

Delta Audiology Concept





The needs

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Despite the availability of increasingly advanced technology, the average age of first time users has shown little change over time ¹. In other words, the industry has not been able to attract more new users; one of the strongest desires for many years. Younger first time users present us with a number of audiological challenges – while they have good loudness sensation and hearing in the lower frequencies their loss is restricted to the high frequency region (Figure 1).

Good low frequency hearing leads to near normal speech understanding for many communication situations ². These situations are typically one-to-one conversations, where visual cues are abundant and background noise is rare. In noisy situations however, the loss of high frequency information is especially damaging due to the reduction in available speech cues ². At the same time availability of visual cues

is reduced as situations with poor acoustics often co-occur with poor visual cues (e.g. multiple talkers, poor lighting, visual distractions). In these situations, the background noise dominates and masks low frequency speech information, resulting in significant communication challenges. It is for these situations, that amplification focused on restoring high frequency speech cues (e.g. place of articulation) in addition to a general audibility improvement can significantly improve speech understanding in noise ³.

Truly meeting the needs of this population requires addressing three key challenges.

1. The focus must be to deliver the best speech understanding in noise. This is contrary to the usual approach for amplification where the aim is to provide improved overall audibility in all situations, and speech understanding in noise being but one situation. The key for this population, is not to solve solely a general audibility issue, but to maximise speech understanding in the most difficult listening situations.
2. This population offers a number of psychological and social challenges. Being younger and more active, they need to preserve their lifestyle and do not wish to have a device that carries with it the perceived stigma of a conventional hearing aid ⁴. While sound quality and speech understanding are of paramount importance, aspects such as appearing younger and fashionable are crucial parts of initial acceptance.

3. Excellent sound quality must be delivered for all listening experiences. The user must be able to experience the benefits of amplification without actually noticing the technology. Therefore, all side effects of amplification, such as occlusion, audible transitions between automatic states and compression artefacts (e.g. pumping) must be reduced at all times. This requires a rethinking of the conventional approach to amplification.

When a hearing instrument is designed, there are certain implications that must be taken into account. There is a trade off between the optimum performance of the product and the acceptable level of the side effects. For people with slightly more pronounced hearing losses, the need for amplification often overrides the small number of

processing artefacts and audible side effects that may be required to deliver the desired level of performance. Conversely, for people with a high frequency hearing loss, who essentially have a speech in noise problem rather than an audibility deficit, the limiting factor is side effects. They wish to have the maximum speech understanding possible with absolutely no side effects. Therefore, the tolerance level for amplification related issues (e.g. occlusion, sound quality, compression artefacts, tube resonance) is extremely limited and these aspects must be overcome. This means that we must take a totally fresh approach to amplification.

Delta (Figure 2), a new micro hearing instrument offers a solution to meet the specific needs of the user and their demanding listening situations.



Figure 2: The unique design of Oticon Delta allows for both sleek cosmetic design and the ability to provide the optimum microphone spacing and excellent horizontal alignment of the microphones behind the ear.

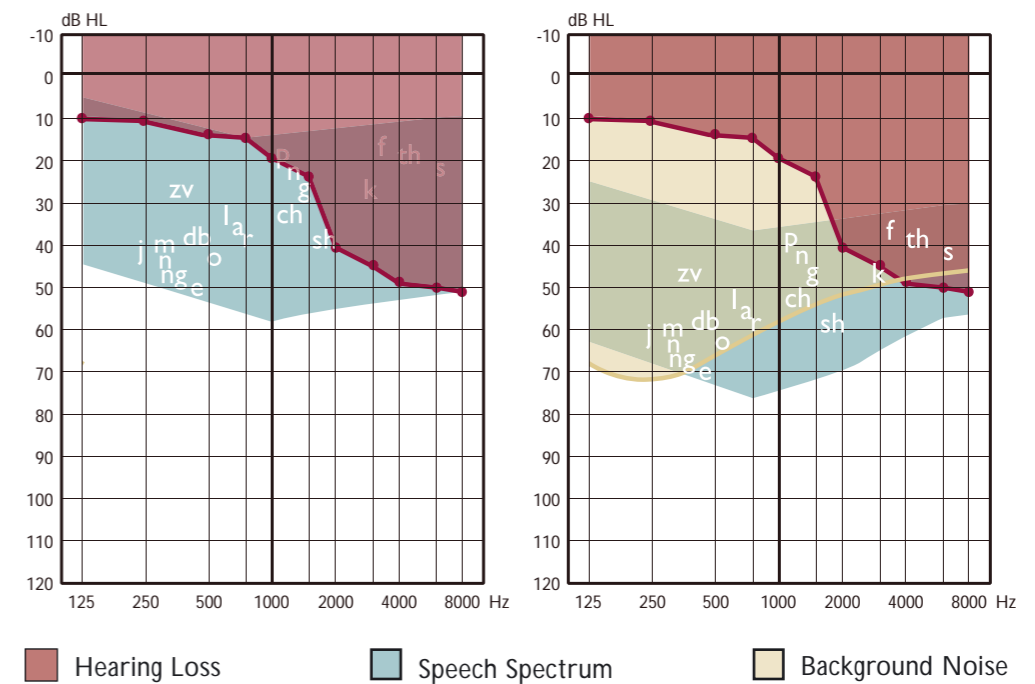


Figure 1: Comparison of the speech understanding potential of people with a mild-to-moderate high frequency hearing loss in quiet versus noise situations. Left panel illustrates that low frequency cues are preserved allowing access to significant cues for speech understanding. Conversely, when communicating in noisy situations (right panel) we see that while people talk louder, the increase in loudness is primarily in the mid frequencies (1000 - 2500 Hz), while high frequency sounds remain inaudible. Unfortunately, background noise masks out the residual low frequency hearing, thus drastically reducing the listener's speech understanding.

