

BELTONE BOOST™ — A REVOLUTIONARY SUPER POWER HEARING SOLUTION

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Individuals with severe and profound hearing losses make up the smallest segment of hearing instrument users as defined by hearing loss severity. However, they form a diverse group with widely varying preferences in terms of amplification. A successful hearing instrument must be able to meet these varying preferences, as well as provide robust performance. Beltone Boost brings super power users powerful connections to people and devices. With industry leading advanced features like Feedback Eraser, Sound Shifter and CrossLink Directionality, clients get access to the amplification they need, without distraction or distortion. Wireless technology is critical for managing phone conversations or hearing in difficult environments. While Beltone Boost includes traditional analog wireless technology, it is also fully compatible with Beltone Direct wireless accessories. And finally, Beltone Boost is Made for iPhone®, bringing the convenience and enjoyment of direct sound from Apple® devices to the hearing instruments.

We often talk about “groups” when speaking of hearing impaired. We define these groups in different ways, but one common way is in terms of severity of hearing loss. The underlying assumption is that each group will share many characteristics that will help to understand who they are and what they need, and this information will point to appropriate solutions for them. Less than 10% of the hearing impaired population has a degree of hearing loss that would be categorized as severe-to-profound [1], [2]. You would think that such a small group would have many similarities. In fact, although this “group” is the smallest, it is diverse in terms of many factors such as age, etiology of the hearing loss, ability to benefit from amplification and comfort level with new technologies. What these individuals do tend to have in common is that the majority have prior experience with hearing instruments, and they are highly dependent on amplification to function in their daily lives. For more than any other group, flexibility is the key word.

This paper introduces the Beltone Boost, a premium hearing instrument that brings cutting edge hearing technology to people with severe-to-profound hearing losses. Beltone recognizes that severe-to-profound hearing losses present different and unique challenges. In other words, an appropriate product for this group is not just an extension of existing products with more gain and output. Beltone Boost is unmatched as the flexible solution for individuals with severe-to-profound hearing losses. It not only incorporates proven technologies, it adds fitting functionality that is crucial for satisfying hearing instrument users in this group. Moreover, Beltone Boost is the first hearing instrument of its class to offer direct-from-the-source digital wireless connectivity and direct connectivity to iPhone, iPad®, and iPod touch®.



AMPLIFICATION NEEDS

“They are very different from other patients. Most are almost desperate to hear better as their personal relationships, self image and activities are greatly affected by the severity of the hearing loss.”

“They are different. Their entire world of sound comes through the hearing aid, unlike the vast majority of partial loss patients. Their management of skill sets required for speech understanding is considerably more demanding.”

These statements from audiologists who are experienced in working with individuals with severe and profound hearing losses exemplify the overwhelming impact of the hearing loss on the life of the hearing instrument user. While these statements highlight the effects of dealing with such a severe hearing loss, they also touch on important audiometric and psychoacoustic differences that must be considered in the design of an appropriate amplification system. The most obvious of these is that the individual with a severe-to-profound hearing loss has only a small range of usable hearing compared to someone with a less severe hearing loss. A primary goal of hearing instrument fitting is to provide amplification that makes sounds audible without exceeding levels of discomfort. This goal is particularly challenging to meet for those with severe and profound hearing losses due to the extremely narrow dynamic range. As illustrated in Figure 1, the residual area of hearing for a profound hearing loss versus a more typically encountered mild-to-moderate loss is severely limited. There is a very small range in which the broad range of speech and environmental sounds must be targeted.

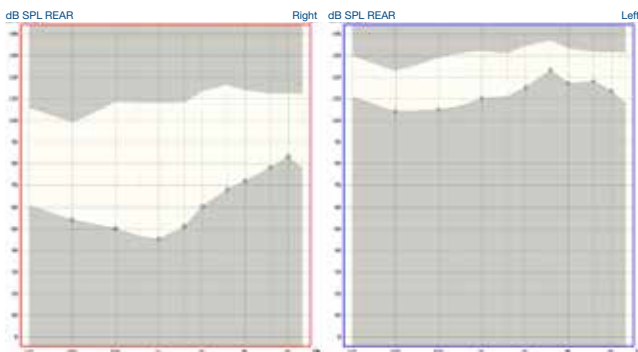


Figure 1. The dynamic range for a typical mild-to-moderate hearing loss (right ear) greatly exceeds that for a profound hearing loss (left ear). It is much more difficult to amplify a wide range of sounds to fit within the dynamic range of the listener with severe-to-profound hearing loss.

