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Oticon Frequency Lowering

Access to high-frequency speech sounds with Speech Rescue™ technology

EDITORS OF THIS ISSUE

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ABSTRACT

Frequency lowering is a well-known technology in hearing aids that shifts high-frequency sound to lower spectral regions. Research and clinical findings have revealed the challenges of developing a strategy that can provide access to high-frequency speech without introducing unacceptable amounts of low-frequency distortion.

Oticon Speech Rescue™, the latest frequency lowering processor on the market, is explicitly designed to transmit temporal features of high-frequency speech with minimal distortion of low-frequency spectral features. It is unique because it uses a multi-layered lowering technique that overlaps copied segments from a wide region in the high-frequency input in order to present the information in a narrow region in the low frequencies. Prescription of Speech Rescue is based on the principle of Maximum Audible Output Frequency (MAOF), which means that the lowered input will be at the border of the patient's usable hearing.

Here, we highlight the principles behind the Speech Rescue strategy and configurations, and describe the importance of providing a correct frequency lowering setting to optimise the benefit for the patient with a severe-to-profound hearing loss.

Acknowledgements
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If you have any questions regarding the content of the white paper please contact Kamilla Angelo, kian@oticon.com.

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Understanding the challenge

Speech has evolved to be a remarkably robust signal that facilitates communication in the face of severe distortion. For example, the telephone transmits only a portion of the full speech spectrum (300 to 3300 Hz), yet intelligibility in quiet remains largely intact. Speech processed by cochlear implants, which transmit the slow modulations of speech in a sparse number of bands, can be largely understood in favourable listening conditions. However, communication begins to break down as sources of signal degradation accumulate. Sensorineural hearing loss is a major source of signal degradation that makes verbal communication quite frail when noise, reverberation and unpredictability in speech are added. Therefore, even though a hearing aid can present much greater spectral detail than a cochlear implant over a wider frequency range than a telephone, it can be very effortful and cognitively taxing to follow a conversation in noise. This fact, which has long been known among hearing aid developers, has inspired them to design signal processing strategies, such as noise reduction and directionality. More recently, there has been an awareness that information from the amplified speech signal can be made more robust by reintroducing the high-frequency cues that were given up on long ago due to limitations in receiver technology and the severity of loss in these regions.

Introduction

Perceptual importance of high-frequency energy – understanding the potential benefit

A growing body of evidence shows that the high-frequency end of the speech spectrum plays a significant role in our perception of speech and voice quality, talker identification, speech source localisation and speech-in-noise performance (Monson et al. 2014). In particular, studies with hearing-impaired individuals have revealed that improved speech understanding in noise is possible when an effort is made to amplify the high frequencies (Hornsby et al., 2011; Levy et al., 2015; Plyler and Fleck, 2006; Turner and Henry, 2002). Furthermore, studies have shown that receiving insufficient audibility at high frequencies negatively affects the speech production, language development and word learning rate of hearing-impaired children (Pittman, 2008; Stelmachowicz et al., 2004).

While access to high-frequency speech cues is not paramount to comprehension in quiet and favourable listening conditions, the additional information they provide becomes increasingly important for successful communication when listening conditions become complex. High-frequency hearing loss can put individuals at a disadvantage since they do not have access to the full spectrum of speech cues that can facilitate communication in difficult acoustical environments. Consequently, these individuals may struggle to follow a conversation, may miss important information, and may become more easily fatigued.

Depending on the degree and configuration of hearing loss, the greatest risk to speech perception is the inaudibility of consonants with significant high-frequency energy. For example, perception of fricative consonants such as "f", "s" and "th", which depends on frequencies above 4 kHz, may be completely missing from the incoming speech stream for individuals with severe-to-profound hearing loss. Depending on the linguistic context and background noise, information from the low frequencies may be inadequate for these individuals to fill in the missing content. At a minimum, they may have to apply additional cognitive resources when trying to perceive these sounds, thus making listening more effortful. Conversely, unlike an individual with normal hearing, they will not be able to rely on information gleamed from the high frequencies when information from the low frequencies is less reliable due to unfavourable signal-to-noise ratios, etc.