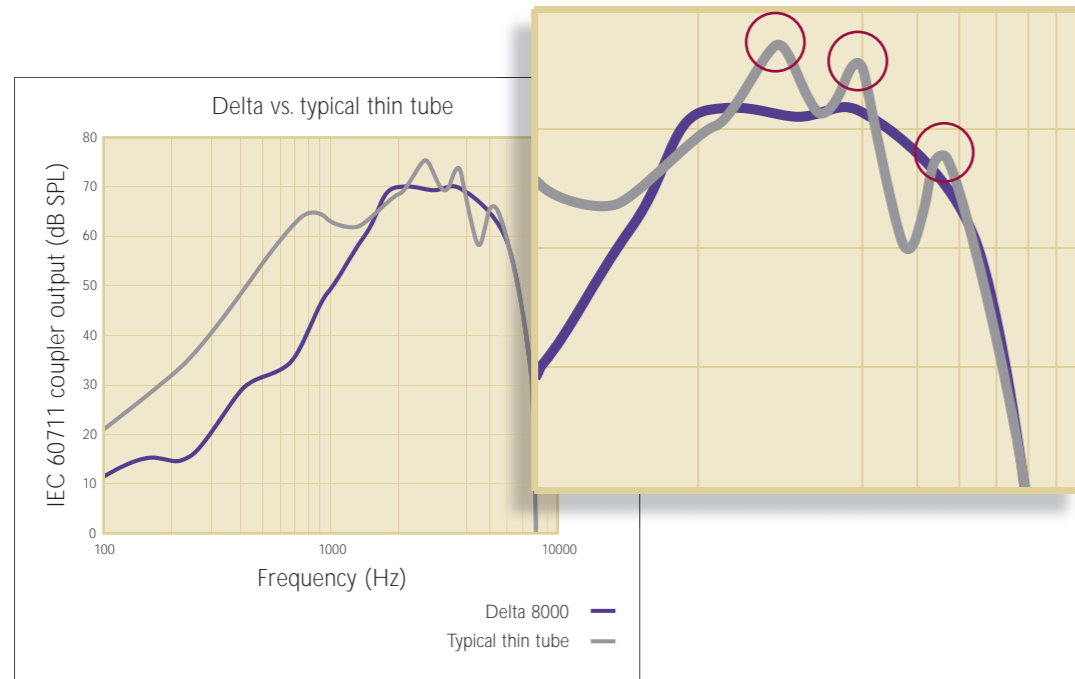


Figure 3: Frequency response from Delta compared with a typical “thin tube” solution showing the improved sound quality by placing the receiver in the ear canal. The typical tube resonance occurring at 2500, 3500 and 4500Hz can be avoided thereby improving sound quality.

results in poorer sound quality. Clearly, the best solution is to bypass the need for compensation and corrections and to place the receiver in the ear canal.

A key concept in Delta is to allow the user access to an extended high frequency bandwidth. This is the key to better speech understanding. Figure 4, highlights the speech intelligibility in noise improvement that can be gained from increasing the high frequency bandwidth from 6000 to 8000Hz on a test of consonant identification. It can be seen that 10 of 11 participants showed a significant improvement in access to speech information in a speech reception threshold (SRT) test. Examination of specific speech sounds showed an overall accuracy improvement, but also access to high frequency consonants such as /s/ were improved with an extended high frequency bandwidth. This increased access to high frequency speech energy not only increases speech understanding in

noise but also reduces the degree of perceived listening effort required during the day.

Occlusion Free

The younger population want excellent sound quality in a cosmetically suitable solution. Previously, the primary way to achieve this was with a CIC. Unfortunately, while CIC's provide the desired cosmetics, two problems arise. First, advanced functionality such as directional microphones are not compatible with the deep insertion and small footprint required. Second, even with a collection vent, the deep insertion of a CIC does not allow for a totally occlusion free fitting. The resulting occlusion is often enough to limit the acceptance of traditional technology for this very particular group.

The optimum solution is to implement a unique way of providing sound to the ear canal. One that combines the occlusion free properties of a BTE with

the sound quality and cosmetic benefits of a CIC. With Delta's innovative design, we were able to place the microphones and battery behind the ear in an extremely discrete shell-set and place the Receiver In The Ear (RITE style). To ensure occlusion free listening, the open dome used in Delta provides for the same acoustic response as an open ear, thus providing total occlusion relief (Figure 5). By placing the microphone unit behind the ear in a small package, we are able to deliver important technology such as directional microphones which are not available in CICs. Therefore, people who have a high frequency hearing loss no longer need to make compromises in the hearing solution provided.

Importantly, the large vent coupled with the significant degree of residual hearing results in a need for less amplification than would be considered if viewing the hearing loss on its own. The totally open vent allows for a

The Delta Solution

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Delta is designed to seamlessly combine enhanced clarity of speech in noise with a sleek cosmetically attractive design. In this way, Delta could be said to have evolved the “beige banana” to provide a hearing solution that is more in line with what new users actually want.