Amplification modes

Multichannel Wide Dynamic Range Compression (WDRC) offers the best possibility to squeeze a full range of speech and environmental sounds into the reduced dynamic range for those with severe-to-profound hearing losses. However, the benefit and acceptance of any type of compression processing is dependent on the interrelationship between improved audibility and distortion. As pointed out by Kates, 2010 [3], this is a complex relationship that involves hearing loss severity and configuration in addition to acoustic environmental factors. Compression by its very nature introduces distortion to the signal. While this may be desirable to some degree for milder hearing losses, where the primary physiological issue is loss of compressive nonlinearity of the cochlea, it may not be so for more severe hearing losses which involve both inner and outer hair cell loss. This is partly why hearing aids intended for severe-to-profound hearing losses were slow to incorporate compression schemes in their processing. It has since been demonstrated that compression provides a speech audibility benefit for those with more severe losses [4], and that WDRC is preferred over linear amplification by a significant percentage [5]. The use of low compression ratios (< 2:1) has also been found to be preferred [6]. It must be highlighted that in any of the studies dealing with preference for amplification schemes, there was not an unequivocal result. Some participants preferred linear amplification in each investigation. In fact, Keidser and colleagues [6] emphasized that those with more severe hearing loss are complicated to fit with amplification, and that fine-tuning is important. They further underlined that individual preferences were not predictable from simple audiometric data, time of onset of loss or past experience with linear or nonlinear amplification.

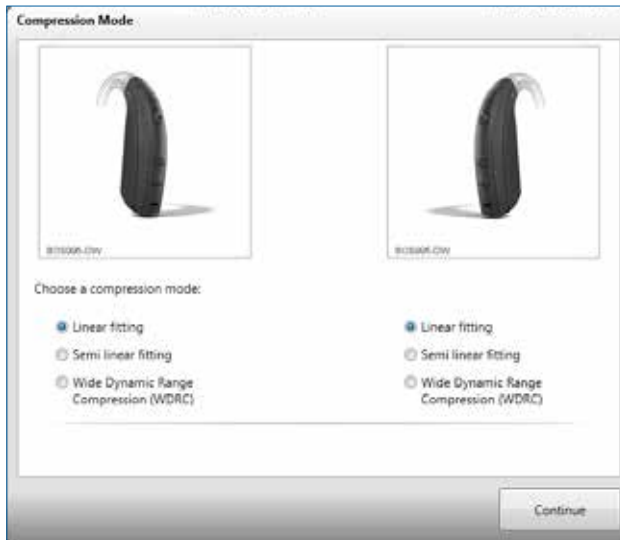


Figure 2. Three amplification modes can be selected for fitting Beltone Boost to most efficiently meet individual preferences.

The implications of these findings are that the appropriate hearing instrument for someone with a severe-to-profound hearing loss has the flexibility to provide varying types of amplification schemes. Therefore, the Beltone Boost can be fit with one of 3 schemes: WDRC, semi-linear, or linear. Any of these modes may be selected as part the hearing instrument fitting connection process (Figure 2), and can also be accessed from the Solus Pro fitting screen at any time. In addition, different amplification modes can be chosen per program, giving users the opportunity to make comparisons in their daily environments. Figure 3 illustrates how gain is affected by the selected amplification mode. Linear amplification provides the same gain for all input levels until the maximum output setting is reached. When linear mode is selected, the output limiting method (soft or hard peak clipping) can also be specified. This can be especially helpful for fitting clients who prefer the sound of their previous hearing instruments. WDRC provides input level dependent amplification with maximum linear gain below the low compression kneepoint. Semi-linear can help accommodate the preference for a low compression ratio demonstrated in Keidser et al [6]. It provides relatively less gain for soft sounds and more gain for loud sounds than WDRC. This scheme can also help reduce feedback likelihood while preserving loudness and audibility for moderate level inputs.

