Empowering hearing aid users with directional technology designed for the real world

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ABSTRACT

Beltone Serene™ is the next generation of hearing aids with the smallest rechargeable Receiver-in-the-Ear style. Top-rated for hearing in noise, it allows users to hear their best automatically. Directionality and other noise management features are automatically controlled by environmental classifiers in hearing aids. This paper compares the accuracy of environmental classification for different premium hearing aid brands and explains the importance of the approach for applying automatic settings. Useability of hearing aids in everyday life is a priority for Beltone and means that hearing aid users should be empowered to control their listening experience. The performance of strong noise management features across hearing aid brands is also explored with respect to how they may or may not disconnect hearing aid users from their surroundings.

A publication describing a feature in another premium hearing aid brand specifies that sound will be processed in a particular way 'if the signal contains information the wearer wants to hear.' This statement starkly illustrates the philosophical difference between the approach to product development taken by Beltone and most other hearing aid brands. This is because no hearing aid intelligence has a valid way to determine whether a signal contains information the hearing aid wearer wants to hear. This approach implies that the hearing aid is empowered to make decisions on behalf of the hearing aid user to help them. Beltone takes the opposite approach, where the hearing aid provides help that empowers the user to control their listening experience. Inspired by the way people naturally hear and use their hearing, this enables people to connect to the world around them in the most intuitive and natural way.

Self-perceived hearing difficulty is a strong determinant of whether people with hearing loss seek help,[1] and Hearing Care Professionals (HCPs) will recognise that hearing difficulty in noise is a primary complaint. Those who acquire hearing aids report improved life quality and high satisfaction with hearing aids.[2] However, approximately one-third of hearing aid users are not satisfied with their ability to follow conversations in large groups or in noisy backgrounds.[3] Therefore, Beltone puts special emphasis on developing solutions to help people manage better in noise.

Managing noise in the real world

Noise is often represented in laboratory testing by a static speech-shaped noise or the babble of many talkers. But in real-life situations, noise is anything that interferes with the hearing aid user's listening goals. It can be static noises, such as the rush of an air conditioner or hum of a motor, but it can also be the sound of a dog barking or a TV program, or even people talking. In fact, participants in a study where they were asked to keep a diary of annoying sounds in their daily environments listed 'verbal human sounds' more than any other type.[4] Furthermore, what is noise at one moment may become the signal of interest the next. Imagine the hearing aid user is driving a car whilst listening to music on the car's sound system, and two passengers are chatting together about something that doesn't interest the hearing aid user. The conversation of the passengers can be considered to be noise. But if one of the passengers suddenly gives the driver some important information, such as 'Turn left at the next stoplight', then the music becomes the noise and the passenger's voice is the signal of interest. The environmental analysis system of the hearing aids will control how it enhances or suppresses the different signals

in this situation. As shown in testing of environmental classifiers reported in this paper and elsewhere,[5,6] the analysis may lead to settings that don't support the hearing aid user's ability to focus, monitor, and change focus at will.

Beltone makes solutions to help people hear better in the noise of daily life and not just in artificial laboratory conditions. In other words, they are useable; they help to lessen hearing difficulties without creating secondary problems. Directional microphones are the most powerful onboard tool currently available in hearing aids to help with hearing in noise. But the strategy used to apply directional microphones can rob hearing aid users of control over what they want to hear. In addition, directional microphone technology in hearing aids has technical drawbacks, including less sensitivity for low- frequency sound regardless of direction of arrival, greater susceptibility to wind noise, loud-sounding own voice, and loss of localisation and binaural hearing cues.

With a unique binaural beamformer that uses all four microphones of a bilaterally worn pair of hearing aids, the directional benefit of the Beltone system has been shown to be an improvement over legacy technology with 4.36 dB better signal-to-noise ratio (SNR), translating to a 150% improvement.[7] This performance leap was made possible by better resolution in the binaural beamforming which better accounts for acoustic effects of head and torso. Although the beamforming is only carried out in the mid-band of a 3-band system (Figure 1), equivalent directional benefit is expected compared to other hearing aids with full bandwidth beamforming because important binaural hearing cues are preserved.

