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Increasing the Effectiveness of Hearing Aid Directional Microphones

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ABSTRACT

Directionality is the only hearing aid technology — in addition to amplification — proven to help hearing aid users hear better in noise. Hearing aid directionality has been documented to improve speech intelligibility in multiple laboratory studies. In contrast, real-world studies have shown a disconnect between the potential of the technology and what hearing aid users experience in their daily life. This article describes the real-world studies that inspired ReSound to take a different approach to applying directional microphone technology. This approach is based on the idea that hearing aid directionality can leverage natural binaural hearing and inherent listening strategies. The directional strategy includes three listening modes that will be explained. These are the Spatial Cue Preservation mode, the Binaural Listening mode, and the Speech Intelligibility mode. The strategy and the advantages it provides in terms of sound quality, spatial hearing, and improved signal-to-noise ratio with maintained awareness of surroundings are explained.

KEYWORDS: directional microphones, binaural hearing, improved signal-to-noise ratio, situational awareness

Individuals with hearing loss have reduced audibility, but they often also have increased difficulty hearing in noise. While the loss of audibility can be compensated by amplification, it is more challenging to compensate for difficulties hearing in noise using hearing aids. Manufacturers of hearing aids strive to provide technology that improves hearing and hearing-

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related quality of life for users as much as possible. They are particularly focused on ways to alleviate problems with hearing in noise. According to MarkeTrak 10,[1] people with hearing loss who use hearing aids are less satisfied with how they perform in noisy places than in other listening environments. Yet, they report vastly greater satisfaction with hearing in noise than those who do not use hearing aids. This same report also found that almost half of hearing aid users perceived their hearing aids as exceeding their expectations. So while there is still great potential for improvement in hearing aid benefit and satisfaction, the current status provides a positive starting point for further progress. This article discusses directional microphone technology in hearing aids and how studies on the real-world use of directional microphones have influenced its development and application.

DEFINING THE PROBLEM AND COMMON SOLUTION APPROACHES

In addition to greater perceived difficulties hearing in noise, people with hearing loss perform worse on speech-recognition-in-noise tasks than people with normal hearing. One way to quantify performance differences is by measuring an individual's signal-to-noise ratio (SNR) loss.[2] SNR loss is the increase in SNR (in dB) required by a person with hearing loss to understand speech in noise, relative to the average SNR required for a person with normal hearing. Research has shown that people with hearing loss may require SNR improvements of 2 to 18 dB, depending on the magnitude of the hearing loss, to hear as well as people with normal hearing under the same listening conditions.[2–7]

Beginning in the 1970s, directional microphones were incorporated into hearing aids as a way to help hearing aid users hear better in noisy situations.[8] Directional microphone technology improves SNR by amplifying sounds coming from the direction of the signal relatively more than sounds ("noise") coming from other directions, thereby providing a directional benefit. Apart from the benefits of amplification itself, directionality is the only hearing aid technology that has been shown to improve speech intelligibility in prototypical noisy situations where users are listening to speech coming from in front of them with competing sound from other locations.[9,10]

There are excellent overviews of the principles of how directional microphones in hearing aids work and factors that affect benefit.[11] It also bears mentioning that terminology has evolved such that directional technology in hearing aids is often generically named and not technically accurate. Originally, a "directional microphone" in a hearing aid referred to a single transducer with two sound ports. The sound entering each port strikes the microphone's diaphragm from opposite directions, and depending on phase relationships of the sound coming from each port, it is canceled. Today, the term "directional microphone" is loosely applied to any type of directional response exhibited by the hearing aid regardless of how it is achieved. Virtually all modern hearing aids are fully digital and use dual-microphone designs that build on the principles of the classic directional microphone. Delays applied to the input received by one of the microphones — usually the rear one — result in cancellation or partial cancellation of sound coming from specific directions. Because this happens in the digital domain, the algorithms responsible for this technology can be quite sophisticated, incorporating frequency specificity and adaptive behavior. Steering algorithms can also switch between microphone modes or behaviors depending on an analysis of the listening environment. Directional processing can even contribute to the decision-making of such a steering algorithm. For example, the dual microphones on a hearing aid may be used to "measure" the level of noise to the rear of the user by applying a pattern that is most sensitive to the rear. This information can then feed the steering algorithm that decides the likely optimum microphone response for hearing in the given listening environment (see the article by Andersen et al in this issue for a similar approach that uses beamformers to estimate SNR). The same two microphones may then be activated to provide preferential amplification for sound from in front of the user. The possible permutations and functions of the