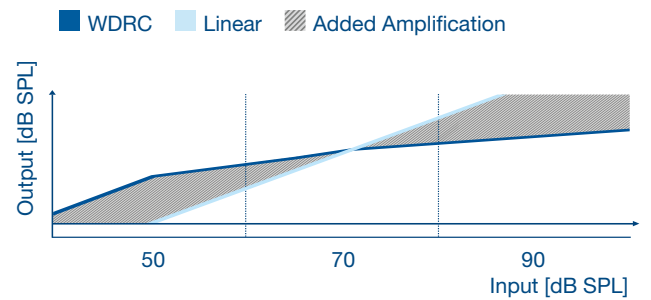


Figure 3. An illustration of how gain is affected by amplification scheme. The semi-linear mode provides relatively less gain for soft sounds and more gain for loud sounds than WDRC.

Gain prescription

As mentioned, a further complication to a small dynamic range is that individuals' preferences for gain and performance with different amplification schemes are quite variable. Gain prescriptions such as the proprietary Beltone BAFA aim to provide gain that is a good starting point for balancing audibility, speech understanding and sound quality. Individual fine-tunings vary from this starting point depending on individual ear and fitting acoustics to meet targets as well as individual preferences. Figure 4 shows fine-tuning results for from two field trials. The panel on the left is from a trial of Beltone Boost with severe-to-profoundly hearing impaired participants, and the panel on the right is from a trial of Beltone First™ with mild-to-moderately hearing impaired participants. For both data sets, the medians are similar. This indicates that the fitting rationale provides a good starting point for fitting a wide range of hearing losses. However, there is much greater variability in the data for the severe-to-profound group. This means that fine-tuned changes were larger for this group, presumably due to more variable preferences for gain settings. Beltone Solus Pro fitting software provides peer-reviewed gain prescription formulae in addition to BAFA. However, the variability in fine-tuning is independent of the prescription. In other words, those with severe-to-profound hearing loss will require more gain adjustments relative to target regardless of what target is selected.

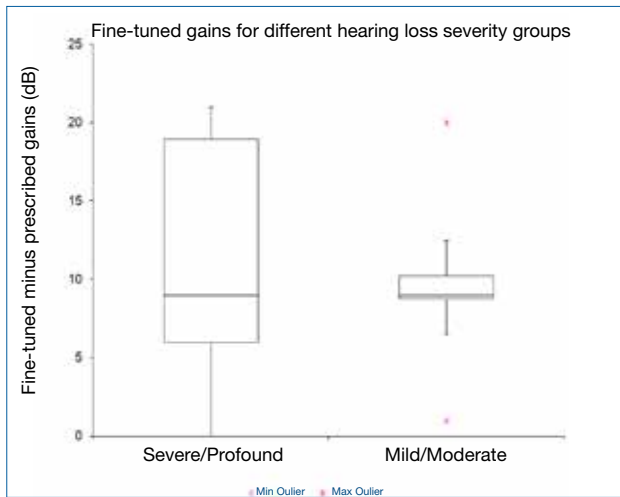


Figure 4. Box and whiskers plots showing fine-tuned gain changes relative to the initial fit for test participants with severe-to-profound hearing loss versus mild-to-moderate hearing loss. Although the median changes are similar, there is much greater variability in the fine-tuned changes for the severe-to-profound group.

A sound quality enhancing fitting tool

One thing to note in Figure 4 as indicated by the upper quartile is that some users with severe-to-profound losses prefer very large gain increases relative to what is prescribed. This may reflect dissatisfaction with sound quality and loudness provided by hearing aids compared to those with less severe hearing losses. The most severely hearing impaired have been shown to rate all categories of hearing aid sound quality except those related to occlusion effect worse than the less severely hearing impaired groups [7]. Psychoacoustic experiments have established that relatively smaller increases in level in low frequencies result in a greater perception of loudness increase than in higher frequencies. Because those with severe-to-profound hearing losses most often hear best in the lower frequencies, a small boost in low frequency hearing aid gain can result in immediate perception of louder, fuller sound quality. The Low Frequency Boost feature offered in the Solus Pro fitting software provides the fitter with a tool to efficiently meet individual preferences for fuller sound quality. There are three Low Frequency Boost settings available, with frequency dependent gain offsets given in Table 1.