"Frequency lowering can be viewed in terms of an improved audibility vs increased distortion Tradeoff"
(Souza et al. 2013)

Fortunately, with today's hearing technology, these "out of reach" high-frequency sounds can now be restored within the usable bandwidth of hearing aid users. This can be done either by extending the bandwidth of conventional amplification for individuals with moderate high-frequency loss or by utilising signal processing strategies such as frequency lowering for individuals with more severe high-frequency loss. It is, however, important to realise that the challenge of using frequency lowering to provide access to high-frequency speech sounds is that it may come at the cost of distorting the natural frequency patterns contained in the low-frequency portion of the speech spectrum. Thus, pursuing high-frequency audibility by providing high-frequency gain with conventional amplification ought to precede the prescription of frequency lowering in modern hearing aids (AAA, 2013). However, in cases where it becomes necessary to employ frequency lowering technology, striking the right balance between improving access to high-frequency sounds and minimising low-frequency distortion is paramount to obtaining the optimal benefit for the individual patient (Alexander, 2013; Souza et al., 2013).

Frequency lowering technologies

Frequency lowering is the umbrella term for the signal processing in hearing aids that makes high-frequency sounds available at lower frequencies, where the patient can hear. Today, frequency lowering is achieved in as many different ways as there are hearing aid manufacturers. However, conceptually, the different technologies use one of three basic techniques: compression, transposition, and composition (Fig. 1). Frequency composition is the latest technique on the market. It superimposes a high-frequency source band onto a low-frequency destination band, but it first divides the source band into 2 or 3 segments and then overlaps them in the destination band in order to present information from a wider input region in a narrower output region.

Frequency lowering technology

different strategies

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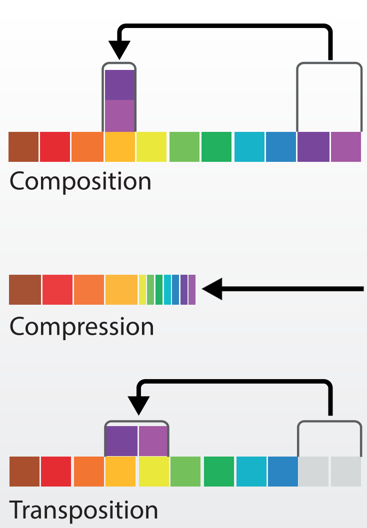


Figure 1: Frequency lowering strategies.
From top to bottom: Frequency Composition, Compression and Transposition. With ***Frequency Compression****, sounds above a selected start frequency are squeezed to fit within the audible bandwidth of the patient. Depending on the position of the start frequency, the low-frequency spectra important for vowel identification are likely to be altered, at the risk of creating vowel confusion.* ***Frequency Transposition*** *cuts out a portion of the high-frequency spectrum and reproduces it at a lower spectral position. To avoid compressing the high frequencies only a small high-frequency section is selected.* ***Frequency Composition*** *superimposes a high-frequency source band on a low-frequency destination band, but it first divides the source band into 2 or 3 segments and then overlaps them in the destination band in order to present information from a wider input region in a narrower output region. Note that with frequency composition the output bandwidth is intact. Whereas for frequency compression and for some variations of transposition there is an output band-limiting effect.*

Oticon frequency composition
Speech Rescue in essence

Speech Rescue is a technology that, simply put, copies high-frequency sound and moves it into a lower audible frequency range (Fig. 2). The part of the spectrum where sound moves from is the source region and the part where it moves to is the destination region (Fig. 3a). A total source region spans approx. 3 kHz. It consists of sub-sections that are then overlaid at the destination region (Fig 3 a). In this way, the destination region becomes narrow, spanning only 800 to 1600 Hz. Since the algorithm copies and keeps the original high-frequency sound, the hearing aid retains the full output bandwidth to provide patients with maximum benefit in case they can extract any information (e.g. musical or environmental) from the high-frequency sounds.

Advantages of the Speech Rescue design:

- The source region is placed at a frequency range that optimises the transfer of information from high-frequency frication*.
- The destination region is narrow and is not placed too low to minimise the disruption in the perception of low-frequency temporal and spectral information.
- Speech Rescue maintains the original high-frequency sound in order to prevent unintentional limitations in the bandwidth available to the patient.
- Speech Rescue utilises principles of auditory processing (cochlear filtering) so that frequency-lowered sound is minimally compressed on a psychophysical (critical band) scale.