Table 1 Overview of Common Types of Microphone Directionality

Directionality type	Description
Omnidirectional microphone	Microphone which is equally sensitive to sounds coming from all directions
Fixed directionality	Microphone system for which the directivity pattern is unchanging. Usually, optimized to be most sensitive to sound coming from directly in front
Adaptive directionality	Microphone system for which the angle or angles at which the directional response is least sensitive (called a null) can be moved. Typically, the nulls are positioned such that the output is minimized[12] or the SNR is maximized
Automatic switching directionality	Microphone system which switches between directional patterns automatically, for example, between being directional and omnidirectional
Bilateral beamformer	Microphone system that uses the microphones of both hearing aids in a bilateral fitting to cancel more noise and achieve more directivity than is possible with a microphone system using only the microphones on one hearing aid
Pinna compensation directionality	Directionality which attempts to mimic the directionality of a pinna to compensate for the disadvantageous microphone location above/behind the pinna

digital dual-microphone system and control of the system are limitless, but some commonalities can be observed. Table 1 provides a high-level overview of the different directional options in today's hearing aids with dual-microphone directionality. In addition, readers are referred to the article by Derleth et al in this issue for details on how wireless communication between hearing aids can be used to form an array of microphones that can further increase SNR beyond what can be achieved using independently operating ear-level hearing aids.

FACTORS IN REAL-WORLD EFFECTIVENESS OF DIRECTIONAL MICROPHONES

A limitation of directional microphone technology is that the SNR benefit is realized only when certain conditions are met. First, the signal of interest, which hearing aid developers assume to be speech, must be spatially separated from the noise sources. Second, the signal of interest must be located within the directional beam. Third, the signal of interest should be within 2 m of the hearing aid user depending on the amount of reverberation. Another limitation is that directional microphone systems are, with few exceptions, designed to have a forward-facing beam as worn on the head. This means that hearing aid users must face what they want to listen to, which limits the situations where the directional technology can potentially benefit hearing in noise.

Directional benefit is easily demonstrated in a laboratory test setup where the earlier-mentioned conditions are met,[13–19] but in real-world settings, the perceived benefits of directionality have shown to be less dramatic.[20,21] Numerous factors likely play a role in this discrepancy. Real-world listening environments often bear little resemblance to laboratory test environments ("acoustic scenes"), as they are unpredictable in terms of access to visual cues, reverberation, type and location of sounds of interest, and type and location of interfering noises. To complicate matters further, any of these sounds may move and/or the hearing aid user may move or change position.

Walden et al[22] observed significant directional benefit under laboratory conditions but then found that this benefit did not carry over to everyday situations because subjective ratings of directionality were not significantly different than omnidirectionality. They explained individual factors which could account for the inconsistency. For one, hearing aid users may not have learned to use the directionality feature. Appropriate use of selectable directionality, which allows users to manually select a directional or omnidirectional response, requires that they (1) analyze and recognize situations in which directionality would be advantageous, (2) know how to activate it and do it, and (3) are able to manipulate their surroundings to maximize the directional advantage. Additionally, in order for hearing aid users to benefit from directionality, they must encounter enough real-world situations where directionality is potentially beneficial. Finally, directionality has the potential to interfere with users' ability to maintain awareness of the listening environment or their ability to shift attention to other sound sources in the environment.

Based on the aforementioned findings, it should come as no surprise that many hearing aid users fit with selectable directionality do not use this feature. Cord et al[21] interviewed 112 hearing aid users who had been fit with selectable directionality at least 6 months prior. They found that over 30% of them did not switch between the omnidirectional and directional microphone modes. The participants who used the directional mode described the listening environments where it was most helpful as those where (1) noise was present, (2) the signal of interest was in front, and (3) the signal was relatively near them. The influence of these acoustic and spatial characteristics in determining microphone preference was corroborated by Surr et al,[23] who fit 11 individuals with selectable directional hearing aids and asked them to keep detailed journals describing situations in which a particular microphone mode was preferred. In a follow-up study, Walden et al[24] investigated to what extent characteristics of listening environments could predict preference for omnidirectional versus directional microphone modes. They, too, found that the directional microphone mode was preferred in listening environments with background noise and where the signal source was located in front of and near the hearing aid user. They suggested that "knowing only signal location and distance and whether background noise is present or absent, omnidirectional/directional hearing aids can be set in the preferred mode in most everyday listening situations."