Value	250 Hz	500 Hz	750 Hz	1K
None (dB)	0 dB	0 dB	0 dB	0 dB
Low (dB)	3 dB	6 dB	3 dB	1 dB
Medium (dB)	6 dB	9 dB	5 dB	2 dB
High (dB)	9 dB	12 dB	8 dB	3 dB

Table 1. Low Frequency Boost settings apply a gain offset that is frequency dependent, and give the fitter an efficient way to enhance sound quality for the individual.

LOTS OF GAIN – BUT IS IT USABLE?

Feedback is a particular issue for hearing aid users with severe-to-profound losses due to the very high gain levels required. Dealing with feedback for this population has traditionally involved acoustic modifications that can come with their own issues in terms of comfort and ventilation to the ear canal. Even with an unvented earmold, it is possible to achieve average insertion gains of only 64 dB at 1000 Hz, 41 dB at 3000 Hz and 45 dB at 4000 Hz [8]. This means that without additional feedback management, many users of the Beltone Boost would not have access to the amount of gain that the device is capable of providing.

Beltone Boost uses Feedback Eraser feedback cancellation with built-in Whistle Stop for feedback management. Feedback cancellation works by analyzing the pathways by which amplified sound returns to the hearing aid microphones, constructing a model representing these pathways, and subtracting the model from the actual input signal. Although the concept of feedback cancellation is simple, modeling feedback pathways involves much complexity. Adding to the complexity is the fact that these pathways are ever-changing as the hearing instrument is worn, and the model must constantly be updated to reflect these changes.

Feedback Eraser is a 2-channel system that can account for the differing feedback paths at each hearing aid microphone. In addition, it uses two cancellation filters. One is calibrated at the fitting and accounts for relatively stable elements of the fitting such as earmold acoustics and responses of the transducers. During use of the hearing instrument, an adaptive cancellation filter supplements the static one to account for dynamics of the feedback path. Although feedback cancellers can be shown to allow more than 30 dB of added stable gain in certain test conditions, a realistic expectation for added stable gain in actual use is 10 to 15 dB.

Like other super power BTE hearing aids, Beltone Boost has its peak gain in the mid-frequency range. While high levels of gain at higher frequencies are still critical in terms of feedback for this device category, the

very high available gain levels in the mid-frequency area must also be accounted for if the user is to have access to this gain. Because feedback is much less likely to occur in the mid-frequency range for most hearing aids, feedback cancellation systems are designed to focus on the high frequency area. For Beltone Boost, the Feedback Eraser parameters have been tuned to also deal with feedback in the mid-frequency area and ensure that usable gain is maximized for every fitting.

To illustrate the superiority of the Feedback Eraser, comparative measurements of maximum stable gain were made with other premium technology super power BTE devices. These measurements were made by mounting each device on a 2cc coupler with a tube in which a hole was cut to create acoustic leakage. Then, with the feedback cancellation system engaged, the overall gains were increased from 0 dB until feedback occurred. While this test does not necessarily correspond to the real ear, it does isolate feedback cancellation performance and device stability across devices. The results, shown in Figure 5, compare the peak gain from the device datasheet with the gain measured under the described conditions. The measured maximum stable gain was significantly lower for other devices than for the Beltone Boost.

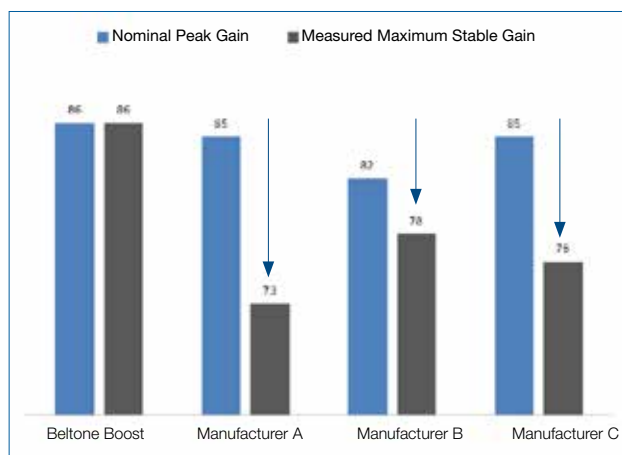


Figure 5. Comparison of nominal peak gain with actual measured maximum stable gain for Beltone Boost and other super power BTE devices.