Oticon frequency composition
Speech Rescue technology in every detail

Speech Rescue is available in the new Oticon Super Power hearing aids, Dynamo for adults and Sensei SP for children. Oticon has implemented frequency composition in these high-powered instruments to help alleviate some of the speech perception deficits of patients with severe-to-profound hearing losses. The majority of these patients have the greatest loss of usable hearing in the high frequencies and are likely to gain the most from using frequency lowering technology. However, the challenge of implementing frequency lowering for this patient group is that they often have a narrow audible bandwidth available to re-code the missing high-frequency information. If frequency lowering distorts the low-frequency speech information, the patient may well loose more than what is gained. Thus, paradoxically, the patients who need frequency lowering the most are also those that are most vulnerable to the undesirable effects of frequency lowering. It is therefore crucial that a modern frequency lowering strategy delivers high-frequency speech cues while concurrently minimising distortion of what else the patient hears.

The Speech Rescue algorithm and settings are based on the following three guiding principles: 1) Capturing a wide high-frequency source region where the important speech cues are, 2) Using the natural frequency selectivity of cochlea to introduce minimal distortion and 3) Maximising protection of the low frequencies to preserve vowel information and guard sound quality.

The processor simply copies segments of high-frequency sound and moves them into a lower audible frequency range (Fig. 2). The part of the spectrum where sound moves from is the source region and the part where it moves to is the destination region (Fig. 3a). The goal is to provide the patient with as much high-frequency information as possible. This means that, in principle, the source region should cover the entire speech spectrum that is unusable to the patient. On the other hand, packing too much information from the source region together in the destination region would likely make it too dense and thereby unusable to the patient. This would compromise Oticon's efforts to achieve the best sound quality and our aim to provide the brain with the cleanest and most intact signal possible. Instead, the source region covers a ~ 3 kHz range, which for each configuration is positioned to maximise the amount of new information provided to the patient. That is, as the distance between source and destination bands increases, the correlation of the information in the two bands will decrease and hence more information is added.

**Frication is when we bring the mouth into a position to block the airstream, yet, without making complete closure. The air moving through the mouth will generate audible friction. Try saying the 's' in "sister", or the 'z' in "zebra".*

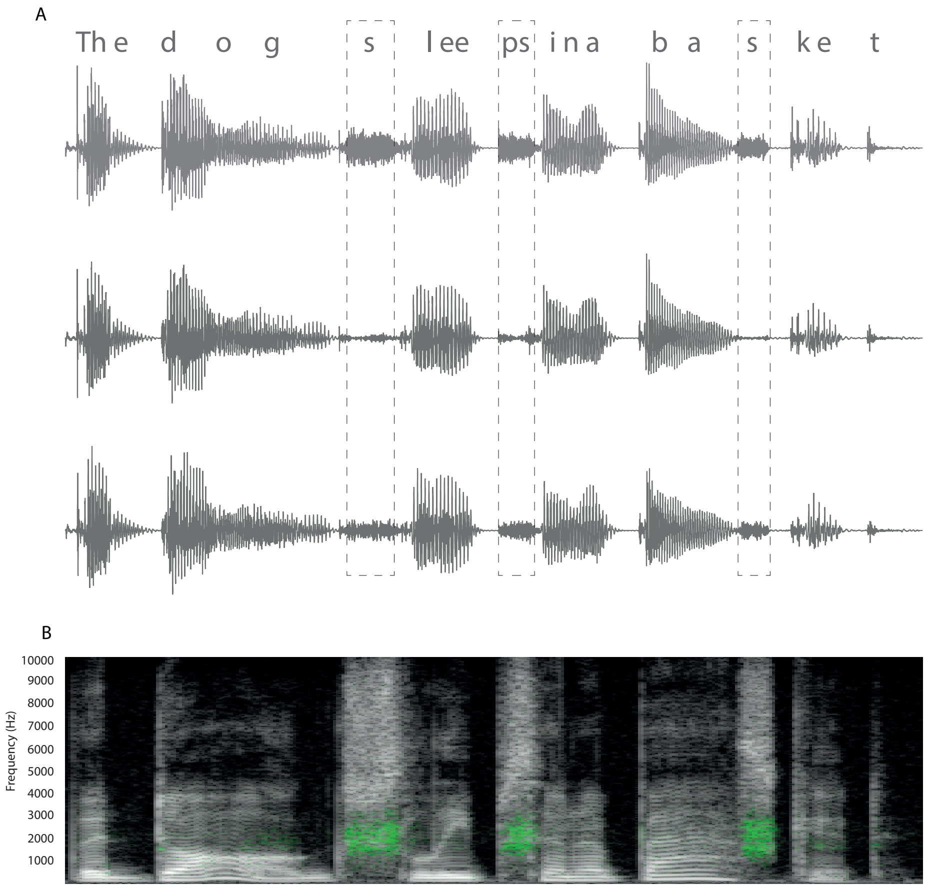
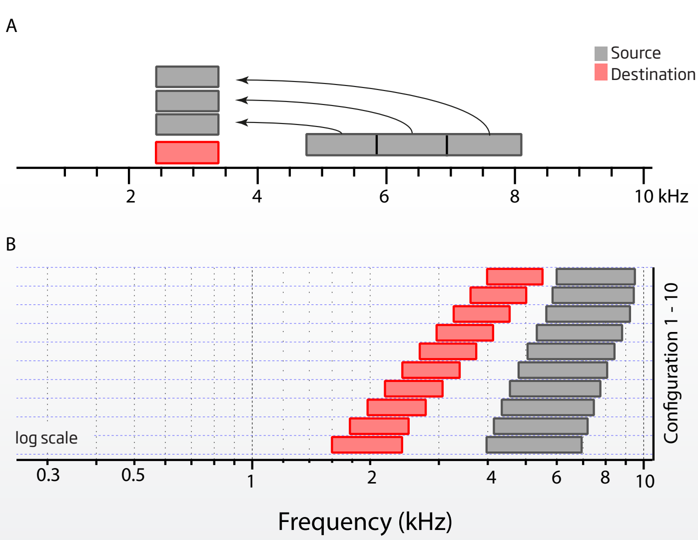