To maximise speech understanding in background noise, Delta provides the new Clarity amplification strategy which takes full advantage of the combination of a totally open fitting and excellent high frequency performance. Unique to the Delta design, the receiver is placed in the ear

canal to preserve sound quality. To ensure optimum performance in even the most challenging of listening situations, Delta takes advantage of Oticon's unique Artificial Intelligence technology⁵. This implies that various clarity enhancing solutions such as Multiband Adaptive Directionality and TriState Noise Management are implemented when it provides a measured benefit.

High Frequency Performance and Sound Quality

A key to improved speech understanding in noise is to ensure that speech information in the higher frequencies is made salient without any audible

distortion. Placing the receiver in the ear canal removes the need to compensate for the resonances created by the sound tubing (Figure 3). This tube resonance is present whether the tube is a conventional 2mm wide tube or the new “thin tube” style, as it relates to tube length and not width⁶. It is possible in modern fitting software to compensate for these tube resonances by adjusting the calibration of the hearing aid. Unfortunately, once the audiologist changes the settings or tube length from those prescribed at the factory these potentially disturbing resonances reappear. Therefore, the inherent limitations of traditional hearing aid design remains a problem and

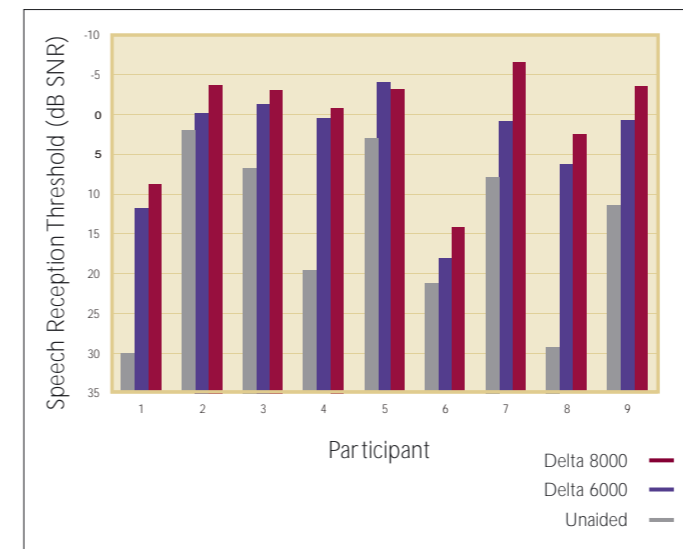


Figure 4: Comparison of performance of 11 participants on a test of consonant identification in noise. It is clear that Delta provides not only a significant improvement, but also that the performance improves when the bandwidth is extended to 8000Hz.

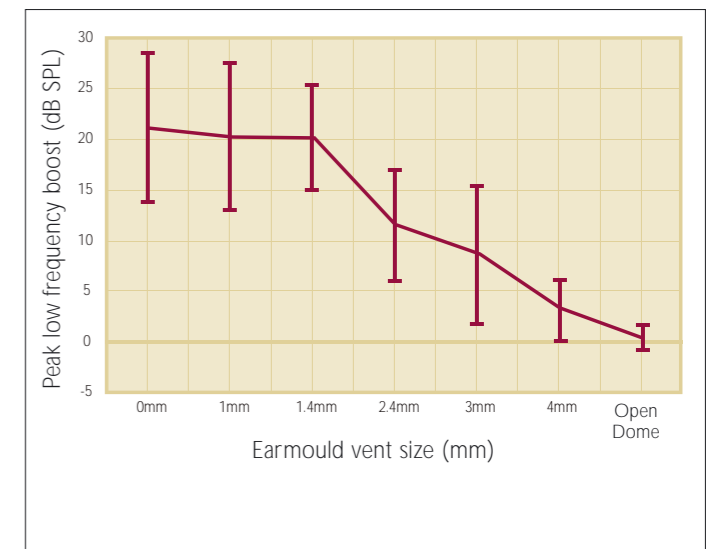


Figure 5: Open ear responses from different vent diameters, indicating that the OpenDome has the same response as a totally open ear canal.