An important technological implication of the discussion thus far is that since hearing aids can accurately characterize a listening environment's acoustic and spatial characteristics, they should also be able to select the preferred microphone mode much of the time. Today's hearing aids typically implement a steering strategy that attempts to do just that, making it easier for users to benefit from directionality without having to consciously activate it. Most often, the hearing aid will use environmental classification (see the article by Hayes in this issue for more details) to estimate the SNR of speech and will select a directional response when SNR is low. The exact rationale, criteria, and technical implementation differ depending on the hearing aid manufacturer.

The relationship between directional benefit in the real world and in the clinic test booth was also examined by Cord et al.[25] They examined whether successful users of directional microphones in everyday living showed greater directional benefit in the clinic than people who were unsuccessful users. If this were the case, this finding could be used clinically to identify users who could benefit the most from directional microphone technology. Their findings revealed that everyday success with directional microphone hearing aids could not be reliably predicted by the magnitude of directional benefit in the clinic; the mean directional benefit obtained in the test booth did not differ significantly between participants who reported everyday success and participants who reported little or no success. These findings support the conclusion that the benefit of directional microphones in everyday life may depend more on the lifestyle, listening environments, hearing aid usage patterns of users, and other factors rather than an inherent and individual ability to benefit.

DEVELOPMENT OF A BINAURAL STRATEGY FOR USING DIRECTIONAL MICROPHONES

Based on the body of research, several things are clear about directional microphones in hearing aids:

1. There is a potential benefit of significantly improved SNR that could help listening in noisy conditions.
2. The real-world benefit may not be realized, and it is not easy to predict who will benefit.
3. The real-world benefit may be enhanced by microphone mode switching based on acoustic analysis of the environment.

4. The automatic switching to a particular microphone mode can also potentially be at odds with listener intent and natural listening behavior.

A novel way to think about solutions for hearing in noise in real-world situations is to consider how technology might work in synergy with abilities that are inherent to the user. An example of how this type of innovation has been applied in a completely different domain is how smart devices use natural human movements and gestures to control them. Rather than clicking buttons or turning knobs to navigate a modern smart device, users can use their fingers in an intuitive way to touch, swipe, write, and draw on touch-sensitive screens to carry out their desired tasks. In the case of directional microphones, conventional wisdom has dictated that they should always be fit on both ears to maximize the potential SNR benefit, which assumes that the technology does the heavy lifting. This axiom ignores the contribution of the user's inherent auditory processing abilities and how the technology might supplement these abilities.

Having two eyes allows the brain to construct a three-dimensional landscape of our surroundings in the visual modality; similarly, having two ears enables us to form a sound-based image of the surroundings in the auditory modality. The human auditory system integrates, analyzes, and compares information from both ears. Collectively, these processes are called binaural hearing. Among other benefits, binaural hearing helps us hear in noise[26] (see the article by Derleth et al in this issue for more discussion about binaural hearing). Additional perceptual improvements associated with binaural hearing include localization, loudness, sound quality, noise suppression, and speech clarity. Binaural hearing enables us to quickly and reliably detect and recognize sounds, making it possible to selectively attend to something of specific interest, like a single voice among many talkers.[27]

When in noise, a person can understand speech more easily with two ears than with one because of the head shadow effect, binaural redundancy, and binaural squelch. The head shadow effect is a purely physical phenomenon: When noise and the desired signal come from different directions, the SNR will be better at the ear away from the noise. This advantage is often referred to as the "better ear effect." Binaural redundancy refers to the advantage of receiving the same signal in both ears. This includes binaural loudness summation (the loudness of a sound is greater if heard with two ears than with only one). Binaural squelch relates to the auditory system's ability to employ interaural timing differences (ITDs) and interaural level differences (ILDs) to spatially separate competing sounds and to attend to the ear with the better SNR.[26]

Implicit in the discussion of binaural hearing is that it also enables spatial hearing, which is the ability to localize and externalize sounds in terms of direction and distance. Spatial hearing is critical for constructing auditory images. In addition, by providing a sense of the environment we are in, spatial hearing again helps us segregate sounds to choose what to focus on. The acoustic cues upon which sound localization is based — ITDs, ILDs, and monaural spectral cues — also enable spatial hearing.