SOUND SHAPER FOR IMPROVING HIGH FREQUENCY AUDIBILITY

Providing audibility for high frequency speech sounds is particularly challenging when fitting individuals with severe-to-profound hearing losses. From a technical perspective, the receivers that are used in high power devices have a comparatively low resonant frequency due to the size and mass of the receiver diaphragm. This means the response rolls off in the higher frequencies to a greater extent than hearing instruments for less severe hearing losses.

In addition to technical limitations with amplification, it has been suggested that providing high frequency amplification may not always be beneficial. The presence of a non-functional cochlear “dead region” with few or no functioning inner hair cells may not transduce energy from the basilar membrane, leading to off-frequency listening and possibly worse speech understanding [9].

Sound Shifter can help improve audibility of high frequency sounds. By use of proportional frequency compression, Sound Shifter lowers high frequency sounds to a region where they are more likely to be heard by the hearing instrument wearer. In this way, it helps circumvent the issues with receiver response and cochlear dead regions.

COMPENSATING FOR REDUCED SPEECH RECOGNITION ABILITY

Another significant difference between hearing instrument users in the severe-to-profound range compared to those with milder hearing loss is in speech understanding ability. It is recognized that greater degrees of hearing impairment are related to decreased ability to make use of speech information. Figure 6 shows aided results for a speech in noise test as a function of pure tone average (PTA). In this test, a lower score indicates better performance. Two important observations can be made about this data. One is in agreement with the accepted finding that individuals with less severe hearing loss do better on speech recognition in noise tasks than those with more severe hearing losses. The other observation is that the group with PTA not exceeding 60 dB HL exhibited little variability in performance while those with the more severe losses showed a large spread in performance. This suggests that in addition to being generally worse in making use of speech

information with increased hearing loss, there is also greater variability in this ability among individuals with more severe hearing loss.

While the essentials of providing sufficient gain for audibility is the most important factor for fitting those with severe-to-profound hearing loss, other tools can further enhance the benefit of amplification. The potential for directional benefit is theoretically less for those with severe-to-profound hearing loss due to their reduced ability to make use of speech information. Nevertheless, significant directional benefit has been demonstrated for this population [10], and directional microphones are recommended as a useful feature that should always be considered [11]. It is further recommended to equalize the inherent low frequency roll-off when directional microphones are used. Beltone's Mixing Point Frequency technology avoids the necessity to equalize the low frequency response of the hearing aids because omnidirectional processing is applied in the low frequencies. This has been shown to provide

