. As described previously, this technology is unique in the way it enhances SNR in the speech important frequencies while preserving binaural hearing cues.

ULTRA FOCUS

There are some situations where a hearing aid user might want only to focus on speech in a one-to-one conversation with someone they are facing. Ultra Focus is a user selectable program offered for the first time in ReSound ONE hearing aids. It allows users to override automatic settings in these special circumstances. For example, airports are notoriously noisy places where it can be challenging to hear the ticket agent. With speech also occurring nearby from other locations, All Access Directionality might steer to the mode which supports binaural listening. But because the user's intention is to hear one person in a challenging environment, they might be best helped by manually changing to Ultra Focus, a special listening program designed to maximize SNR and speech clarity for one-to-one conversation.

The settings for Ultra Focus include activation of the binaural beamformer at the lowest crossover frequency of 550 Hz, which can improve SNR by up to 2 dB, or approximately a 30% improvement in speech recognition. In addition, signal clarity is prioritized in Ultra Focus. A slow time constant scheme is used to maintain the temporal envelope of speech as well as short-term changes in the spectral pattern of sounds which convey information in speech.[35,36] This also helps preserve short-term level changes, such that cues for localization based on ILD are not markedly disrupted. Acoustic environments where users might want to activate Ultra Focus are likely to be reverberant as well as noisy. NoiseTracker II noise reduction is therefore set to a moderate level for minimum signal distortion[21] and based on recent findings indicating that use of strong noise reduction in reverberation adversely affects SNR, speech recognition, and listening effort without significantly adding to listening comfort.[37]

SUMMARY

Directional microphone systems can be beneficial to users and are associated with higher user satisfaction with hearing aids. However, many hearing aid users are unaware of the advanced features in their hearing aids, and the effects of features such as directional microphones are context dependent. Thus, the control mechanism for directionality is as important as the sound processing technology. Driven by the Organic Hearing philosophy, ReSound ONE stays true to the evidence-based binaural hearing strategy for steering directional microphone systems with All Access Directionality. At the same time, All Access Directionality adds advanced ear-to-ear binaural beamforming that improves speech recognition in noise without eliminating important spatial cues for a natural hearing experience.

REFERENCES

1. Picou EM. MarkeTrak 10 (MT10) Survey Results Demonstrate High Satisfaction with and Benefits from Hearing Aids. Seminars in Hearing. 2020; 41(1):21-36.
2. Groth J. Hearing aid directionality with binaural processing. AudiologyOnline. 2016 May. Available from www.audiologyonline.com.
3. Appleton J, König G. Improvement in speech intelligibility and subjective benefit with binaural beamformer technology. Hearing Review. 2014;21(10):40-2.
4. Picou EM, Aspell E, Ricketts TA. Potential benefits and limitations of three types of directional processing in hearing aids. Ear and Hearing. 2014 May 1;35(3):339-52.
5. Jespersen CT, Kirkwood B, Groth J. Effect of directional strategy on audibility of sounds in the environment for varying hearing loss severity. Canadian Audiologist. 2017;4(6). Available from: http://canadianaudiologist.ca/issue/volume-4-issue-6-2017/directional-strategy-feature/.
6. Best V, Roverud E, Mason CR, Kidd Jr G. Examination of a hybrid beamformer that preserves auditory spatial cues. The Journal of the Acoustical Society of America. 2017 Oct 12;142(4):EL369-74.
7. Brimijoin WO, Whitmer WM, McShefferty D, Akeroyd MA. The effect of hearing aid microphone mode on performance in an auditory orienting task. Ear Hear. 2014; 35(5): e204-e212.
8. Archer-Boyd AW, Holman JA, Brimijoin WO. The minimum monitoring signal-to-noise ratio for off-axis signals and its implications for directional hearing aids. Hearing Research. 2018 Jan 1;357:64-72.
9. Van den Bogaert T, Klasen TJ, Moonen M, Van Deun L, Wouters J. Horizontal localization with bilateral hearing aids: Without is better than with. The Journal of the Acoustical Society of America. 2006 Jan;119(1):515-26.
10. Groth J, Laureyns M, Piskosz M. Double-blind study indicates sound quality preference for surround sound processor. Hearing Review. 2010;17(3):36-41.
11. Goyette A, Crukley J, Galster J. The Effects of Varying Directional Bandwidth in Hearing Aid Users' Preference and Speech-in-Noise Performance. American Journal of Audiology. 2018 Mar 8;27(1):95-103.
12. Groth J, Laureyns M. Preserving localization in hearing instrument fittings. The Hearing Journal. 2011 Feb 1;64(2):34-8.
13. Møller K, Jespersen C. The Effect of Bandsplit Directionality on Speech Recognition and Noise Perception. Hearing Review Products. 2013 Jun:8-10.
14. Pavlovic CV. Band importance functions for audiological applications. Ear and Hearing. 1994 Feb;15(1):100-4.
15. Ricketts TA. Directional hearing aids. Trends in Amplification. 2001 Dec;5(4):139-76.
16. Bo Nielsen J, Dau T, Neher T. A Danish open-set speech corpus for competing-speech studies. The Journal of the Acoustical Society of America. 2014 Jan;135(1):407-20.
17. Walden B, Surr R, Cord M, Dyrlund O. Predicting hearing aid microphone preference in everyday listening. J Am Acad Audiol. 2004:15;365-96.
18. Walden B, Surr R, Cord M, Grant K, Summers V, Dittberner A. The robustness of hearing aid microphone preferences in everyday environments. J Am Acad Audiol. 2007:18;358-79.
19. Preves DA, Sammeth CA, Wynne MK. Field trial evaluations of a switched directional/omnidirectional In-The-Ear hearing instrument. Journal of the American Academy of Audiology. 1999 May 1;10(5):273-84.
20. Humes LE, Rogers SE, Main AK, Kinney DL. The acoustic environments in which older adults wear their hearing aids: insights from datalogging sound environment classification. American Journal of Audiology. 2018 Dec 6;27(4):594-603.
21. Rallapalli V, Anderson M, Kates J, Balmert L, Sirow L, Arehart K, Souza P. Quantifying the Range of Signal Modification in Clinically Fit Hearing Aids. Ear and Hearing. 2020 Mar 1;41(2):433-41.
22. Orton JF, Preves D. Localization as a function of hearing aid microphone placement. Hearing Instruments. 1979: 30(1); 18-21.
23. Westerman S, Topholm J. Comparing BTEs and ITEs for localizing speech. Hearing Instruments. 1985: 36(2); 20-24.
24. Udesen J, Piechowiak T, Gran F, Dittberner A. Degradation of spatial sound by the hearing aid. Proceedings of ISAAR 2013: Auditory Plasticity – Listening with the Brain. 4th Symposium on Auditory and Audiological Research. August 2013, Nyborg, Denmark. Dau T, Santurette S, Dalsgaard JC, Tanebjaerg L, Andersen T, Poulsen T eds.

