WHITEPAPER
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The Audiology of Oticon Xceed and Oticon Xceed Play

SUMMARY

Hearing difficulties encountered by people with severe-to-profound hearing loss often vary greatly across individuals and cannot be simply explained by the pure-tone audiogram. This whitepaper discusses the characteristics of severe-to-profound hearing loss and describes how the hardware and audiological features in Oticon Xceed and Oticon Xceed Play are designed to meet the needs of power users. This whitepaper reports technical measurements showing Oticon Xceed provides a maximum improvement of up to 11 dB in signal-to-noise ratio.

Oticon Xceed and Oticon Xceed Play are power hearing aids built on the Velox S platform which offers the highest peak gain and maximum power output in the industry and introduces open sound experience to people with severe-to-profound hearing loss for the first time. By providing the users with optimal amplification with better access to speech with less noise, Oticon Xceed and Oticon Xceed Play can help them to overcome the struggles in daily communication.

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Understanding severe-to-profound hearing loss

Severe hearing loss is commonly defined as an average hearing threshold of 71 - 90 dB HL, and profound hearing loss is defined as 91 dB HL or above (e.g. ASHA, 2015). The barriers, challenges and needs of people suffering from severe-to-profound hearing loss are often more complicated compared to people with milder degree of hearing loss because of for example the mixed etiology and the more impaired auditory system. Hearing difficulties vary greatly across individuals and cannot be simply explained by the pure-tone audiogram. For example, Ching et al. (1989) showed that there were considerable variations in aided speech recognition for people with severe-to-profound hearing loss.

Having reduced audibility is the major problem. Achieving 100% speech understanding is not always possible even in quiet. Such degree of hearing loss characterizes reduced dynamic range (less distance between hearing threshold and uncomfortable loudness levels), which is also linked to abnormal loudness growth (loudness perception grows rapidly over a small range of intensities). This is illustrated in Figure 1. Severe-to-profound hearing loss usually involves damage of both outer and inner hair cells, the presence of dead regions in the cochlea, and may involve also dysfunction of the auditory nerve and the rest of the central auditory system. Damage of the inner hair cells can cause broadening of auditory filters, resulting in poor frequency selectivity. Together with reduced temporal resolution, such hearing loss often leads to a loss in clarity and distorted speech perception (e.g. Killion, 2000; Souza, 2009).

Listening to speech in noise is a common challenge for people with hearing loss as a consequence of reduced frequency selectivity and presence of dead regions. People with a severe hearing loss usually have a greater reliance on temporal cues for speech understanding (Souza et al., 2005). However, the presence of background noise masks the temporal envelopes of the speech signal, which provide important cues that are particularly helpful for them. They may struggle in many different real-life situations where they need to rely on other cues and information such as lip reading, background knowledge and context for successful speech communication. Increased listening effort is also linked to severe-to-profound hearing loss. All these can result in fatigue and also impose extra load on the brain, which is probably related to the additional effort spent on listening and following a conversation, for both adults and children (Bess & Hornsby, 2014). Severe-to-profound hearing loss may lead to a greater level of anxiety and depression (Carlsson et al., 2014) and poorer quality of life (Ringdal & Grimby, 2000) for adults than the general population.

Amplification needs

The main goal of amplification is to provide people with severe-to-profound hearing loss with optimal audibility so that they have access to all sounds. To provide prescribed gain, the hearing aid needs to give high output. When amplified sound leaks from the ear canal, reaches the microphone and is re-amplified, feedback occurs. The nature of severe-to-profound hearing loss means that these people are more susceptible to experience feedback occurrence due to the high levels of gain needed. In general, clarity and details in sounds with reduced risk of feedback are important aspects of amplification.

For these hearing aid users it is important to consider how to best fit sounds into the reduced dynamic range. There are pros and cons to the compression level chosen and to the speed of the system. While high compression ratios squeeze the sounds into the dynamic range, they also distort the signal, providing poor sound quality without increasing speech understanding. The speed of the system is also important to consider; while a fast-acting system will capture quick drops or increases of