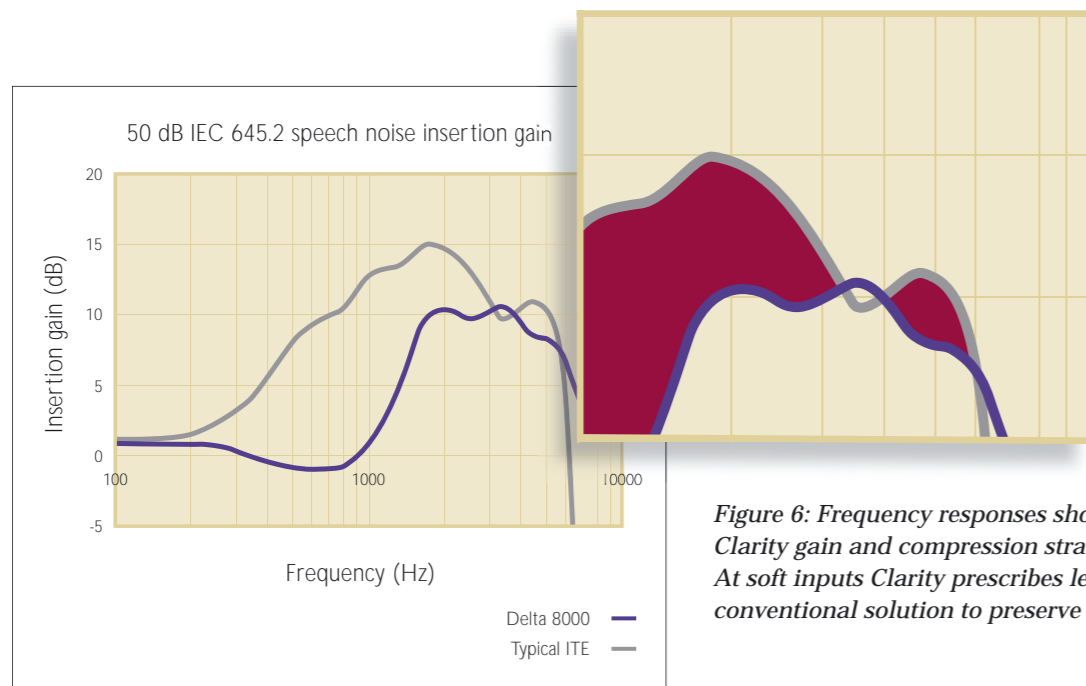


Figure 6: Frequency responses showing the unique Clarity gain and compression strategy in Delta. At soft inputs Clarity prescribes less gain than a conventional solution to preserve comfort.

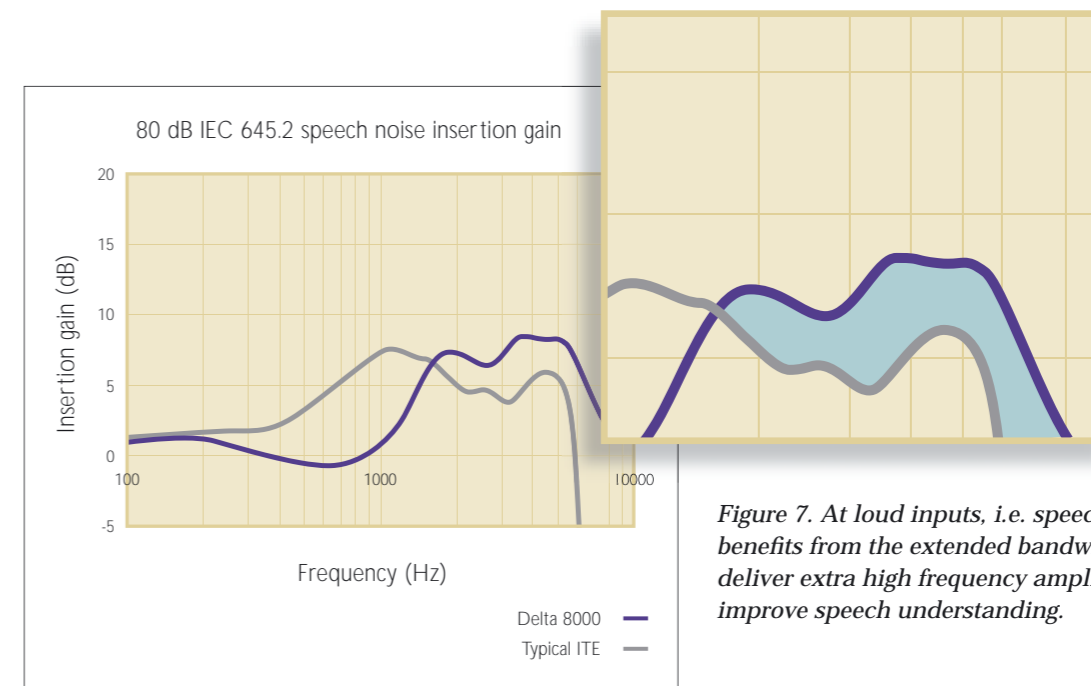


Figure 7: At loud inputs, i.e. speech in noise Clarity benefits from the extended bandwidth in Delta to deliver extra high frequency amplification to improve speech understanding.

mixing of the direct sound and amplified sound. This mixing of sound sources results in the need to develop a totally different amplification strategy and provides the possibility to provide less gain than would ordinarily be prescribed in traditional hearing loss compensation strategies. Therefore, it is crucial to design the rationale with both the user's need for speech understanding in noise and occlusion free fitting (mixing of direct and amplified sound).

Amplification for speech understanding – not hearing loss correction

(a) A new starting point: clarity enhancement not hearing loss correction

It was clear early in the development of Delta that our usual starting point for amplification was not going to provide the level of benefits that we wished. Typically, when developing a rationale or identity, we start with the person's hearing loss and attempt to correct and restore loudness based on a hearing loss correction model. For people with minimal hearing loss, this approach does not provide the solution that they are after. They do not wish to have loudness compensation in all

situations. What they wish for is additional clarity in difficult-to-understand situations.

Audiologically, it is clear that the combination of significant low frequency hearing and a mild-to-moderate loss in the higher frequencies results in good speech understanding in quiet listening conditions. However, when listening becomes more difficult in background noise, assistance is required. This assistance must be provided in a way that preserves natural sound quality.