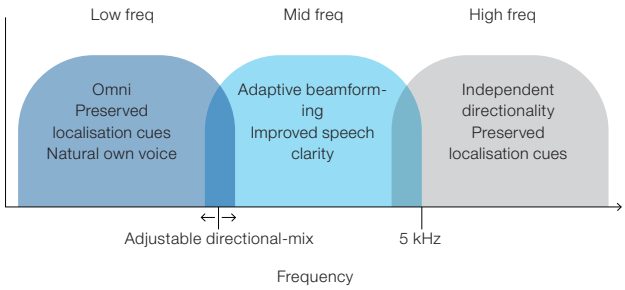


Figure 1. The unique 3-band directional system in the Beltone Serene improves SNR whilst still preserving natural sound quality and spatial hearing cues.

The Beltone approach to applying directionality so that it is most useable was conceived in the early 2000s and is based on the ways people use binaural hearing to either listen with their 'better' ear or maintain awareness of their surroundings. This research direction was against conventional wisdom regarding directional technology, which assumes that the hearing aid user will always face the signal of interest. According to the better ear strategy, listeners will accommodate their position relative to the desired sound to maximise audibility of that sound, and rely on the ear with the best representation (SNR) of that sound. The directivity patterns of both ears contribute to this ability to focus and were discussed at length by Zurek.[8] An extension to the better ear strategy model includes the omnidirectional directivity effects of binaural listening to describe the listener's ability to remain connected and aware of the surrounding soundscape. Whilst the head shadow effect plays a role in improving the signal-to-noise ratio in one of the two ears, the awareness strategy looks at how the two ears, due to their geometric location on the head, allow for the head to be acoustically transparent and keep the listener connected to their listening environment. The listener can make use of either the better ear strategy or the awareness strategy at will.

With ear-to-ear connectivity, the Beltone binaural strategy for automatic microphone control enables the hearing aids to apply one of four patterns to best support listening in daily situations (Figure 2). A Spatial Cue Preservation mode is active in quiet and moderately complex listening environments where listeners are most likely to rely on spatial hearing cues to orient to their environment, and where sound quality is especially important. In noisier situations, where speech may be present at different locations, the Binaural Listening mode will apply an asymmetric directional response. The binaural beamforming response will be presented on one side, whilst the sound from the directional side will be streamed to the opposite side to provide the best all-around audibility. Finally, in noisy situations where speech is only identified in front, the Speech Intelligibility mode uses the binaural beamforming response in both hearing aids.

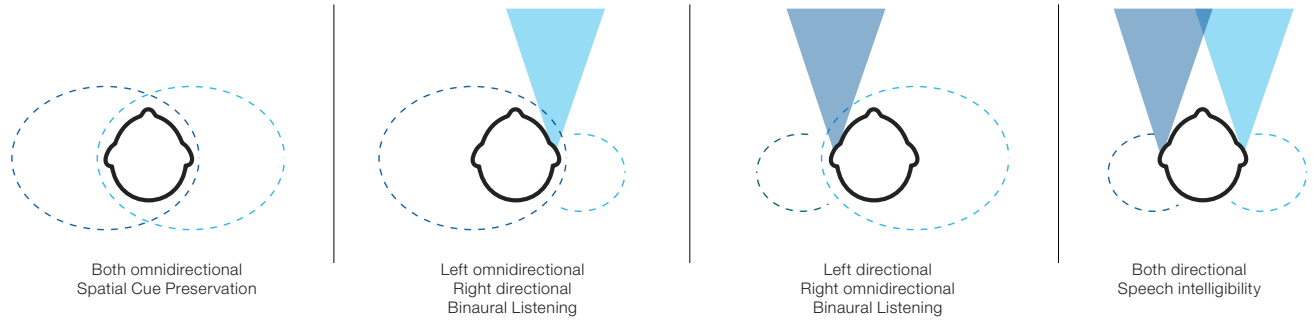


Figure 2. The Beltone strategy for automatic assignment of microphone modes to optimise listening in all daily situations.