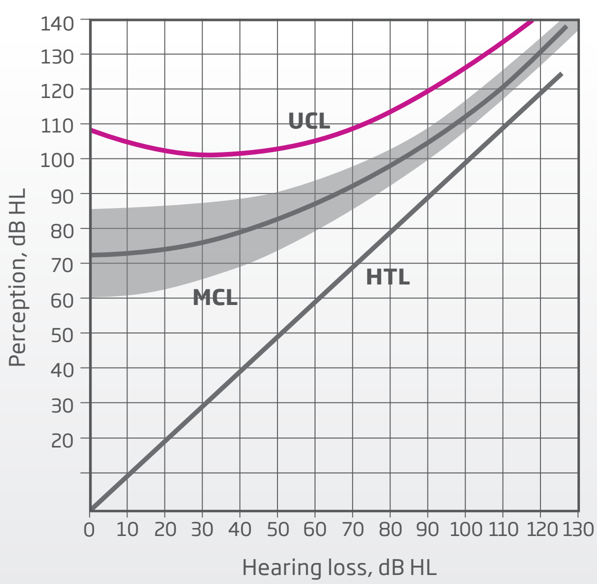
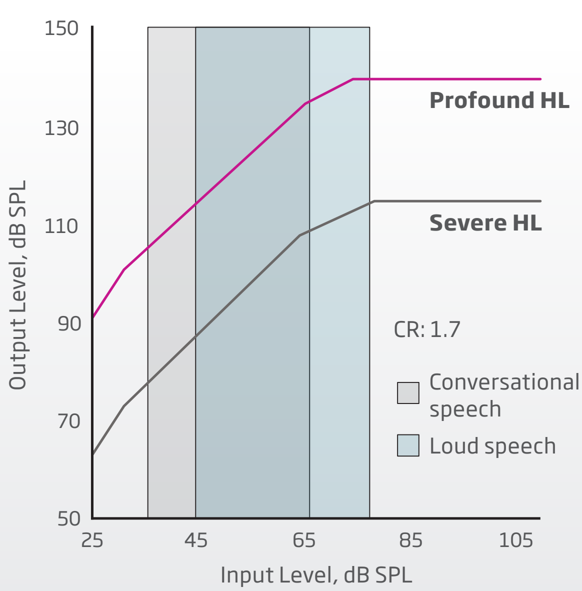


Figure 1. Relationship among the most comfortable loudness levels (MCL), uncomfortable loudness levels (UCL), and hearing threshold levels (HTL) (Pascoe, 1988). This figure illustrates as HTL increases, the residual dynamic range decreases.

the signal to increase or decrease output, it is also likely to smear the intensity variations of a signal where peaks and troughs are diminished. A slow-acting system protects the amplitude-time envelope of the speech signal. The limitation of traditional slow acting systems is that it does not protect against sudden loud sounds, a fast attack time is needed, but this can lead to an unstable sound picture in dynamic listening environments. Ultimately, the use of either fast- or slow-acting systems alone do not provide what the users need. Since these users rely heavily on temporal cues for speech recognition, it is important to preserve the temporal envelope of the amplified speech signal.

Children with severe-to-profound hearing loss have additional amplification needs and challenges. Early identification and intervention, such as hearing aid amplification or cochlear implantation, is crucial for this population. The goal is to provide adequate sound for speech and language development. For children fitted with hearing aids, it is important to provide optimal and consistent gain to ensure audibility. These children are especially prone to the feedback problem due to high intensity output level (Dyrlund & Lundh, 1990) and growing ears. Therefore, regular replacement of earmolds and good feedback handling in hearing aids is important.

In this whitepaper, all the descriptions and technical information concerning Oticon Xceed also apply to Oticon Xceed Play. Clinical evidence is applicable to Oticon Xceed only.



Introducing Oticon Xceed and Xceed Play

Oticon Xceed, which are power hearing aids built on the Velox S platform, are designed with the specific needs and challenges in mind to reflect our understanding and knowledge about the nature of this degree of hearing loss. From hardware to the implementation of the features and technology, Oticon Xceed, which offers the highest peak gain of 87 dB and maximum power output of 146 dB in the power hearing aid category, introduces the open sound experience to people with severe-to-profound hearing loss.

Re-design of microphone inlet to reduce mechanical feedback

Delivering high gain to the user is not solely about how much gain or sound pressure level output can be given by a hearing aid amplifier. Simply producing sounds of high sound pressure level inside a hearing aid can cause mechanical vibrations. This would cause the entire hearing aid including tubing to vibrate and produce distortion sounds when this vibration is transmitted to the microphone. This is one of the limiting factors of the highest gain that a hearing aid can produce. The microphone inlet of Oticon Xceed has been re-designed to balance out the mechanical vibrations normally created by the microphone tube and the membrane in the microphone. This hardware re-design, including better control of the mechanical vibrations, is made possible through the new mechanics in Oticon Xceed, allowing broadening the limit of maximum output.