(b) Clarity enhancement

Providing better speech understanding requires that our amplification strategy ensures extended high frequency information in louder listening environments (Figure 6 and Figure 7). To preserve a natural sound quality, Delta sparingly implements compression. We do not provide low frequency amplification because of the combination of good low frequency hearing and open fittings. This eliminates the risk of upward spread of masking, and ensures that good speech understanding in quiet situations is retained. In addition, unlike conventional hearing solutions, Delta does not require vent compensa-

tion. With Delta, we compensate less, delivering a different mix of amplified and direct sound, which is an essential ingredient for excellent sound quality⁷.

Compared to typical wide dynamic range compression algorithms, the Clarity rationale does not try to fully correct for the hearing loss but enhances the speech information by using the extended bandwidth to deliver additional high frequency information.

Improved speech understanding in background noise is achieved by:

- Focusing amplification in the high frequency region with little amplification for the low frequency speech sounds. Reducing low frequency gain prevents upward spread of masking and improves sound quality.
- Implementing compression sparingly to preserve natural sound quality, and to ensure that the maximum amount of temporal and spectral cues are available for speech understanding in difficult listening situations.

- Setting the compression kneepoint to 50 dB SPL to ensure audibility of soft consonant sounds in noise, without being so low that it provides annoyance in quiet.
- Enhancing listening comfort in loud environments (>80dB SPL) so that for very high inputs there is no amplification (0 dB gain).
- Providing less insertion gain which reflects the clarity needs of the listeners and the benefit achieved by mixing the amplified and direct sound sources.
- Having fast release times (80-320ms) combined with slower attack times (5-10ms) to match amplification speed with the good residual auditory capacity of the listeners. This allows the maximum preservation of speech cues and the opportunity to "listening in the dips".

All of these factors combined with the canal level receiver, open fitting and advanced automatic systems ensure optimum speech clarity in all difficult listening situations without the side effects obtained when attempting to fully correct for the hearing loss.

Automatic Speech Enhancing Features driven by Artificial Intelligence

Artificial Intelligence allows the hearing aid to make fully informed decisions about when and how the various automatic features such as directionality and noise management are to be applied at all times^{5,8}. Artificial Intelligence provides the advantage over prediction based systems in that systems are only enacted if they are shown to provide a benefit in terms of Speech-to-noise ratio (SpNR). This focus on SpNR ensures that the understanding of speech in noise remains the focus and that systems are not enabled needlessly.

(a) Delta Memory

The Delta Memory collects the data recorded by Delta on the hearing instrument's operation. It then analyses and displays it as an Envirogram in the Genie 7.0 fitting software⁹. The audiologist can now quickly confirm that the operation of Delta using Artificial Intelligence has provided benefit to the patient. In addition, the Envirogram¹⁰ allows the audiologist to quickly gain access as to how Delta's systems have benefited the patient. The audiologist can furthermore use the Envirograms to demonstrate to the client how Multiband Adaptive Directionality and TriState Noise Management specifically add value to the client in their actual daily listening situations. Similarly, the audiologist can use the Envirograms to explain to the client the types of listening situations they are in and how Delta provides specific solutions for them. Therefore, the Delta Memory is an integrated part of the Delta fitting giving a quick and easy demonstration of the benefit to the client using their actual listening experiences.

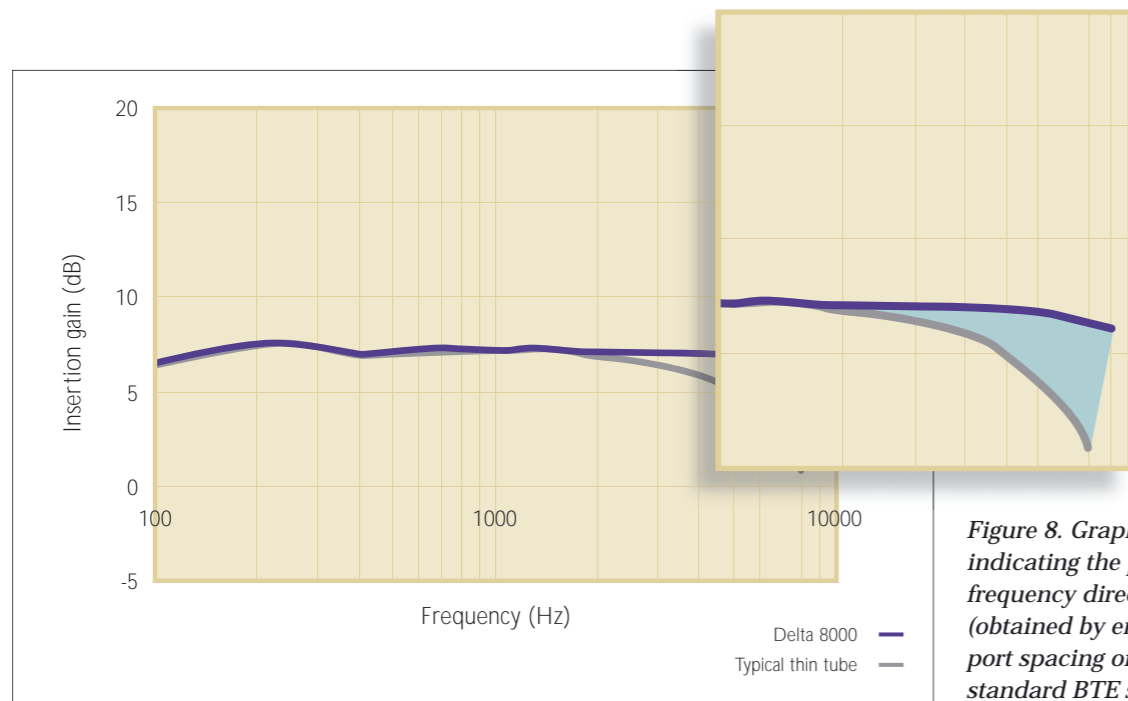


Figure 8. Graph of the DI by frequency indicating the preservation of high frequency directionality in Delta (obtained by ensuring a microphone port spacing of 9mm) against a standard BTE shell casing.