In developing a strategy for directional microphones, it is key to understand that binaural hearing advantages exist even in the presence of peripheral damage to the auditory system. These advantages are almost as substantial as for normal hearing individuals when audibility of auditory cues is provided via amplification. Essentially, hearing aids make sounds audible, which can enable the same binaural advantages as in normal hearing.[27]

Binaural hearing benefits become meaningful when listeners leverage them to achieve their listening goals, even though this is somewhat unconscious. Binaural listening can be described in terms of two broad strategies: the "better ear strategy" and the "awareness strategy." According to the better ear strategy described by Zurek,[28] listeners will position themselves relative to the desired sound to maximize the audibility of that sound, and they will rely on the ear with the best representation or best SNR of that sound. The directivity patterns of both ears contribute to this ability to focus, with the head shadow effect playing a critical role. The combined directivity characteristics of the two ears form a perceptually focused beam that the listener can take advantage of depending on the desired sound's location. Therefore, if at least one ear has a favorable SNR, then the auditory system will take advantage of it.

The awareness strategy is an extension of the better ear strategy. This strategy includes the omnidirectional aspects of binaural listening that allow the listener to remain connected and aware of the surrounding soundscape when the head shadow effect improves the SNR in one of the two ears. Due to the geometric location of the two ears on the head, the brain can either use the head shadow to enhance the sound of interest or make the head acoustically "disappear" from the sound scene so that the listener can attend to sounds all around.

Microphone directivity can help or hinder either of these listening strategies. For example, hearing aids with an omnidirectional response might not help with listening to speech in front as much as hearing aids with a directional response. Unfortunately, a directional response could reduce the listener's awareness of their surroundings and interfere with conversation following behaviors in group situations. These conflicting demands can be resolved by leveraging the better ear strategy and the awareness strategy. Specifically, if the hearing aids on the two ears are fitted with different directional responses, then the user can apply the strategy that is consistent with their listening intent.

Multiple studies have demonstrated the viability of the approach described earlier. For example, Bentler and colleagues[29] measured speech recognition in noise and sound quality judgments in listeners with different microphone configurations. These included bilateral omnidirectionality, bilateral directionality, and two conditions where either the right hearing aid was directional and the left was omnidirectional or vice versa. They found that directional benefit on the speech recognition task was equivalent for all conditions where a directional microphone was used, regardless of whether it was on one or both ears. There were also no significant differences in sound quality judgments among the directional conditions. This result confirmed that listeners take advantage of the ear with the best SNR and that the ear with the poorer SNR did not improve or hinder speech recognition in the better ear. Other investigations have corroborated these findings,[30–33] although some have suggested that directional benefit could be slightly better with a bilateral directional response depending on the test conditions.[34]

The idea of applying directional microphone technology asymmetrically in hearing aid fittings was tested in both laboratory and real-world conditions by Cord et al.[30] They specifically wanted to determine if an asymmetric fitting would be advantageous in situations where directional processing is often preferred, and if it would be detrimental in situations where omnidirectional processing is often preferred. In the laboratory, participants performed significantly better with the asymmetric fitting compared with the binaural omnidirectional fitting. In real-world use, participants rated the asymmetric fitting significantly better than the omnidirectional fitting in terms of ease of listening. Greater ease of listening with the asymmetric fitting was found in listening environments that typically favor directional microphones. In other environments, ease of listening was not significantly different with the asymmetric fitting than the omnidirectional fitting. These real-world findings validated the viability of asymmetric directionality as a strategy that can improve the overall effectiveness of directional microphones.

A STRATEGY FOR DIRECTIONALITY BASED ON BINAURAL HEARING

With this literature review in mind, the remainder of this article describes the strategy for using directional microphones in ReSound hearing aids. The underlying philosophy is to supply the hearing aid user with the acoustic information that the auditory system needs to resolve difficulties hearing in noise in a natural way[35] by allowing the user to selectively attend to a target sound while simultaneously monitoring other sounds (see Broadbent[36] for further discussion on selective attention).