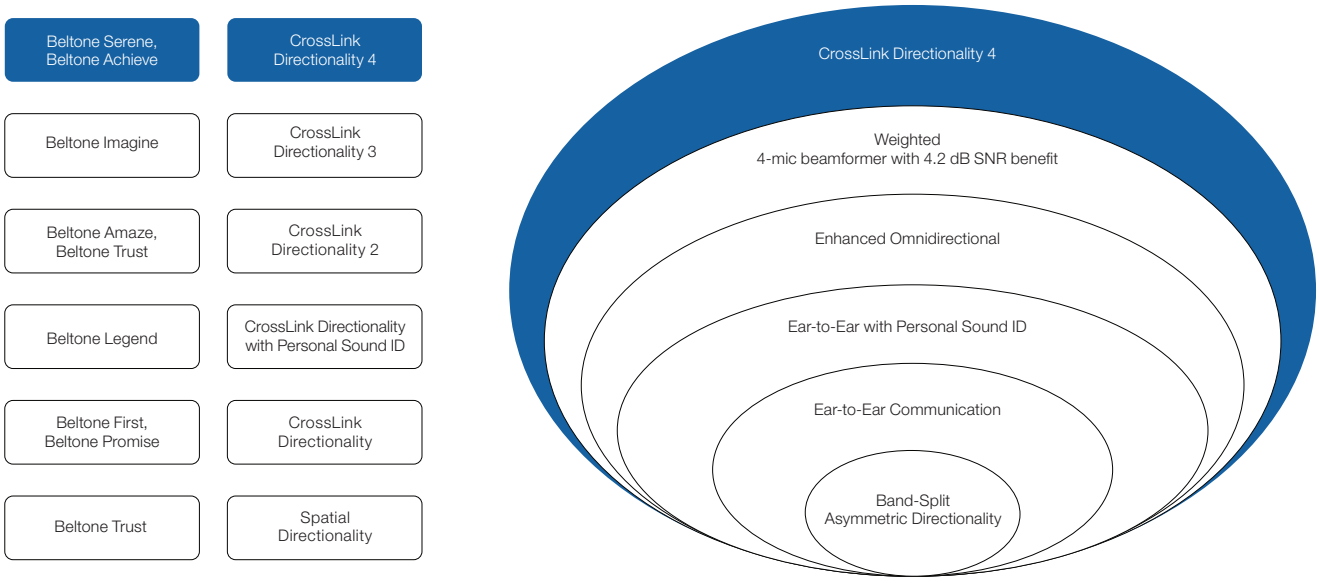


Figure 3. Beltone has followed a binaural directional strategy for applying microphone modes for more than a decade. Improvements to this strategy have been added as technology became available, ultimately resulting in the 360 All-Around automatic program.

A history in supporting binaural hearing

The first iteration of the Beltone binaural noise management system was introduced in 2010. With each successive generation, new features have advanced our ability to support the natural ways people listen in both quiet and noisy real-life situations. In recent years, other hearing manufacturers have also begun to promote the importance of being able to hear in noise without being cut off from the surroundings, and to preserve binaural and spatial hearing cues. This tells us we have been on the right path all along. Figure 3 provides an overview of how the Beltone binaural strategy has evolved.

The heart of the hearing aid

The action of all hearing aids is controlled by environmental acoustic input, beginning with the level of the input sound that determines amplification and limiting of the output. Today's advanced hearing aids extract many additional acoustic features that determine both the sound processing as well as how and when different sound processing features are applied. The system that carries out the analysis of these acoustic features can be generically referred to as the environmental classifier. Due to its vital role in determining how settings intended to meet the hearing aid user's needs are automatically applied in different environments, this system is essentially the core of the hearing aid. A challenge for environmental classifiers is that the intent of the hearing aid user and what sounds are of interest or noise are not straightforward to infer from acoustic data. Therefore, algorithms that apply directionality and other settings meant to optimise the listening experience are necessarily crude. The settings that are automatically applied may have the unintended effect of interfering with the hearing aid wearer's listening intent either due to the strategy for applying the settings or due to errors in the environmental classification or both.

We reported on accuracy of environmental classifiers in commercial hearing aids in 2017, where we found that more complex environments that included multiple talkers and various background noise sources were difficult to classify according to a human perceptual standard.[5] In this study, hearing aids were mounted in a test box and exposed to looped sound files of various environments for many hours, after which they were connected to their respective fitting software and the output of their environmental classifier was read out. One striking finding was that hearing aids that included classification of music often 'disagreed' with human assessment because in environments containing music and speech it is not possible for the hearing aids to know which signal the hearing aid user would be interested in listening to. In the study, human listeners had classified a scenario with a conversation in a supermarket where the background included music as speech-in-noise, but hearing aids that classified music identified a significant portion of the time exposure to this environment as music. Yellamsetty and colleagues[6] carried out a similar study where they presented the sound scenarios for different brands of hearing aids in a more realistic test environment that would also allow for direction of arrival of speech or other sounds to be included in the classification. Their results were similar to Groth & Cui[5], showing that agreement on the classification of environments between human judges and hearing aid classifiers decreased as the complexity of the environment increased, and that background music was identified in an environment where the human listeners assessed that music would likely not be the signal of interest.