Reducing step-size of the volume control for finer adjustments

People with severe-to-profound hearing loss typically have a highly reduced residual dynamic range and therefore a very steep loudness growth function (see Figure 1). This means that small changes in level make a much larger change in their perception compared to people with normal hearing. These users are as a result often much more sensitive to small changes in amplification. In Oticon Opn™ and Oticon Opn S™ hearing aids the step-size of the volume control (VC) is 2.5 dB. Each time the VC is used via the local controls on the hearing aid or via the Oticon On App or remote control the gain is changed by this amount. For people with a very narrow

Figure 2. The Input/Output (In-situ) curve at 1 kHz only for DSE with a compression ratio 1.7:1 for a profound and a severe hearing loss. This illustrates how the Speech Guard LX level detectors are set up. This shows the linear handling of soft sounds below the kneepoint and the implementation of two high compression threshold kneepoints.

dynamic range this change in gain can be too big. Imagine a dynamic range only half as wide as the one for normal hearing: for a person with severe-to-profound hearing loss a change of 2.5 dB in physical gain could be perceived as how a 5 dB gain change is perceived for people with normal hearing. This would make it hard for the user to adjust the hearing aid to the preferred volume. To cater for this phenomenon of the very steep loudness function, Oticon Xceed hearing aids come per default with a 1 dB step size for VC changes. This allows for much finer adjustments of the gain. The VC step size can be changed to the regular 2.5 dB by the hearing care professional if needed.

In addition to the configuration of the VC step size it is also possible to adjust the upper and lower VC range in small steps. This is especially useful in the area of pediatrics but also in any other case where the user shall have some limited influence on the volume.

Fitting prescription tailored for severe-to-profound hearing loss

Dynamic Speech Enhancement (DSE) was developed with the goal of prescribing sufficient sensation level of speech without reaching the feedback limit and UCL while preserving reasonable envelope details of the amplified signal, which is all of particularly great importance to people with severe to profound hearing loss. Different considerations are taken into account in the attempt to achieve this from the prescription point of view, some of which will be described below.

The loudness compensation of DSE is developed based on the loudness modelling for severe and profound hearing loss (Elberling, 1996; Lundh, 2001). Compression ratio of the hearing aid reflects the slope of the loudness function and most comfortable level, which means this model considers the effects of such hearing loss on loudness perception. Compared to VAC+, DSE provides less compression. Less compression is made possible by having two high kneepoints and linear amplification below the first kneepoint to ensure minimal distortion of temporal cues. This is because the goal of amplification is to enhance speech understanding rather than restoring exact loudness. As such, VAC+ tries to reach normalized loudness restoration, whereas DSE uses the loudness compensation model specifically for these users (Lundh, 2001). Figure 2 shows an input/output curve of 1 kHz as example of how DSE works.

Preservation of temporal envelopes

Both temporal fine structure (TFS), which are all the detailed changes in the waveform of sound over short time, and the envelope of the speech signal are important for speech understanding. The more severe the hearing loss becomes, the use of the TFS gets of lesser importance or even completely lost since people with severe-to-profound hearing loss are not able to extract useful information from the TFS due to their distorted temporal resolution. Instead they more and more rely on the envelope information. Since this information may be the only one left it is crucial to keep the shape of that envelope best possible when the speech signal gets amplified by a hearing aid. Figure 3 illustrates the temporal envelope of a speech signal. Fast acting compression can have a detrimental effect on that shape; especially when higher compression ratios are applied. To keep the intensity differences of the envelope shape, Speech Guard™ LX applies a linear window. The linear window of Speech Guard LX keeps the envelope shape and therefore provides crucial information for the severe-to-profound hearing loss user for understanding speech, because the signal in the linear window is not as squeezed. Speech Guard LX defines the dynamic properties of the compressor, i.e. attack and release times, while DSE defines the static properties, compression ratios and compression kneepoint. Together, the combination of Speech Guard LX and DSE work together to provide a signal that preserves as much of the natural speech detail as possible for the people with this degree of hearing loss.