25. Kollmeier B. Peissig J. Hohmann V. Real-time multiband dynamic range compression and noise reduction for binaural hearing aids. Journal of Rehabilitation Research and Development. 1993; 30: 82-94.

26. Carette E, Van den Bogaert T, Laureyns M, Wouters J. Left-right and front-back spatial hearing with multiple directional microphone configurations in modern hearing aids. J Am Acad Audiol 2014;25(9):791-803.

27. Groth J. The technical proof for clearer, fuller and richer sound with ReSound LiNX Quattro. ReSound white paper. 2018.

28. Groth J. An innovative RIE receiver with microphone in the ear lets users "hear with their own ears". ReSound white paper. 2020.

29. Cord MT, Surr RK, Walden BE, Dittberner AB. Ear asymmetries and asymmetric directional microphone hearing aid fittings. American Journal of Audiology. 2011.

30. Zurek PM. Binaural advantages and directional effects in speech intelligibility. In G. Studebaker & I. Hochberg (Eds.), Acoustical Factors Affecting Hearing Aid Performance. Boston: College-Hill, 1993.

31. Cord MT, Walden BE, Surr RK, Dittberner AB. Field evaluation of an asymmetric directional microphone fitting. J Am Acad Audiol. 2007;18:245-56.

32. Bentler RA, Egge JLM, Tubbs JL, Dittberner AB, Flamme GA. Quantification of directional benefit across different polar response patterns. J Am Acad Audiol. 2004:15;649-59.

33. Hornsby B. Effects of noise configuration and noise type on binaural benefit with asymmetric directional fittings. Seminar presented at: 155th Meeting of the Acoustical Society of America; June 30-July 4, 2008; Paris, France.

34. Kirkwood B, Jespersen CT. How asymmetric directional hearing aid fittings affect speech recognition. Canadian Audiologist;4(1). Available from: https://www.canadianaudiologist.ca/issue/volume-4-issue-1-2017/asymmetric-speech-recognition-feature/.

35. Drullman R, Festen JM, Plomp R. Effect of temporal envelope smearing on speech reception. The Journal of the Acoustical Society of America. 1994 Feb;95(2):1053-64.

36. Kluender KR, Coady JA, Kiefte M. Sensitivity to change in perception of speech. Speech Communication. 2003 Aug 1;41(1):59-69.

37. Reinhart P, Zahorik P, Souza P. The interaction between reverberation and digital noise reduction in hearing aids: Acoustic and behavioral effects. The Journal of the Acoustical Society of America. 2017 May;141(5):3971.

Manufacturer according to FDA:

GN ReSound North America
8001 E. Bloomington Freeway
Bloomington, MN 55420
USA
1.800.248.4327
pro.resound.com

ReSound Government Services
8001 E. Bloomington Freeway
Bloomington, MN 55420
USA
1.800.392.9932
gs.resound.com

Manufacturer according to Health Canada:

Resound Canada
2 East Beaver Creek Road, Building 3
Richmond Hill, ON L4B 2N3
Canada
1.888.737.6863
pro.resound.com

MK605332 Rev B 2020.08