Due to the similarity in results in these two studies, we updated our previous findings by repeating the original experiment with currently available hearing aids from four premium brands along with Beltone Serene. Hearing aids were exposed to 12 to 24 hours of nine different sound scenarios which human listeners showed high agreement in classifying. The readings from each brand's fitting software were mapped to three broad environments according to the presence of speech and 'not speech' which we labelled as 'noise'. The three environments are 'quiet and

speech only', 'speech in noise' and 'noise'. Accuracy was determined by calculating the percentage of exposure hours that agreed with human classification. The results per each of the three environments and the overall accuracy based on the sum of all three environments are shown in Figures 4 through 6. All hearing aids showed the most accurate results for the 'quiet and speech only' environment and the least accurate results for 'speech in noise'. Beltone hearing aids were the most accurate across all categories, with an overall accuracy of 91%. The overall accuracy for the other brands ranged from 39% (Brand A) to 71% (Brand B).

We conclude that: 1) differences still exist across brands in identification of acoustic environments, and more complex environments are difficult to classify accurately; 2) Beltone hearing aids continue to lead the field in accuracy of environmental classification compared to other hearing aid brands; and 3) hearing aids that identify music make the most errors in classification. In real-life situations, these errors could include mistaking music as the signal of interest in a complex environment. However, it was also observed in this experiment that false positive errors were oddly made in response to what human listeners unanimously judge to be a source of noise – the sound of a vacuum cleaner running (Figure 6). Because music listening is an intentional activity, Beltone does not include music classification to control the hearing aid processing. Rather, an optimised program is available for music listening that is user selectable. Therefore, the HCP can be confident that the automatic CrossLink Directionality 4 program is providing appropriate support for the acoustic surroundings regardless of what sounds are present.

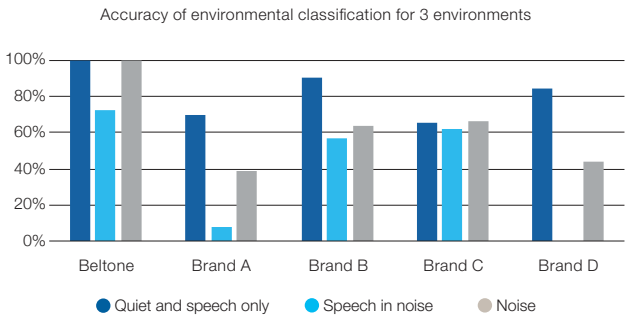


Figure 4. Accuracy of environmental classifiers was determined by calculating the percentage of hours of exposure to sound scenarios that were in agreement with human assessment. The Beltone vsystem showed the highest accuracy.

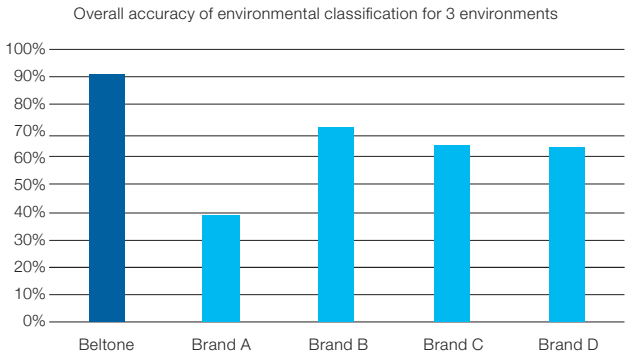


Figure 5. Accuracy across the different sound scenarios for each hearing aid brand.

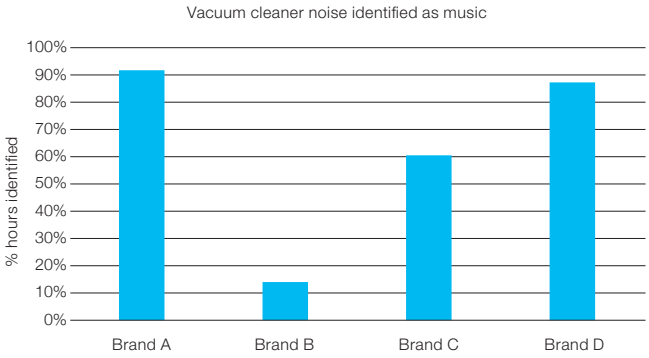


Figure 6. A sound that human listeners categorise unanimously as noise was identified as music by hearing aids that have music identification in their environmental classifiers. These results suggest that the criteria used by each brand for music identification may be quite different, as the percentage of false positive identifications ranged from 14% to 92%.