Figure 2: Effect of Speech Rescue on the speech signal
A: *Time waveforms of the sentence "The dog sleeps in a basket". (Top) Wideband signal representing normal hearing, (Middle) simulated severe-to-profound hearing loss by low-pass filtering at 2.5 kHz and (Lower) activation of Speech Rescue, still with low-pass filtering at 2.5 kHz. The input stimuli is from the Hint-C speech-in-noise sentence material. Speech Rescue was set in configuration 1 with the strongest strength level. The dashed boxes highlight where sounds are missing from the sentence with the hearing loss. As Speech Rescue is turned ON the s, ps, and s are re-introduced into the speech. Also, note how the speech signal outside the dashed boxes is unaltered upon Speech Rescue activation*
B: *Merged spectrogram of the wideband signal and restricted with Speech Rescue ON. Note the high-frequency energy lowered by Speech Rescue in green.*



C

Conf.	Destination	Source
1:	1587 - 2429	3940 - 6985
2:	1763 - 2522	4116 - 7228
3:	1957 - 2790	4310 - 7496
4:	2169 - 3083	4522 - 7789
5:	2402 - 3405	4755 - 8111
6:	2658 - 3758	5011 - 8664
7:	2938 - 4145	5291 - 8851
8:	3246 - 4570	5599 - 9276
9:	3583 - 5036	5806 - 9480
10:	3954 - 5547	5954 - 9547

Figure 3: The Speech Rescue processor and configurations.
A: *Speech Rescue technology copies and keeps the high-frequency sound at the original place. The copied sub-regions (grey) are moved (arrows) and layered at a lower frequency region defined by the destination region (red). This example is of configuration 5.* ***B:*** *There are 10 configurations of Speech Rescue. The configuration determines where the high-frequency information is captured (grey) and where it is lowered to (red). A configuration is a pair of a source and a destination region, which moves in concert between configurations.* ***C:*** *Frequency values of the destination and source regions of configuration 1 to 10.*

The specific Speech Rescue settings complement the natural frequency selectivity of the cochlea. The frequency selectivity is defined by the width of cochlear bandpass filters (auditory filters). Their widths, measured in ERB (equivalent rectangular bandwidth), increase approximately logarithmically towards higher frequencies (the base of the cochlea). Following this natural perceptual arrangement, Speech Rescue captures several high-frequency bands and re-codes them in a lower-frequency band according to a logarithmic scale. Consequently, on a perceptual frequency axis, the width of the destination regions (~ 3 ERB) is only a little smaller than the width of the source regions (4-5 ERB) (see log scale in Fig. 3b). This arrangement thus introduces minimal compression of the lowered signal. For configuration 1 to 5, the total source region is split into three sub-source regions to fit into the very narrow destination region (on a linear scale). For configuration 6 to 10, division into two sub-source regions suffices since the destination region is positioned closer to the base of the cochlea and is therefore naturally a little wider (on a linear scale).