(b) Multiband adaptive directionality

To maximise speech understanding in noise, we must make use of directional microphones – the only proven method to improve speech understanding¹¹. The benefit of directionality with open fittings has, however, been questioned. The argument being that by opening the vent you lose the processed signal and allow the natural sound to reach the eardrum, thus reducing the benefit of directionality. Fortunately, various reports^{12 13} have demonstrated that it is possible to maintain directionality with a totally open fitting. The key to this is to ensure that the directional microphone maintains a good high frequency response^{5 14}.

For Delta, maintaining the directional benefit was of paramount importance. One of the key design decisions was to ensure that directionality was not only maintained but also enhanced for the high frequencies. While directional benefits rely on a physical separation between two microphones, having too great a distance between microphones results in loss of directivity in the high frequencies. For Delta, we determined that the optimum port placement was 9mm, as opposed to the usual 12-13mm found in most conventional BTE instruments. This allowed us to maintain

directionality at the theoretical limit of 6dB throughout the high frequency region (Figure 8). Similarly, the Delta design ensures a good horizontal position of microphones and ensures the correct distance between the microphones (Figure 9).

To further maximise directionality, it is crucial to recognise that noise sources are not stationary within the sound environment. Similarly, complex listening situations also involve multiple noise sources that differ by frequency. Therefore, we need an adaptive directionality system that can not only track and adjust the polar response to provide the maximum signal-to-noise ratio possible, but is also able to adjust this across three separate frequency regions to attenuate multiple noise sources simultaneously.

As wind noise is often a problem for people with a hearing loss and in particular mild to moderate hearing loss in the high frequencies, a clever solution is required. Directional microphones are extremely sensitive to wind noise which often results in decreased satisfaction and reports of poor sound quality^{15 16}. Previous solutions have mainly focused on attempting to digitally process out the effects of wind

noise by applying noise reduction or notch filtering techniques. These strategies apply other processing artefacts but are rarely successful. A more intelligent solution is to reduce the velocity of the wind before it reaches the microphones.

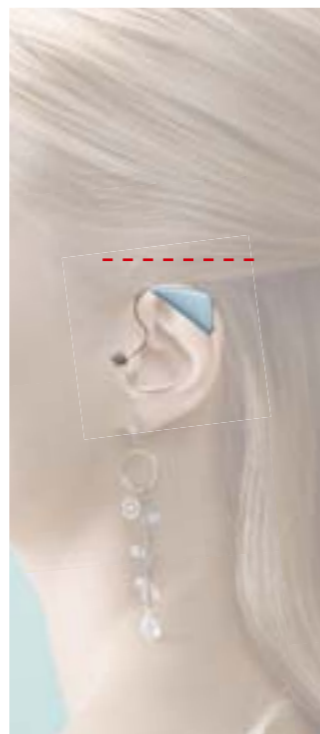


Figure 9: The Delta design ensures a horizontal placement of the two microphones

In Delta, an exchangeable top “grid” above the microphones acts as a combined wind and dirt protection (Figure 10). This grid acts by significantly slowing down velocity of the air just in front of the microphones thus lowering the impact of wind. Importantly, the patented grid was designed to ensure high directivity.

While directionality provides many advantages, it is not, however, the solution for every possible listening environment^{17 18}. Therefore, Delta is driven by Artificial Intelligence that calculates the signal-to-noise for any given listening situation and ensures that directionality will provide a benefit before enabling the system. This removes the unfortunate situations known from other systems where important signals from behind are cancelled. Similarly, the wearing of full time directional system provides an audible distortion to the listener’s sound scene thus providing further loss of transparency. Artificial Intelligence is the key is to ensure that the system is only working when it provides a benefit.

Previous discussion have questioned the benefits of directionality for fully open hearing concepts¹⁹. To ensure that the directionality in Delta provides a benefit we evaluated the directional performance of Delta for a group of hearing impaired adults in a diffuse noise field with speech information from the front speaker for surround (omni) and directional settings. As can be seen in Figure 11 an SNR improvement of 2.95 dB is obtained providing