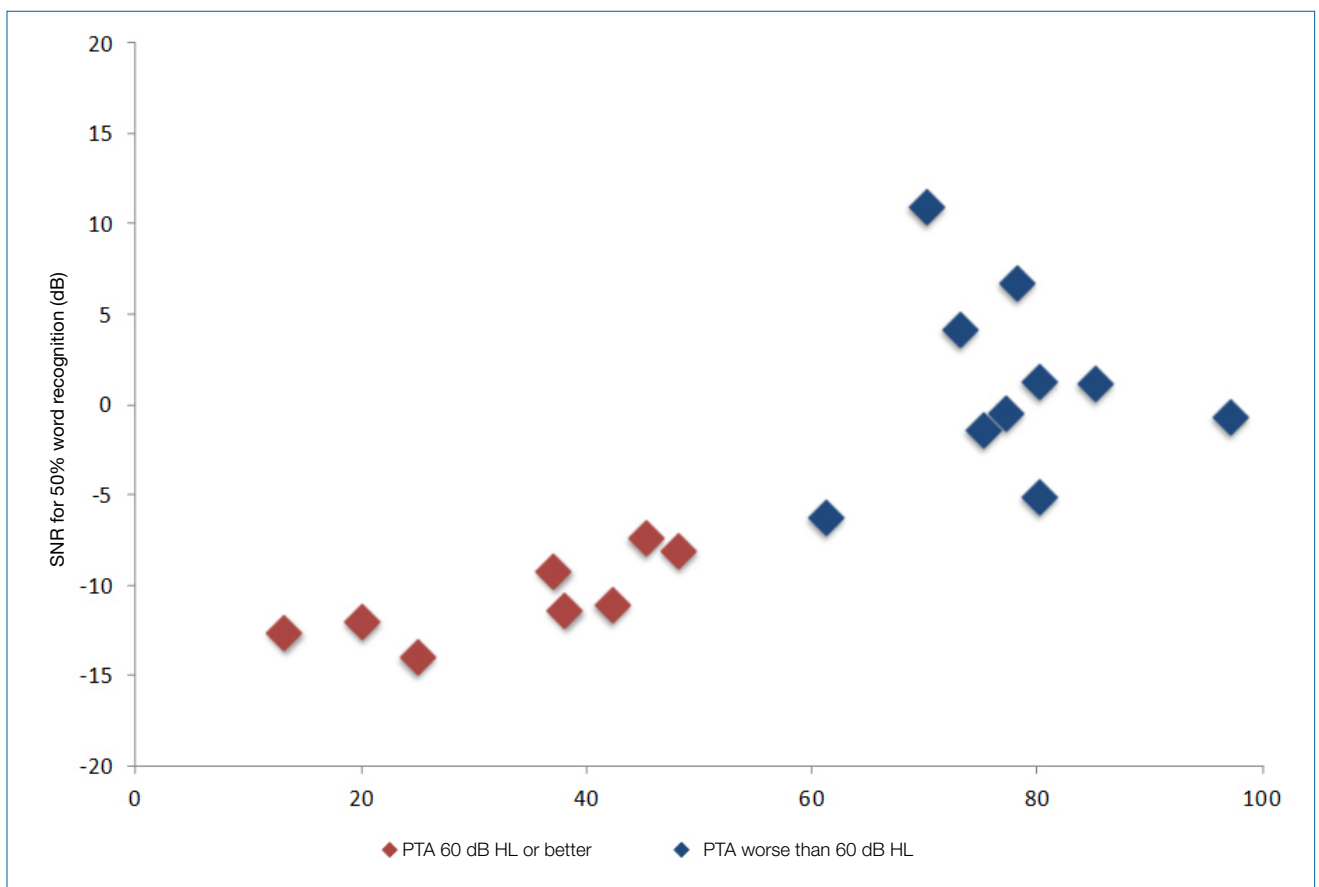


Figure 6. Speech recognition in noise performance as a function of hearing loss severity. Those with more severe losses (blue diamonds) show not only worse, but also much more variable performance than those with milder losses (red diamonds).

preferred sound quality as well as directional benefit for those with mild-to-moderate hearing losses, but it could be anticipated that the Mixing Point Frequency bandsplit directional processing might not provide sufficient directional benefit for those with severe-to-profound hearing loss. One unique advantage of Mixing Point Frequency is that it is prescribed according to hearing loss severity and microphone spacing of the device. For the Beltone Boost and Beltone Boost candidates, the Mixing Point Frequency will virtually always be set to “high”, meaning that the cut-off frequency above which directional processing occurs is 500 Hz. Results from in-house trials with the prescribed Mixing Point Frequency setting showed a consistent directional benefit of 4 to 6 dB depending on the test material and setup.

Flexibility in fitting options is essential for those with severe-to-profound hearing losses. In keeping with this, options for applying directional processing are also flexible. For example, wireless device-to-device communication enables Beltone Boost wearers to benefit from CrossLink Directionality. This microphone steering strategy uses environmental analysis from both hearing instruments to select the optimum microphone mode for each device to support binaural hearing in any type of listening environment [12]. In addition, Smart Beam adaptive directionality options are also offered to customize selectable listening programs.

POWERFUL CONNECTIONS TO EVERYTHING THAT MATTERS

For individuals with milder degrees of hearing impairment, speech recognition in noise ability is essentially equivalent in quiet and in environments with very positive signal-to-noise ratios (SNR). In other words, as long as the signal of interest is sufficiently higher than the noise level, they can understand speech as well as in a noisy environment. For those with severe-to-profound hearing losses, this does not hold true. Ricketts & Hornsby [10] reported that speech recognition performance for those with severe-to-profound hearing losses was significantly poorer at very high SNRs than in quiet even when using hearing instrument directionality. This means that there is potential for further improvement even in favorable listening environments. Convenient and discreet wireless solutions that can bring sound directly from the source to the user’s

hearing aids are a way to reach this potential. As the second generation of products to incorporate both Beltone proprietary 2.4 GHz digital wireless technology and Made for iPhone capability, Beltone Boost is uniquely suited to provide these benefits.