Speech Rescue strives to protect the information naturally carried by the low frequencies in three tangible ways. First, as the destination band is kept narrow (only 800 to 1600 Hz) (Fig 3a). Second, the Genie fitting software assists the clinician in how to place the destination band at the edge of the patient's hearing range. Third, the source band is set so that it never goes lower than 4 kHz (Fig. 3b, c), which allows it to capture the primary energy from the fricative consonants such as 'f', 's' and 'th' without altering the relationship between formant frequencies.

In addition, Speech Rescue takes advantage of the opportunities offered by the natural dynamics of speech. Voiceless consonants naturally contain almost no low frequency energy. Thus, for a single talker, high- and low-frequency speech tend to be mutually exclusive in many situations (Fig. 4). This means that even though Speech Rescue superimposes the source region with the destination region, information from the two will rarely overlap in time. For example, Speech Rescue will position the high-frequency energy from the voiceless fricative, 'f', in a naturally available space in the lower frequency position. Conversely, when voiced speech cues occur in the low and mid frequencies, there will often be no high-frequency speech energy present in the input signal to be lowered by Speech Rescue.

Speech Rescue takes advantage of the opportunities offered by the natural dynamics of speech.

Finally, since the algorithm copies and keeps the original high-frequency sound, the hearing aid retains the full output bandwidth to provide the patient with maximum benefit of high-frequency sounds in case they can extract any sound information (e.g. musical or environmental sounds) from the high frequencies. In this way, Oticon frequency composition algorithm also acts to reinforce the original high-frequency information. For frequency compression and for some variations of transposition there is no output for high frequencies when frequency lowering is enabled in the device.

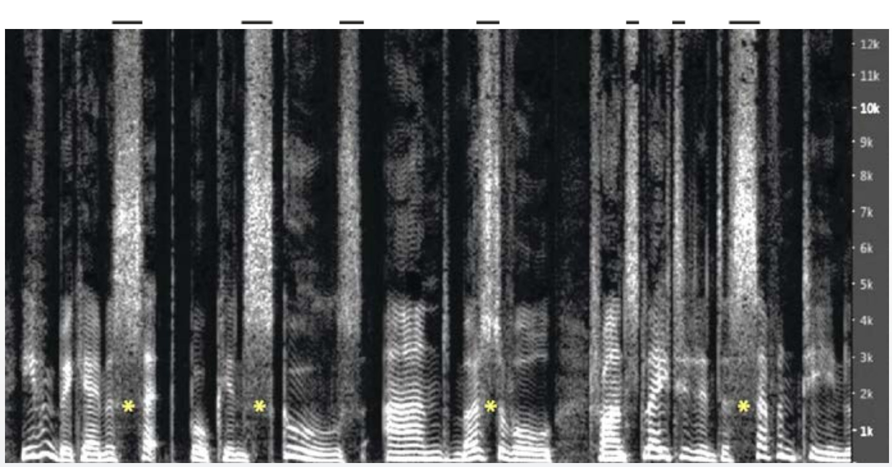


Figure 4: The natural dynamics of speech.
*Spectrogram of a randomly selected BBC podcast illustrating the natural dynamics of speech. For a single speaker, high- and low-frequency speech tend to be mutually exclusive. The horizontal bars indicate the occurrence of voiceless fricatives in the high frequencies. Note that when high-frequency energy from the voiceless fricatives is present there is a naturally available space in the lower-frequency position (see *). Conversely, when voiced speech cues occur in the low and mid frequencies, often there is no high-frequency speech energy present. This means that when Speech Rescue superimposes the source region on the destination region, information from the two will rarely overlap in time.*

Prescribing Speech Rescue

Depending on the severity of the high-frequency loss, a patient needs more or less lowering. The prescription goal is to place the upper limit of the destination region just within the patient's usable hearing. To make it a conscious choice of the clinician to use frequency lowering, Speech Rescue is OFF by default for both children and adults. However, once activated, an individual Speech Rescue configuration will automatically be prescribed based on a calculation of the patient's maximum audible output frequency (MAOF). The MAOF is defined as the highest frequency at which the patient can hear conversational speech with amplification.