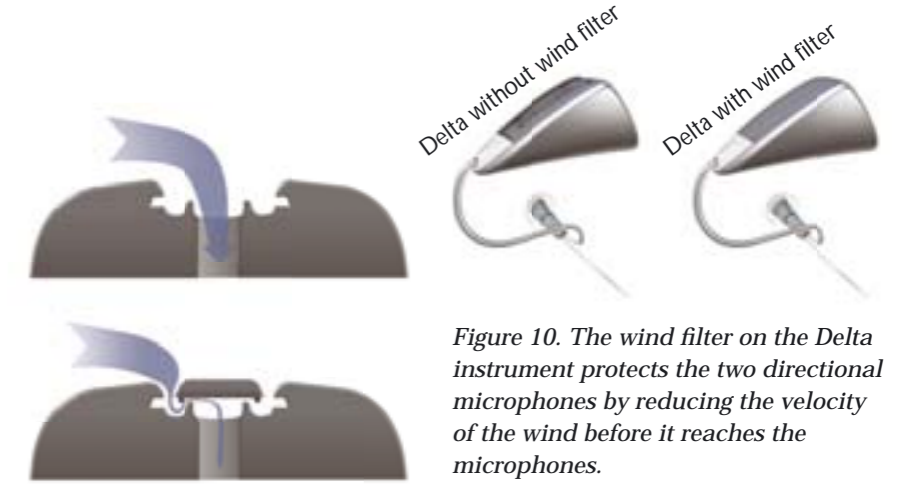


Figure 10. The wind filter on the Delta instrument protects the two directional microphones by reducing the velocity of the wind before it reaches the microphones.

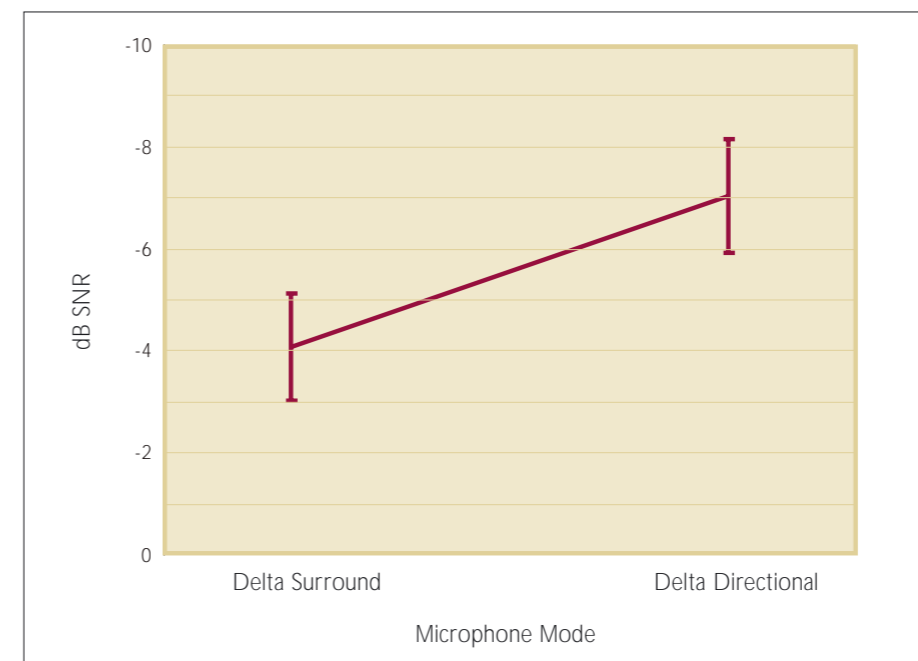


Figure 11. Results from the Dantale-II speech perception test in noise. Showing the significant directional benefit the participants received with the Delta hearing instruments.

significant improvements in speech understanding in noise. Therefore, similar to previous studies, we show that if a system is optimally designed it is possible to ensure directional benefit even with a totally open fitting^{12 13}.

(c) TriState Noise Management

The TriState Noise Management system has been incorporated in Delta to provide the best possible sound quality and comfort in all situations. Unique to the TriState system, is the combination of the VoiceFinder speech detector, which detects the synchronicity unique to the human voice²⁰, and a noise detector that evaluates the modulation depth. This combination ensures that noise reduction can be applied separately for noise situations only versus speech in noise listening situations. Therefore, when listening to speech in noisy situations the amplification is managed so that speech information is never removed. Conversely, for noise only situations, full noise reduction is implemented so that listening comfort is ensured no matter how loud the listening environment. The application of speech centred noise management ensures that the amplification never becomes too aggressive so as to cause annoyance. The transition times between states have been reduced so that the system works as fast as possible to ensure the listener every opportunity to “listen in the dips” and that noises are attenuated as fast as possible for maximum comfort no matter how difficult the listening situation.

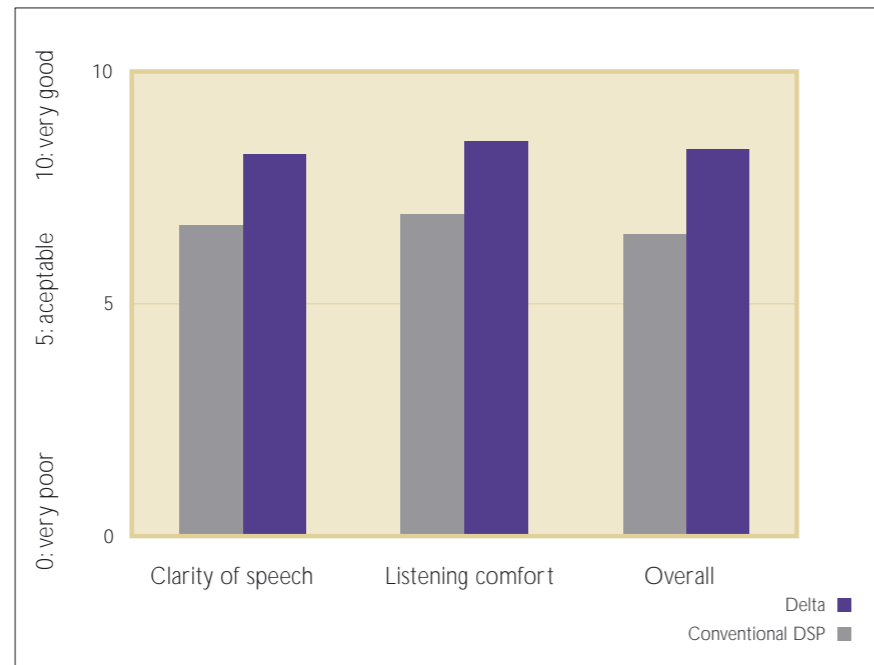


Figure 12. Comparison of performance with Delta versus conventional premium hearing aids on the dimensions of clarity of speech, listening comfort and over all.