The Beltone Boost is fully compatible with Beltone Direct line of wireless accessories, which are a natural progression from well-established analog wireless functionality in hearing instruments for users with severe and profound hearing losses. Telecoils and induction loop systems, and FM systems are the traditional ways that analog wireless capability made it practical to selectively amplify desired sounds and connect users more directly to sound sources via their hearing instruments. But just as digital hearing instruments opened new possibilities for sound processing, digital wireless technologies also offer new user benefits. While existing analog wireless technologies in hearing instruments can convey sound from a remote source to a hearing instrument, each has drawbacks that might be addressed with digital technology. Using a digital wireless transmission system can generally improve the signal-to-noise ratio compared to analog and, depending on the particular technology, be less susceptible to interference. Digital wireless features in hearing instruments can thus extend already established benefits of analog wireless.

The Beltone Direct accessories give users of the Beltone Boost convenient, affordable and effective ways to improve watching TV, using the phone or listening to any audio source. In addition, the Beltone Direct myPAL is particularly valuable for those with severe and profound hearing losses, as it can greatly enhance the SNR for a companion’s voice in virtually any environment. The Beltone Direct myPAL has been shown to provide 18 to 20 dB in improved SNR [13], and the benefit has been shown to be equivalent to that obtained with FM technology [14].

Beltone Boost extends direct wireless connectivity further with Made for iPhone functionality. This means that owners of the iPhone, iPad or iPod touch can enjoy direct streaming of phone calls, music, FaceTime® calls, or any other audio from their Apple device in high quality directly to the Beltone Boost hearing instruments. The convenience of receiving audio from the iPhone without additional accessories is self-evident,

and the benefit of receiving a bilateral wireless signal for improving understanding on the phone is also established [15]. In addition, evidence points to streaming the phone signal directly from the iPhone as offering an additional improvement over other digital wireless technologies, perhaps due to enhanced signal quality [16]. Figure 7 shows the average benefit of three wireless technologies compared to acoustic coupling of phone. Performance in speech understanding on the phone was significantly better when streamed directly from the iPhone than either telecoil or using a digital wireless phone accessory. Those with larger degrees of hearing loss require all the help they can get in terms of phone solutions; the signal quality enhancement afforded by Made for iPhone (MFi) can be an important consideration for them.

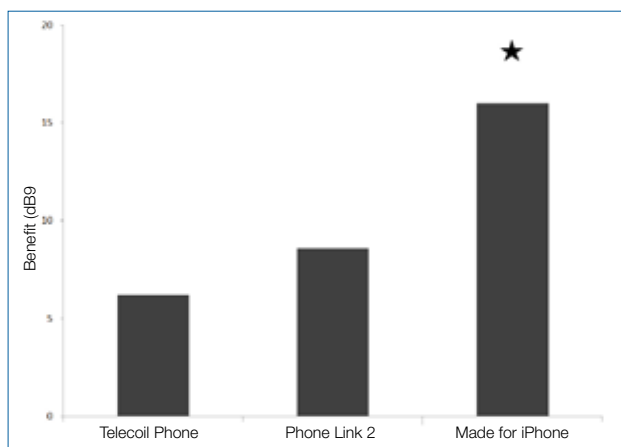


Figure 7. Average benefit when using wireless phone listening strategies compared to acoustic coupling alone.

THE HEARPLUS™ APP FOR ULTIMATE CONTROL OF THE HEARING AID

Apps are emerging as a trend in the hearing aid industry, with manufacturers writing apps for both hearing aid users as well as hearing care professionals for varying purposes. The Beltone HearPlus app lets users control their Beltone Boost hearing aids with iOS and Android™ smart devices. This has two important benefits for users. One is that they can discreetly change settings on their hearing aids from their smart devices without needing to carry any additional accessories or touch their hearing aids. The other and perhaps even more significant benefit is that they can further personalize their listening experience with volume and bass/treble adjustments that they can associate with a geographical location. The Beltone HearPlus app enables them to go back to their saved settings anytime they

are in that environment. Users can also find helpful information to guide them in using their hearing instrument. The Beltone HearPlus app will even help them find a misplaced hearing aid.