Speech Rescue offers three fitting parameters in Genie (Fig. 5):

- How low the high-frequency information should be placed in frequency, as defined by the configuration.
- How much emphasis the high-frequency cues should contribute with, as defined by the strength.
- With or without wide-band amplification, as defined by the high-frequency bands ON/OFF function.

Prescribing Speech Rescue to the individual patient

How low? – the configuration.

Speech Rescue is OFF by default for both children and adults. Conventional amplification is the better choice, if audibility can be established. Unfortunately, obtaining audibility in the high frequencies is often challenging. The typical high-frequency loss combined with the relatively low-level speech energy in this part of the spectrum puts significant gain requirements on the hearing aid, which are often not met because of output limitations inherent to feedback cancellation and receiver design, i.e. bandwidth (Levy et al., 2015; Moore et al., 2008).

Speech Rescue is OFF by default for both children and adults. This way, it becomes a conscious choice of the clinician to activate Speech Rescue.

Once Speech Rescue is enabled, a default setting is automatically prescribed to the individual patient. There are 10 configurations in the Speech Rescue fitting panel of the Genie programming software (Fig. 3b and c, Fig. 5b). Each configuration corresponds to a single, linked pair of source and destination regions. Toggling between configurations allows the destination region to be shifted in small, discrete step sizes in order to accommodate fine-grained tuning to the hearing loss. For reasons identified earlier, the recommendation is to place the upper limit of the destination region just within the patient's usable hearing, as defined by the maximum audible output frequency (MAOF) or the highest frequency at which the patient can hear conversational speech with amplification (Alexander, 2015; Brennan et al., 2014; Kimlinger et al., 2015). When possible, best practice guidelines dictate that probe microphone measures should be used to evaluate the audibility of speech across the spectrum (Alexander, 2015). To visually identify the MAOF, find the point where the aided average speech spectrum intersects the audiogram (arrow, Fig. 5a). However, to aid the clinician, the Genie software will estimate the patient's MAOF using the audiogram, the output level of the device, the rationale, as well as the average speech spectrum. Based on this calculation, Genie will recommend the Speech Rescue configuration that most closely aligns the edge of the destination region with the MAOF. Speech Rescue is prescribed when the MAOF is below 6 kHz.

How much? – the strength

The fitting of Speech Rescue is two dimensional. The configuration determines where the high frequency information is lowered to, whereas the strength determines the intensity of the lowered signal relative to the unlowered signal (Fig. 5b). There are seven fine-tuning levels of the strength (-6 to +6 dB in steps of 2 dB). By default, the strength is set at medium level (i.e. 0 dB), providing the audiologist with the option to tune the level of the lowered sound up or down. High strength puts emphasis on high-frequency cues, whereas a lower strength setting makes the high-frequency sounds more subtle. The goal when setting the strength is to balance the perceptual saliency of the lowered signal (that is, is it audible enough for the patient to hear it and to integrate into the speech stream) and its distractibility (that is, is it so loud that it segregates out of the speech stream). It requires clinical judgment to find the preferred strength for the individual patient since it may depend on the configuration and severity of loss, the interaction with compressive amplification, and the patient's motivation and ability to cognitively handle the additional information provided by the lowered signal. In some cases, altering the strength may help reduce perceptual confusions between lowered speech sounds, for example the /s/ and /sh/ sounds.