As described by Piechowiak et al,[37] the system design in ReSound hearing aids is built on a model of natural binaural auditory and cognitive processing. This system accounts for acoustic effects, such as the way hearing aids amplify sounds differently depending on frequency and direction of arrival and head shadow effects. It also accounts for perceptual effects, such as binaural unmasking.[28] Moreover, it incorporates a model of the binaural auditory process that combines the signal from the left and right ears in a way that allows selective attention to either a target sound or a background sound. By improving the SNR and increasing the audibility of surroundings, the system optimizes both speech intelligibility and situational awareness. Indeed, perceptual data from simulated bilateral responses in the study by Piechowiak et al showed that this approach maintained speech recognition for speech in front while increasing recognition for speech that was not in front. At the time of writing, the most advanced application of this directional strategy in ReSound hearing aids is called "All Access Directionality."

All Access Directionality controls the microphone mode of each hearing aid depending on the presence and direction-of-arrival of speech and noise in the environment. It advances the asymmetric approach to include other microphone mode combinations to best support listener intent and preferences for sound quality in different listening environments. Front and rear speech detectors on each hearing aid estimate the location of speech relative to the hearing aid user. As alluded to in the "Introduction," the dual-microphone system on each hearing aid is used as a noise detector in addition to a speech detector. When speech and/or noise is detected in the bilateral pair of hearing aids, they use 2.4 GHz wireless technology to communicate with each other and coordinate the microphone modes for an optimal binaural response.

All Access Directionality switches between three modes depending on the listening environment: (1) a bilateral omnidirectional response called "Spatial Cue Preservation mode"; (2) an asymmetric directional response called "Binaural Listening mode"; and (3) a bilateral directional response called "Speech Intelligibility mode." The three All Access Directionality modes are derived from research on the optimal microphone response of two hearing aids in different sound environments described earlier. Table 2 provides the justification for each possible binaural microphone response.

SPATIAL CUE PRESERVATION MODE

All Access Directionality is designed to be in the Spatial Cue Preservation mode when the hearing aid user is in quiet and moderately complex listening environments, with or without speech. Spatial Cue Preservation mode focuses on maintaining spatial hearing cues as well as the naturalness of sound. The microphone configuration in Spatial Cue Preservation mode differs depending on the location of the microphone on the hearing aid. The spectral cues provided by the pinna are largely maintained with the hearing aid microphone placement in custom in-the-ear hearing aids, as the microphone of these hearing aids is located at the concha or in the ear canal, where incoming sounds are picked up after the pinna filters them. Spatial hearing is provided

Table 2 Published Findings on Optimal Binaural Microphone Response have been Instrumental in Developing the Four Bilateral Microphone Responses of All Access Directionality

All Access Directionality microphone mode	Research finding
Bilateral omnidirectional (Spatial Cue Preservation mode)	In quiet environments, a bilateral omnidirectional response is strongly preferred by users[24,38]
Asymmetric with omnidirectional on right side and directional on left side or directional on right side and omnidirectional on left side (Binaural Listening mode)	A directional response for one hearing aid and an omnidirectional response for the other hearing aid can improve ease of listening and awareness of surroundings as compared with bilateral fixed directional fittings[30]
Bilateral directional (Speech Intelligibility mode)	A bilateral directional response provides the greatest benefit when the speech signal is predominantly in front of the listener[39]

naturally by in-the-ear microphone placement; therefore, it makes sense for the Spatial Cue Preservation mode to use an omnidirectional response for each hearing aid. However, the microphone location on behind-the-ear (BTE) and receiver-in-the-ear (RIE) style hearing aids (above and behind the pinna) compromises monaural spectral cues, disturbing hearing aid users' ability to localize sounds. Therefore, in BTE and RIE hearing aids, Spatial Cue Preservation mode supports spatial hearing in one of two ways.

Pinna Compensation

Spatial Cue Preservation mode uses a feature called "Spatial Sense" in BTE and conventional RIE hearing aids. Spatial Sense combines a binaural compression algorithm with a pinna compensation algorithm (see Table 1). The binaural compression algorithm uses wireless communication between the hearing aids to restore high-frequency ILDs that are otherwise compromised when wide dynamic range compression operates independently in each hearing aid (see the article by Derleth et al in this issue for more discussion about binaural localization cues). The pinna compensation part of the feature corrects the acoustical side effects caused by the placement of the hearing aid microphones above and behind the ear. It recreates the directionality of an average pinna by applying a front-facing directional mode in the higher frequencies. The pinna compensation algorithm of Spatial Cue Preservation mode has been shown to effectively reduce the number of front/back confusions compared with traditional omnidirectional microphones.[40,41] In a review of studies on pinna compensation, Xu and Han suggested that individual differences in real-world performance with pinna compensation indicate that some hearing aid users may experience a localization benefit relative to omnidirectionality while others may not.[42] This agrees with our own research where some participants performed better with pinna compensation than omnidirectional microphones while others did not.[41] We speculate that participants who benefitted the most from pinna compensation were those whose unique pinna anatomy resulted in spectral filtering that closely resembled the average that was used in the pinna compensation algorithm.