Conclusion

Delta provides an unrivalled degree of performance for people with a mild to moderate high frequency hearing loss. Importantly, the cosmetic benefits and size do not come at the cost of other features or sound processing options. The approach taken by Delta is audiologically novel. The purpose is not to fully correct for the hearing loss, but to focus on providing the best possible speech understanding in difficult listening situations. In this way, Delta meets the needs of people who have good low frequency hearing and a mild to moderate high frequency hearing loss.

Similarly, in addition to refocusing our thoughts in terms of sound processing, Delta also augments the Clarity rationale with the most advanced automatic features (Multiband Adaptive Directionality and TriState Noise Management) governed by the only hearing aid chip platform that is capable of Artificial Intelligence processing. To ensure that occlusion is never an issue, Delta provides a totally open fitting concept, allowing the balanced mix of natural and amplified sound. Similarly, to ensure the best possible sound fidelity

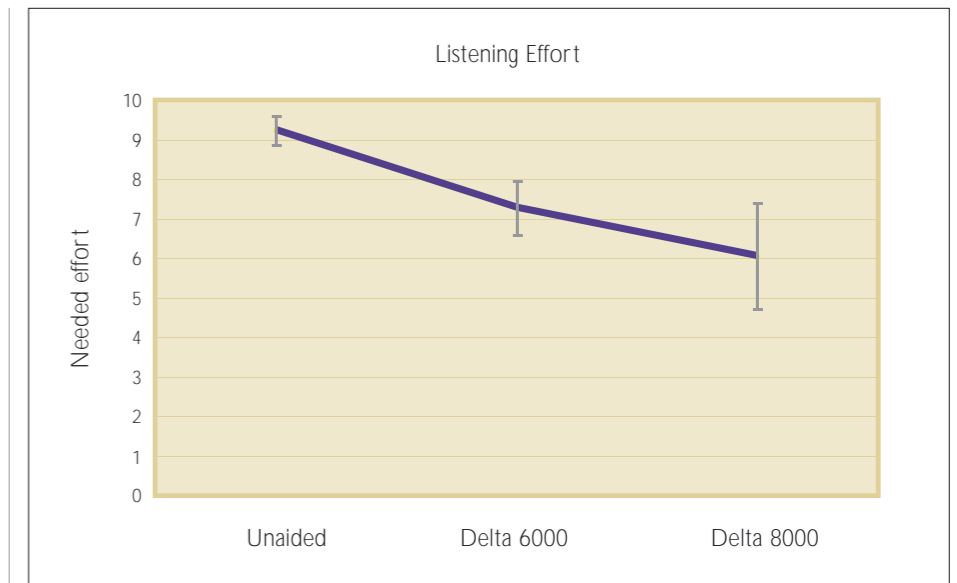


Figure 13. Reduction in the client's perception of listening effort required to listening to speech in difficult listening situations, showing the improvement provided by both the Clarity rationale and also the extended high frequency bandwidth.

and increased high frequency response the receiver has been placed in the ear canal where tube resonances and other sound quality limitations of traditional tubing are not a factor.

Delta is designed to provide the wearer with the best possible speech understanding in as natural a way as possible, for as many communication environments as possible.

Performance of Delta

Performance of Delta

Good design by itself cannot guarantee that the solution will meet the needs of the listener. It is therefore essential to carefully evaluate the performance of Delta against other more conventional solutions. Figure 12 illustrates the reported performance benefits of a group of hearing aid users who were wearers of conventional premium digital hearing aids with advanced features such as multiple channel non-linear amplification, directionality and noise reduction. What can immediately be seen is that while the conventional digital hearing instruments provide a

benefit, the benefit is only rated as slightly over "acceptable", greatly running the risk that the hearing instruments may be rejected. Taking the Delta approach has maximised both speech understanding in noise and listening comfort leading to improved user satisfaction.

An important consideration in the amplification needs of people with mild to moderate hearing loss is, how does the hearing instrument decrease listening effort in difficult listening situations? To answer this question, we used a test of listening effort developed by Oticon's Research Centre: Eriksholm²¹.

This investigation examined the participant's ratings of the degree of listening effort required to understand speech in noise (Figure 13). The results clearly indicated that Delta significantly reduces the degree of listening effort required in difficult situations. Similarly, this required effort also decreased when the bandwidth was extended from 6000 to 8000Hz. The provision of extended high frequency bandwidth combined with the Clarity rationale provides significant benefit in terms of reducing the client's perception of their required listening effort throughout the day.

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People first

We believe that it takes more than technology and audiology to create the best hearing instruments. That's why we put the individual needs and wishes of people with hearing loss first in our development of new hearing care solutions.