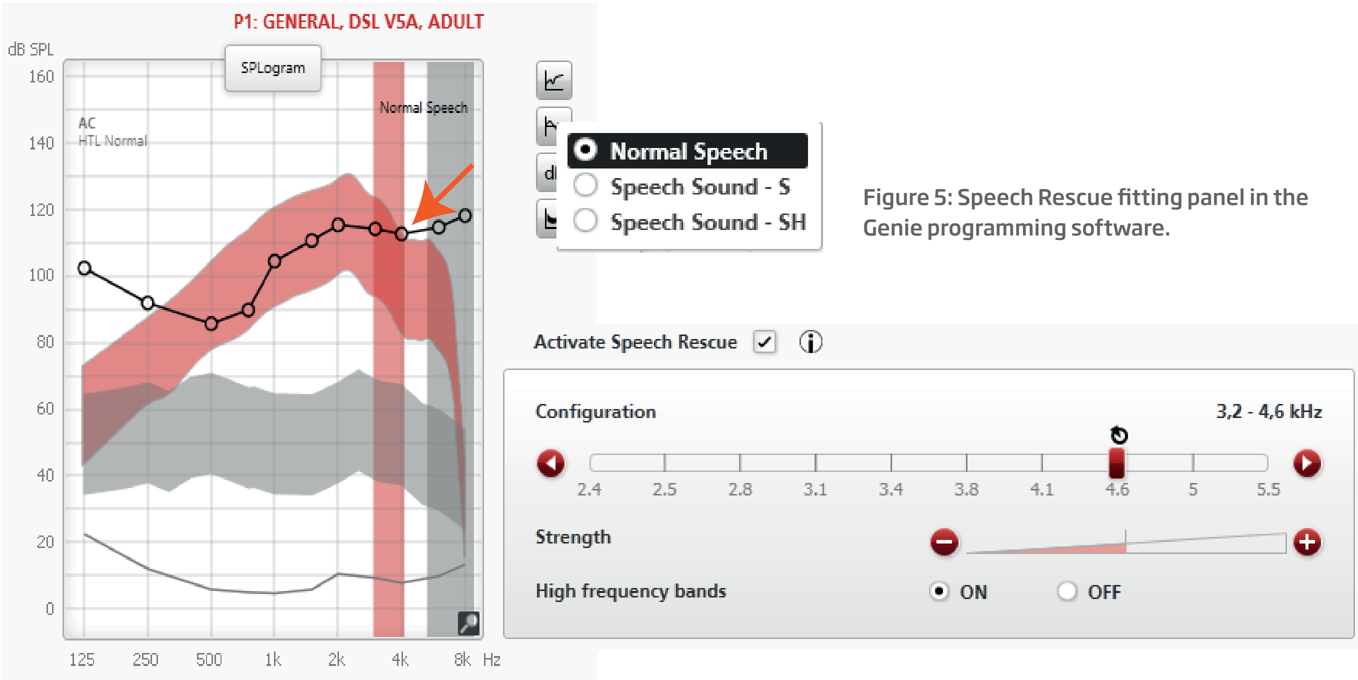


Figure 5: Speech Rescue fitting panel in the Genie programming software.

Activate Speech Rescue. *Speech Rescue is always OFF by default for both children and adults. However, even when this box is ticked OFF, the sign shows what prescribed configuration the patient receives if you choose to activate Speech Rescue.*

When enabling Speech Rescue significant resources are used within the instrument to drive this advanced algorithm. Thus, certain features are disabled to make way for Speech Rescue. This means that Transient and Binaural Noise Management (Dynamo only), Music Widening, Power Bass, and Voice Priority i cannot run simultaneously. A choice of feature priority for the individual patient is needed.

Configuration*: A configuration is a pair of a pair of source and destination regions. The part of the spectrum where sound moves from is the source region and the part where it moves to is the destination region. Oticon has implemented 10 configurations, which offers ample opportunity to fine-tune Speech Rescue to match the individual patient's usable hearing.*

This sign indicates the default prescribed setting. The default configuration is automatically calculated based on the audiogram configuration, the rationale, the aided speech spectrum and the output of the hearing aid.

As you scroll to the left the destination of the high-frequency sound moves to increasingly lower frequencies. When you change configuration you can see the paired movements of both the destination and source regions in the SPL-o-gram.

As you scroll to the right the destination of the high-frequency sound moves to increasingly higher frequencies. When you change configuration you can see the movements of both the destination and source regions in the SPL-o-gram.

Strength*: The strength defines the level of the lowered signal at the destination region. Its level is independent of the original level of sound at the destination region.*

There are 7 strength levels (-6 to +6 dB in steps of 2 dB). By default, the strength is set at medium intensity (i.e. 0 dB). If in doubt, leave the setting at default. If time allows, find the preferred strength level of your patient by letting him/her listen to running speech while you adjust the strength.