Microphone and Receiver-in-the-Ear

Some ReSound RIE hearing aids can be fit with a microphone and receiver-in-the-ear (M&RIE) type of receiver. The M&RIE receiver (illustrated in Fig. 1) includes a microphone placed

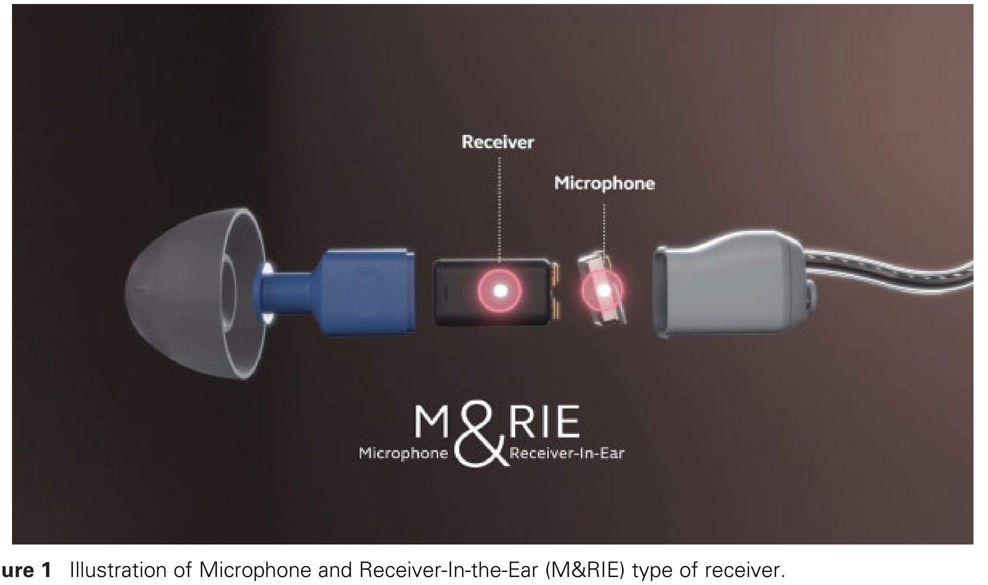

Figure 1 Illustration of Microphone and Receiver-In-the-Ear (M&RIE) type of receiver.

within the ear canal. In this case, Spatial Cue Preservation mode uses the microphone in the ear canal instead of the microphones in the body of the hearing aid. By using the microphone in the ear canal, the influence of the hearing aid user's unique pinna anatomy is maintained. Compared with traditional omnidirectional hearing aids, this technology has been shown to reduce localization errors and to be preferred for sound quality.[41]

BINAURAL LISTENING MODE

All Access Directionality switches to Binaural Listening mode when the rear-facing noise detector measures noise above a certain threshold. Speech may be present but not solely in front of the user. Binaural Listening mode is intended to balance the need to provide the user with access to their surroundings while, at the same time, enhancing the intelligibility of speech coming from the front. Binaural Listening mode puts the hearing aids in an asymmetric microphone mode where one hearing aid is in a directional mode, and the other hearing aid is in a specially designed omnidirectional mode that attempts to compensate for the head shadow effect when the hearing aid is worn.[37] The hearing aid in directional mode provides enhanced SNR for speech in front, while the hearing aid in omnidirectional mode maintains environmental awareness. It has been shown that this asymmetric approach can significantly improve the speech intelligibility of talkers that are not positioned in front of the user.[43] In this study, speech intelligibility for Binaural Listening mode was compared with that for bilateral beamformers in an acoustic scene where the target talkers were from the left of and behind the hearing aid user. As shown in Figs. 2 and 3, speech reception thresholds were approximately 10 to 20 dB better with Binaural Listening mode compared with the bilateral beamformers.