Access to surrounding speech and other important sound

Real-life situations often involve listening to sounds that a person is not looking at. For example, some people enjoy doing other activities whilst watching TV, such as needle-work. This requires dividing one's visual attention between the two activities, remaining oriented about the TV program by following the sound. Similarly, a person waiting for their order at a lunch counter might be conversing with a companion whilst at the same time listening for their name to be called. Cord and colleagues[9] asked hearing aid users to fill out logs of their daily listening situations, including the location of the signal of interest when they were actively listening. They found that 32% of active listening time was spent attending to sound that was to the side or in back of the hearing aid user or was coming from multiple locations or moving. The investigators also carried out speech in noise testing with target speech occurring from different azimuths and found that bilateral directionality resulted in significantly worse performance when the target speech was not in front, and that an asymmetrical directional response yielded better performance. Consistent with these results, the Beltone strategy supports all daily listening scenarios by adjusting hearing aids on both ears synchronously, sometimes applying different spatial directivity patterns on either side of head to maximise head shadow effects and other biological advantages (Figure 2). This bilateral synchronisation in our solution provides the right shape of a beam on each side of the head to provide all the important information needed to send to the brain such that the brain can stitch this information together to provide a very natural and enhanced listening experience. This listening experience is directed by the user, who decides what to focus on or what not to focus on. Hence, we provide a solution in which we lose no information about the hearing aid user's surrounding soundscape.

Previously, we reported on how the microphone steering strategy provided similar directional benefit for speech in front of the listener whilst vastly improving access to speech from the rear and side of the listener compared to other premium hearing aid brands.[10] In the previous test, we compared our hearing aids in Binaural Listening mode (see Figure 2) to the strong directional settings of other hearing aids that used binaural beamforming. Similarly to the Cord and colleagues[9] study, participants were asked to repeat speech that was presented either from in front,

to the side or the back, but with two competing talkers presented from the non-target directions rather than static speech-shaped noise. This made the task exceptionally challenging. Results showed an enormous SNR advantage for the Beltone Binaural Listening mode when speech was to the side or behind the listener. With our latest technology, it would also be the case that the CrossLink Directionality 4 automatic program would steer to the Binaural Listening mode in this test setup. In addition, Jespersen & Groth[7] demonstrated how audibility with the 'true omnidirectional' response in this mode – attained by streaming sound from the directional to the omnidirectional device – would provide even better audibility for speech from directional side. Thus, the benefit of audibility for speech occurring from directions other than in front is maintained and enhanced in our latest technology.

Focus on conversation in front?

The automatic CrossLink Directionality 4 program activates the Speech Intelligibility mode, providing a strong bilateral directional response using the unique Beltone binaural beamformer in noisy situations where speech is detected in front of the user, but not from other directions. The noise background can consist of other people talking, but the SNR for these conversations is very poor when the Speech Intelligibility mode is activated. Datalogging has shown that this condition tends to be active less than 10% of total use time for many people. It is expected and by design that a directional response on both ears seldom is activated automatically, because many everyday environments contain speech all around the hearing aid user at positive SNRs.[11] The Beltone strategy does not assume or decide that only the speech in front of the hearing aid user is the signal of interest, but depending on their listening intent, they may experience maximum benefit with the binaural beamformer active on both sides. Front Focus is a user-selectable directional feature that can solve this challenge. The purpose of Front Focus is to allow the hearing aid user to override the automatically applied microphone mode in any situation where they would like to focus mainly on the talker(s) in front of them. However, this does raise the question of what would happen in a situation where interesting speech occurs in the back when they have manually activated Front Focus? For example, they might forget to return to the automatic CrossLink Directionality 4 program. Does the hearing aid user still have access to speech occurring from directions other than in front? To answer this question, we tested against two other premium hearing aid brands that provide strong directionality with binaural beamforming and one brand that does not use binaural beamforming, but which claims access to sound from other directions than in front of the user.

Methods

Participants

Eleven adult experienced hearing aid users (9 males, 2 females; average age 65.1 years with range 22 to 79 years) with mild-to-moderate sensorineural hearing loss participated.