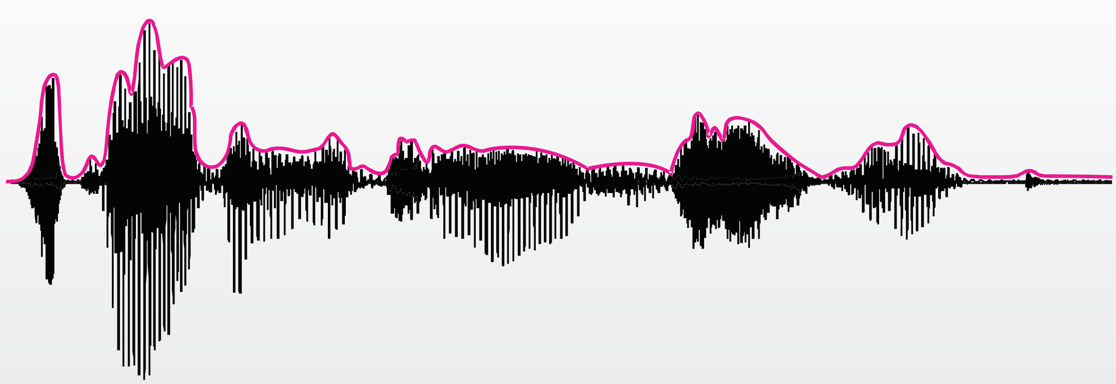


Figure 3. The magenta line represents the temporal envelope of a speech signal.

Inspired by Speech Guard LX, Oticon Xceed has an optimized maximum power output (MPO). This is important because people with severe-to-profound hearing loss often listen to levels that reach MPO. The MPO uses the fast-acting algorithm of Speech Guard LX powered by the Velox S platform to make quick changes based on quick drops in input level for improved sound quality and audibility. This is achieved by having adaptive release after compression in two stages; first, the quick restoration to approach normal compression, and second, continue slowly until the compression is fully released.

In Oticon Xceed, DSE has been adapted to the new platform and fitting software as compared to Dynamo. To accommodate for differences from the previous platform to the new Velox S platform, corrections are made so that the targets provided are the same; i.e. across insertion gain levels, platform corrections are applied to accommodate for differences from previous platform to the new Velox S. This is to provide smoother transfer between platforms. To provide a better target match display in Genie 2, the instrument's maximum performance in terms of gain limit is taken into consideration.

In summary, the gain prescription from DSE and the dynamic behavior of Speech Guard LX takes the special needs of people with severe-to-profound hearing loss into account by focusing on speech and providing the benefits of non-linear and linear compression. DSE is recommended for adult users.

Frequency lowering making high-frequency sounds audible

Residual hearing at high frequencies is usually very limited for people with severe-to-profound hearing loss. Speech Rescue™ LX makes high frequency sounds available by copying the high frequency sounds to a lower frequency range with relatively more residual hearing. For further information, see Oticon Whitepaper (Angelo et al., 2015).

Open sound experience with better access to speech

Oticon Xceed highlights two key features, OpenSound Navigator™ (OSN) and OpenSound Optimizer™ (OSO), which enable the open sound experience for this user group for the first time. These two features provide better access to speech and clearer signals in noise, greatly reduced risk of feedback and also increased headroom for fitting, which also provides more consistent gain throughout the day.
OSN provides 360˚ open sound experience and monitors the sources of noise in the environment. It only applies noise reduction to sources that are identified as noise, and not when sources are identified as interfering speech. This greatly improves the quality of the