In Binaural Listening mode, the side that is in directional mode and the side that is in omnidirectional mode are optimized depending on the listening environment. It has previously been shown that intelligently changing the hearing aid which is in directional mode and which is in omnidirectional mode improves speech intelligibility in an acoustic scene where

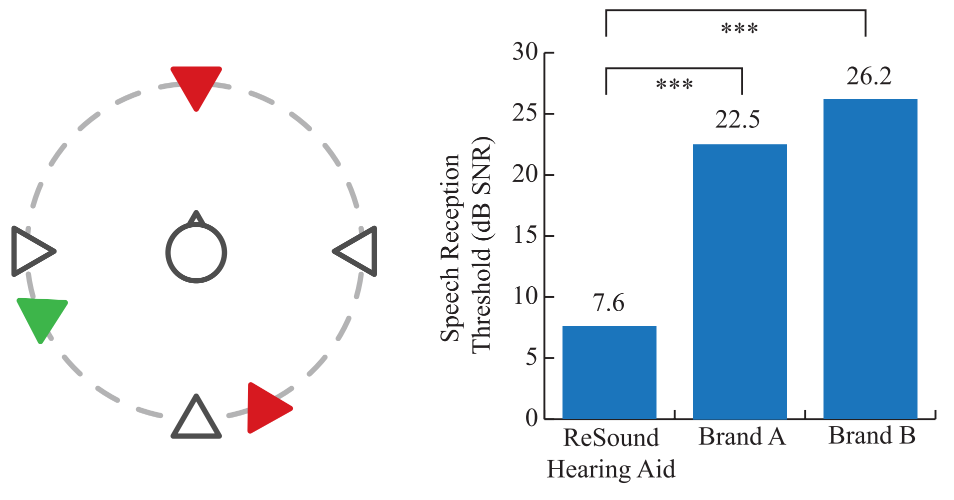

Figure 2 The green arrow indicates the position of the target talker, while the red arrows show the positions of masking talkers. The white arrows indicate the positions of loudspeakers that played speech-shaped noise. Mean speech reception threshold results are shown for the target talker to the left for Binaural Listening mode in a pair of ReSound hearing aids and bilateral beamformers in two pairs of hearing aids of other brands. Lower values are better. The asterisks show significant differences, where ***indicates $p < 0.001$. (Redrawn with permission from Canadian audiologist).

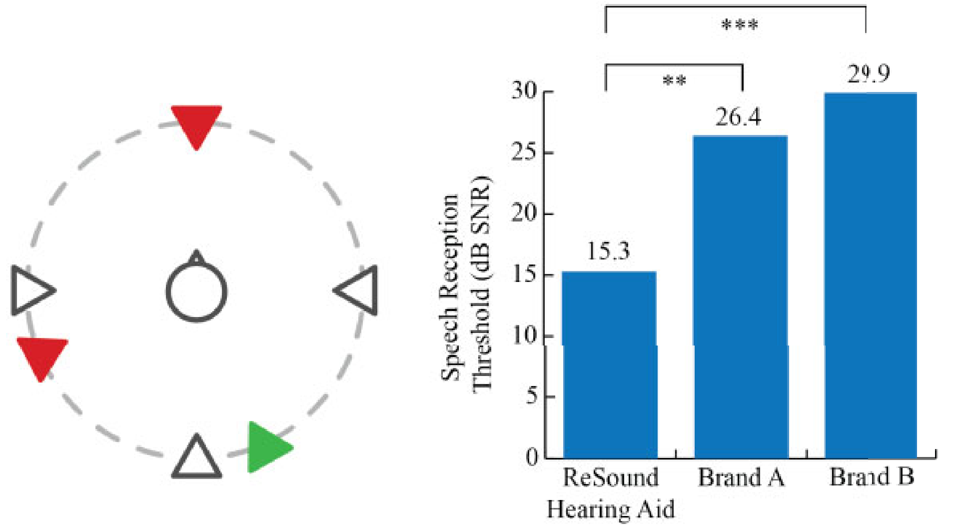

Figure 3 Same as Fig. 2, but for the target talker from behind. (Redrawn with permission from Canadian audiologist). The asterisks show significant differences where ** indicates $p < 01$ and *** indicates $p < 001$.

a talker is to one side of the hearing aid user and noise is to the other side.[33] All Access Directionality adapts to such situations automatically.