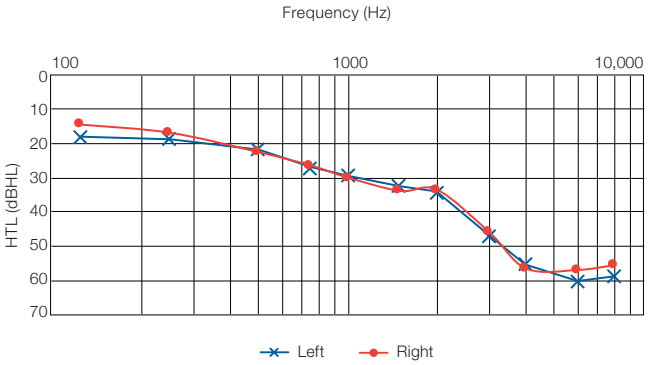


Figure 7. Average hearing threshold levels for the 11 participants in the current study.

Hearing aids

Each participant was fit with Beltone Serene receiver-in-the-ear (RIE) hearing aids as well as the most current RIE hearing aids from three other premium brands. The other brands were chosen as a comparison because of their noise management capabilities. Two of them use full bandwidth binaural beamforming, whilst the third combines conventional directionality with noise reduction based on deep neural networks. The default gain prescription was used for each brand, and the hearing aids were all fit using each brand's most occluding domes to maximise the effect of the signal processing. For each brand, the strongest noise management settings were activated. For the Beltone Serene, this was the Front Focus setting.

Test setup and procedures

Conventional speech-in-noise test

All hearing aids tested were expected to show benefit in a conventional laboratory test setup with diffuse, static babble noise presented in the rear hemifield and speech presented in front. To ensure that this was the case, the Danish Dantale II sentence test[12] was carried out.

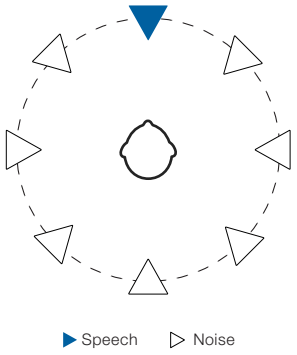


Figure 8. For conventional speech-in-noise testing, the listener was seated in a test environment with speech presented from in front and babble noise presented from seven surrounding speakers.

DAT test

The test participants completed an adaptive speech-intelligibility listening test, hereafter referred to as the 'DAT' test.[13] This test yields a SNR at the speech reception threshold (SRT). In this test, both the signal and the competing noise are individual talkers, which is exceptionally challenging compared to speech-shaped noise or babble, as there is informational as well as energetic masking

taking place. Because the competing speech is intelligible, the DAT test may be more representative of a real-world situation than typical speech-in-noise tests.

The sentences are composed of a fixed carrier sentence beginning with either the name ‘Dagmar’, ‘Asta’ or ‘Tine’ and containing two target nouns, and the listener must repeat the target nouns in the sentences beginning with ‘Dagmar’. Each of the three sets of sentences is spoken by a different female talker. Target sentences were played consistently at 65 dB SPL. Sentences beginning with the names ‘Asta’ and ‘Tine’ comprised the maskers. Masker sentences were played simultaneously from other loud-speakers whilst the ‘Dagmar’ sentence was playing, but the test participant was not asked to attend to the masker sentences. For each trial, the presentation of the masker sentences was adjusted in 2 dB steps depending on whether the target words were correctly identified.

For each set of hearing aids, two conditions were completed in which the target sentences came from either the front or back loudspeaker as illustrated in Figure 9. The sequence of the conditions was counterbalanced among test participants. The maskers were played from the remaining two loudspeakers.

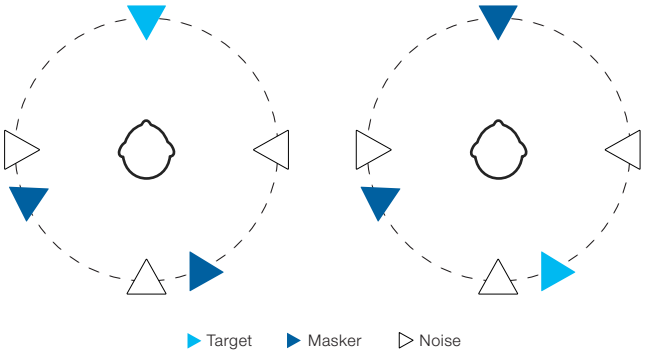


Figure 9. In the DAT test setup, target speech was presented either from the front or the back, with single talker maskers presented simultaneously from the side and either the front or back. Low level speech-shaped noise was also presented in the rear hemifield.