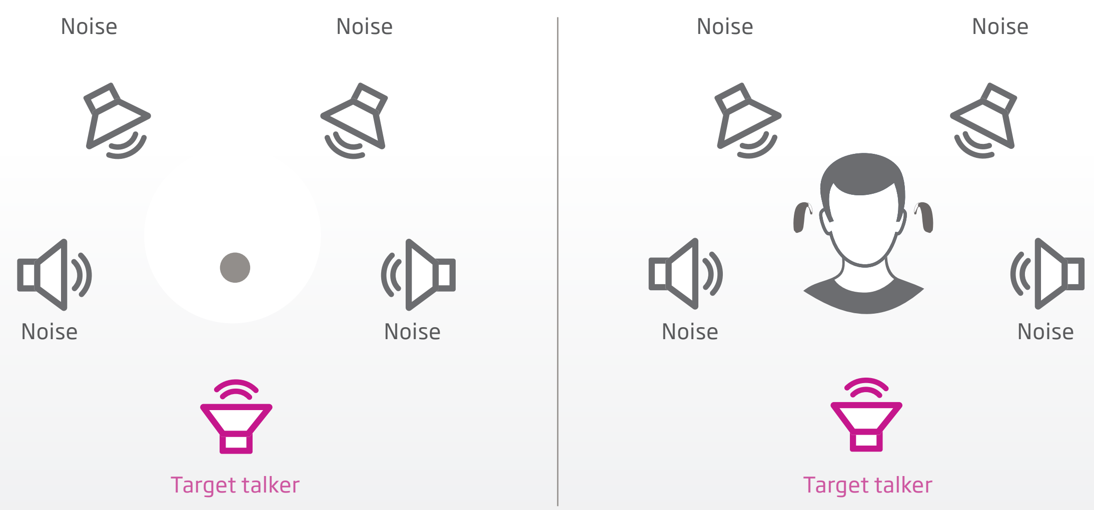


Figure 4. The setups of the technical measurements performed in various listening environments. Two types of background noise were used (4-talker babble and stationary noise, presented at ±90º and ±150º), with target speech coming from the front (0º). The signal-to-ratios of the listening environment is measured in the middle of the sound field (left panel), and the output SNRs of the hearing aids was measured with a mannequin (HATS) wearing a pair of Oticon Xceed 1 BTE UP hearing aids placed in the middle of the sound field (right panel).

speech signal by attenuating interfering noise. By doing so, the temporal envelope is also preserved. More information about OSN can be found in the Oticon Whitepaper (Le Goff et al., 2016).

People with severe-to-profound hearing loss require much more gain than users with milder hearing loss, and this greatly increases the chance of feedback occurrence. Restricting the amount of gain, applying phase cancellation and adaptive notch filters (Chung, 2004), and using full-shell earmold with good acoustic seal are the common ways to reduce the risk of feedback. Dynamic situations such as chewing, talking, wearing hats and hugging often trigger annoying whistling feedback sounds. This is handled by adaptive feedback gain reduction in the conventional technology, which compromises audibility, sound quality and speech understanding. Feedback remains problematic in this user group and this could be embarrassing and unpleasant for not only the users themselves but also the people around them who are able to hear the whistling feedback sounds. OSO in Oticon Xceed proactively prevents feedback and provides an additional 6 dB stable gain, as in Oticon Opn S hearing aids. The advantages of OSO for this user group include 1) allowing more gain for prescription and 2) giving consistent amplification in dynamic situations. Further description of OSO can be found in the Oticon Whitepaper (Callaway, 2019).

The additional gain provides more headroom for fitting. To investigate the benefit of having more stable gain on the availability of audible speech cues to the listener, we performed technical simulations using Speech Intelligibility Index simulations according to the ANSI S3.5 standard (see Technical study 1 in Oticon Whitepaper Callaway, 2019 for further details of the setup of the simulations). There were two conditions in the simulations: 1) Oticon Xceed 1 BTE SP with 0.8 mm and closed micromold fit to prescribed DSE for four common severe/profound hearing loss configurations as represented by standard audiograms N5, N6, N7 and S3 (see Bisgaard et al., 2010 for the details of the standard audiograms), and 2) Oticon Xceed 1 BTE SP prescribed with DSE targets reduced by 6 dB at 1-6 kHz for the same four hearing loss configurations. Simulations with the same conditions were repeated for Oticon Xceed Play 1 BTE SP hearing aid with prescribed DSL v5.0 targets. Results of the simulations showed that with the additional gain of 6 dB, OSO provides up to 20% more speech cues in both Oticon Xceed and Oticon Xceed Play, for both quiet and noise conditions.