COCHLEAR IMPLANT COMPATIBILITY

People with severe-to-profound hearing losses have more options for hearing better than ever before. As candidacy criteria for cochlear implantation has relaxed to allow individuals with more residual hearing to be implanted, it has become common to combine acoustic stimulation via hearing aids with electrical stimulation via the cochlear implant. The most common combination currently is the bimodal fitting, where the user wears a hearing aid on the contralateral ear from the implant. Bimodal fitting has been shown to yield binaural hearing benefits over time [17]. A common platform for wireless connectivity also benefits those fit bimodally as they use the same wireless accessories to broadcast to both their hearing aid and their cochlear implant. Not only is this convenient, it maximizes the potential for hearing and enjoying the signal. Beltone has a strong cooperation with Cochlear™ to develop and license 2.4 GHz wireless technology for their implantable products. While the most obvious benefit of this cooperation is the extension of direct-to-device streaming for cochlear implant users, it also means seamless compatibility between a Beltone digital wireless hearing instrument and the cochlear implant for a bimodal fitting. Both devices can receive the same signal from Beltone Direct or Cochlear branded wireless accessories.

MORE RELIABLE SOUND PER MILLIWATT

One characteristic that hearing aid users with severe-to-profound losses tend to share is a tremendous dependency on amplification. It is thus of the utmost importance that they be designed for robust performance as well as comfortable for long-term wear. Beltone Boost is protected with HPF⁸⁰ NanoBlock™, a 60 to 80 nanometer thin polymer coating that protects all parts of the hearing aid inside and out against damaging agents such as moisture, cerumen and debris. The HPF⁸⁰ NanoBlock coating process differs from that used by other manufacturers in that it encompasses the entire device. It is done by applying a plasma of electrically charged monomer molecules under vacuum conditions to finished hearing instruments. The vacuum conditions draw the coating material into the hearing instrument, thereby coating every exterior as well as interior surface. An internal analysis of hearing instrument service data showed that the volume of repairs observed subsequent to the introduction of HPF⁸⁰ NanoBlock decreased by nearly 30% during summer months when repairs due to moisture-related issues typically spike.

As the largest ear-level air conduction hearing aid style, super power BTE hearing instruments have typically not been known for their streamlined appearance or comfortable fit. There are three design constraints that traditionally have limited the size and appearance of a super power BTE: the battery, the receiver, and the isolation of components necessary to attain stability. Beltone Boost uses a 675 battery to optimize power to the device, wireless performance, and use time between battery changes. However, smart electroacoustic design choices enabled a slimmer, lighter and more attractive design than ever before. A high efficiency receiver that maximizes the output without adding bulk created space in the device to allow effective suspension and isolation of all components. Together with a softer material for the earhook, this damps the tendency for any components in the hearing instrument to vibrate, and enables the industry-leading gain and output levels of the Beltone Boost.

SUMMARY

Individuals with severe and profound hearing losses make up a small but diverse group. Modern hearing instruments for this group must be able to provide very high amounts of stable, usable gain; they must accommodate varying preferences for amplification schemes and sound quality; they must provide the convenience and SNR benefits of wireless connectivity; and they must be compatible with other hearing solutions that are unique to this group. The Beltone Boost is a revolutionary super power hearing solution that meets all of these needs.



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Beltone Boost is compatible with iPhone 5s, iPhone 5c, iPhone 5, iPad Air, iPad (4th generation), iPad mini with Retina display, iPad mini and iPod touch (5th generation) using iOS 7.X or later. Apple, the Apple logo, iPhone, iPad, iPod touch and FaceTime are trademarks of Apple Inc., registered in the U.S. and other countries. App Store is a service mark of Apple Inc.

The Android version of the Beltone HearPlus app runs on newer devices running Android 4.4.2 or later. See www.beltone-hearing.com for a list of Android phones that work with the app. Android and Google Play are trademarks of Google Inc.

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Helping the world hear better