A schematic example of Binaural Listening mode is shown in Fig. 4. The illustration in the left panel shows a directional response on the left ear. To maintain situational awareness in this case, the right hearing aid must compensate for the head shadow. This implies that the left quadrant behind the directional ear may have reduced audibility. In Binaural Listening mode, the response in the right hearing aid has been designed to "fill in" this "blind spot." The different directional responses on the two sides maximize the user's opportunity to hear in all directions. The response on the enhanced omnidirectional side is based on the binaural hearing model that optimizes SNR improvement and audibility of surroundings/situational awareness.[37]

Compared with earlier versions of the Binaural Listening mode, All Access Directionality incorporates a bilateral beamformer to enhance SNR benefit of the directional side as much as possible.[44]

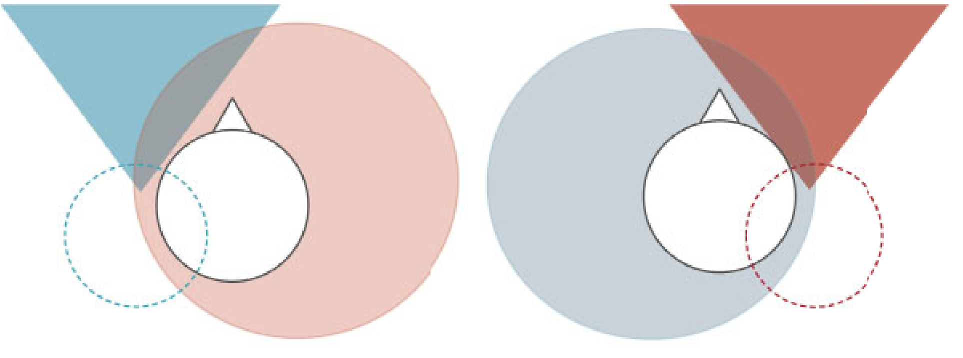

Figure 4 Illustration of how the asymmetric directional configuration maximizes the audibility of sounds all around the user by expanding the omnidirectional microphone response to pick up sounds from the directional side.

SPEECH INTELLIGIBILITY MODE

The Speech Intelligibility mode is active when there is noise and when speech is detected only in front of the hearing aid user. In this type of listening environment, it has been shown that speech recognition scores improve in laboratory testing with a bilateral directional response compared with an asymmetric response.[33,34] In this mode, both hearing aids are configured to be directional. The Speech Intelligibility mode of All Access Directionality uses a bilateral beamformer where wireless communication between the hearing aids enables all four microphones in the bodies of the two hearing aids to create a more directional beam than is possible with only two microphones[44] (for more information about the technology behind bilateral beamformers, see the articles by Derleth et al and by Andersen et al in this issue). In listening environments where the noise is diffuse, the beamforming algorithm weights the inputs of both hearing aids' microphones equally. However, in listening environments with more noise on one side or the other, the algorithm takes advantage of the head shadow by assigning greater weights to the side with less noise than the side with more noise. In addition, the bilateral beamformer is a three-band system. Below an adjustable crossover frequency, the processing is omnidirectional.[45] This preserves ITDs, which are the dominant localization cue in the low frequencies. Sound quality differences between different microphone modes are also minimized with this approach.[46–48] Above 5000 Hz, a monaural hypercardioid response is applied in each hearing aid. This prevents the adaptive bilateral beamformer from interfering with high-frequency ILD cues for localization. The bilateral beamforming is then applied in the mid-band, which contains the most salient frequencies for speech recognition.

SUMMARY

Directional microphone technology is readily available in today's hearing aids and can significantly improve speech recognition in noise. However, despite its level of sophistication, the technology itself does not guarantee that these benefits are realized in daily use situations. In fact, directional microphones have the potential to interfere with the user's awareness of their surroundings and their ability to follow conversations. ReSound developed an approach to applying directional microphones based on the philosophy that they leverage binaural hearing and inherent listening strategies. The current strategy encompasses three listening modes that support the natural ways in which people listen. Compared with a more conventional approach that switches between bilateral omnidirectional and bilateral directional processing, this strategy has been shown to have advantages in terms of sound quality, spatial hearing, and improved SNR with maintained awareness of surroundings.

CONFLICT OF INTEREST
None declared.

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