Results and discussion

Conventional test

When tested in a diffuse noise environment with target speech in front and noise spatially separate in the rear, no significant differences were observed across the hearing aid brands tested. This was an expected result, as each brand’s strongest noise management feature is presumably optimised to perform well in this type of setting. Considering that the binaural beamformer used in Beltone Front Focus provides an omnidirectional response in the low frequencies and an independent fixed directional response per device above 5000 Hz, the equivalent performance to other brands with more aggressive noise cancelling features is impressive.

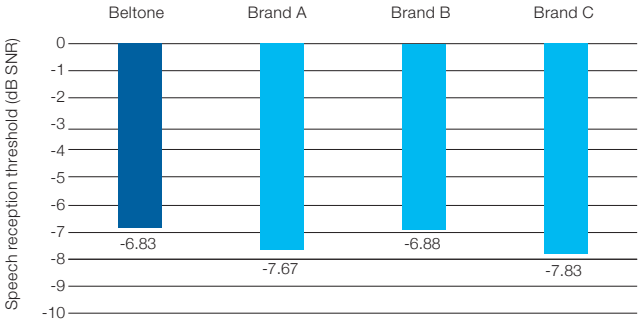


Figure 10. The directional systems of all brands tested showed no significant differences in performance in the conventional test setup regardless of each brand’s technology.

DAT

In 88% of trials, Beltone Front Focus provided at least 2 dB better access to speech from behind than any of the other brands. Because there were no significant differences among the results for the other brands, they were averaged per participant. Comparing to this average, the SNR for speech in back was 5.7 dB for Beltone Front Focus and 10.1 dB for the other brands, a significant improvement (p>.01) of 4.4 dB for Beltone.

Considered together with the results of the conventional speech-in-noise test, these findings are a compelling illustration of how the Beltone philosophy leads to highly useable solutions that empower the hearing aid user. In the example given earlier where a hearing aid user might forget to return to their default automatic program, Front Focus would provide much better access to speech all around than other solutions without compromising on directional benefit for speech in front. With Front Focus – as well as the Speech Intelligibility mode of the automatic CrossLink Directionality 4 program – hearing aid users are not cut off from their surroundings and maintain the opportunity to monitor and shift focus if they want.

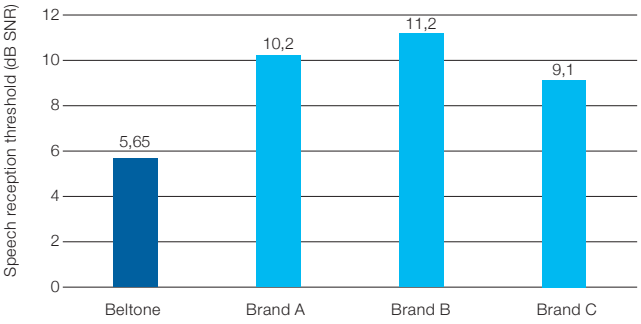


Figure 11. When target speech was presented from the back with competing single talkers presented from the side and in front, the Beltone technology allowed significantly better access to the target speech than other brands.

Summary

Today's hearing aids apply automatic algorithms to control different hearing aid features, including directionality. The action of these algorithms is based on analysis of the acoustic environment carried out by the hearing aids. Therefore, it is important that environmental classifiers are as accurate as possible so that they do not apply settings that interfere with the hearing aid user's listening intent. We previously showed that environmental classifiers often were inaccurate in complex listening environments, and that music identification seemed to be responsible for much of the inaccuracy. An updated investigation with current hearing aids showed that Beltone continues to have the most accurate environmental classifier. The rationale for using the environmental classifier data to control the hearing aids is also critical. The philosophy followed by Beltone aims to empower the hearing aid user to control their listening experience rather than empowering the hearing aids to make decisions about what sounds are relevant for the user.

Some hearing aid brands apply strong noise management features either automatically or as a user selectable feature. Beltone Serene also offers users Front Focus to override any automatic functionality in situations where they want to focus on conversations in front of them. We demonstrated how Front Focus provides equivalent benefit to other brands when speech is in front without cutting hearing aid users off from their surroundings. Front Focus allowed for 4.4 dB better SNR for speech in back of the listener compared to other brands with binaural beamforming or other noise management that claims access to surrounding sounds.

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