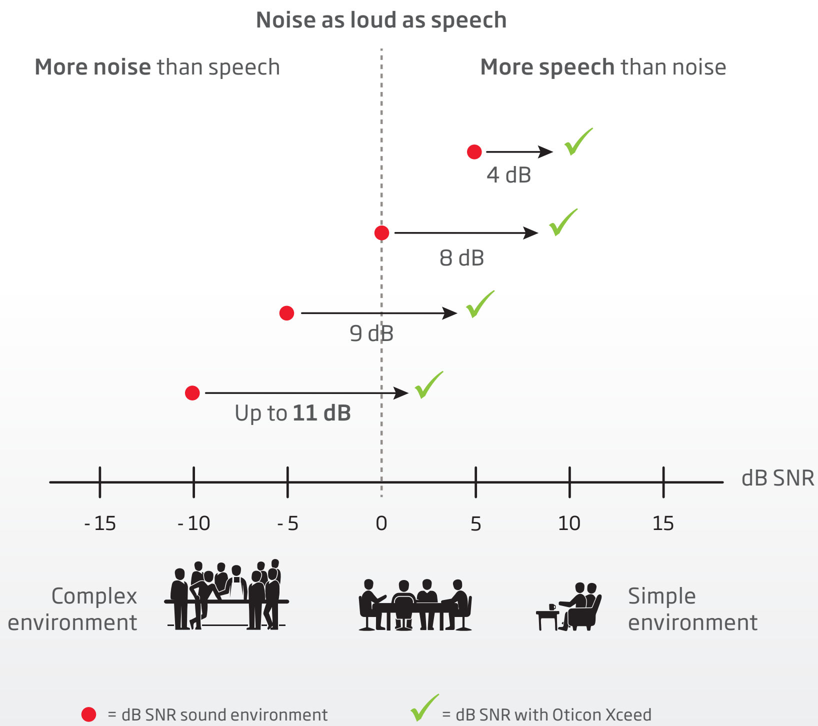


Figure 5. The output SNRs of Oticon Xceed 1 BTE UP in various listening conditions ranging from -10 to +5 dB SNR. The maximum effect is up to 11 dB improvement in signal-to-noise ratio when the sound environment is -10 dB SNR.

Oticon Xceed delivers up to 11 dB improvement in SNR

Oticon Xceed with OSN and OSO gives access to clearer speech in different listening environments by improving the signal-to-noise ratios (SNRs). SNR refers to the difference between the level of the target speech and the level of the background noise. A positive SNR means the target speech has a higher level than the background noise, which is more favorable for good speech understanding than a negative SNR. The more challenging the listening environment becomes, the more noise reduction the hearing aid will provide. In complex listening environments, where the users are challenged the most, Oticon Xceed delivers the maximum effect and provides up to 11 dB improvement in signal-to-noise ratio. To illustrate this, we performed technical measurements in various listening environments ranging from complex to relatively simple listening conditions (-10 to +5 dB SNR), which represent everyday listening environments where noise reduction is much needed for successful speech understanding. We compared the SNRs of the listening environment (Figure 4, left panel) and the output SNRs of the Oticon Xceed 1 BTE UP hearing aids (Figure 4, right panel). The hearing aids were programmed with a standardized reference test setting (IEC 60118-0) with the overall gain reduced by 20 dB. The DSE fitting rationale, with both OSN and OSO activated, was used.

A significant improvement was observed across all listening environments and the improvement became more substantial as more noise was added to the situation (see Figure 5). In the noisiest condition where SNR in the listening environment was -10 dB, the output SNR of the hearing aids were approximately +1 dB. In this listening environment, the speech level was 10 dB lower than the background noise level. This is the input signal to the hearing aids. The output signal from the hearing aid had a speech level approximately 1 dB higher than the background noise level. This corresponds to up to 11 dB improvement in SNR. These technical measurements provide evidence on Oticon Xceed giving more access to clearer speech in various listening situations.

Clinical evidence: Proven BrainHearing™ benefits delivered by Oticon Xceed

Oticon Xceed now offers market leading gain and maximum output in the power category. The technical measurements show that Oticon Xceed (with both OSN and OSO activated) provides improvement in SNRs by up to 11 dB, depending on the complexity of the listening environment. Both optimized audibility and clear signal with preserved speech details in static and dynamic situations are the basis of the BrainHearing technology found in the device. An independent research study conducted at the Örebro University hospital in Sweden evaluated the benefits of Oticon Xceed and OSN. Results show that Xceed with OSN activated improves speech clarity by up to 10%, reduces listening effort by up to 10 % and enhances short-term memory recall performance by up to 15%. These results suggest the BrainHearing technology in Oticon Xceed can provide better access to speech with less effort and can facilitate cognitive processing of speech for people with severe-to-profound hearing loss by providing better access to speech, reducing listening effort and improving memory recall for speech communication (see Oticon whitepaper Ng & Skagerstrand, 2019 for more detail).

Concluding remarks

The hardware and audiological features in Oticon Xceed and Oticon Xceed Play are designed to reflect our knowledge and understanding of people with this degree of hearing loss and their needs. Oticon Xceed and Oticon Xceed Play have a wide range of connectivity options and can be used with the ConnectClip wireless microphone to further support speech understanding in challenging listening situations.

Having limited audibility and poor speech recognition are not the only negative consequences of severe-to-profound hearing loss. People with severe-to-profound hearing loss would need greater support in different aspects. It is crucial to provide the users with optimal amplification with better access to speech with less noise and less effort so as to help them to overcome the struggles in daily speech communication, which can positively impact their quality of life.

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