Lowering the strength makes the high-frequency sounds more subtle

Increasing the strength puts more emphasis on high-frequency cues

High frequency bands: *The Speech Rescue algorithm is a copy-and-keep algorithm, which means that, by default, the Dynamo and Sensei SP hearing aids amplify the high-frequency sound when Speech Rescue is ON. With this functionality, you can choose to turn the gain in the high-frequency regions above the patient's usable hearing ON or OFF. See text for advantages and disadvantages of turning the high frequencies ON or OFF.*

ON *Default setting which preserves amplification of the high frequencies. It prevents restricting the patient's audible bandwidth in case of over-prescription. It may be the safer choice if the threshold readings of the patient's audiogram are poor, and may help some patients with environmental awareness.*

OFF *Cutting of the high-frequency bands can reduce internal perceptual distortion in some patients and increase the battery life of the hearing aid.*

Tuning the strength does not affect the overall output levels, and activating Speech Rescue will therefore not have any visual effect on the output of the added average speech spectrum (Normal Speech, Fig. 5a). To see the effect on high-frequency sound during fine-tuning of Speech Rescue, switch the signal type from "Normal speech" to "Speech sound – S" (Fig. 5a). The calibrated S snd SH stimuli were kindly provided by Dr. Susan Scollie at the National Centre for Audiology, Western University, London, Canada. These stimuli form part of the Western frequency lowering verification protocol. Download guidelines and .wav files here: http://www.dslio.com/?page_id=166

High frequency bands: ON or OFF?

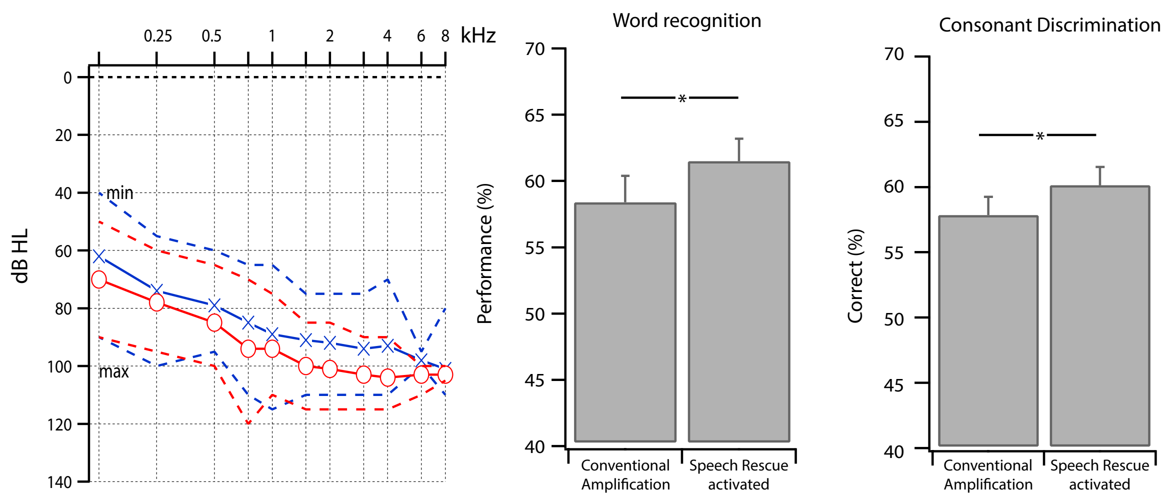
The Speech Rescue algorithm preserves the original signal of the high frequencies. This means that, by default, the Dynamo and Sensei SP hearing aids amplify the high-frequency sound above the maximum audible output frequency (MAOF) even when Speech Rescue is ON. Not restricting the output removes the risk that the patient's audible bandwidth is unintentionally limited in case a non-optimal configuration is selected. For some patients high-frequency amplification may increase musical and environmental awareness even if that part of the spectrum is perceptually unusable for speech. However, some studies have revealed that the speech perception performance of some patients decreases when giving high-frequency gain in the inaudible region (Baer et al., 2002; Ching et al., 1998; Vickers et al., 2001). In these cases, the clinician can simply turn down the gain above the MAOF by enabling the high-frequency band OFF button in the Speech Rescue panel (Fig. 5b, bottom panel). For infants and young children with sparse audiometric data, it is also safer to retain the wideband signal in order to stimulate the maturing auditory system.

The Benefit
– added value of high-frequency cues

Clinical tests have been run at Oticon Headquarters in Denmark on Danish adults with severe-to-profound sensorineural hearing loss. All test subjects required activation of Speech Rescue to get adequate audibility in the high frequencies, and Speech Rescue was prescribed to the default setting of the individual patient. Speech-in-noise testing showed a significant improvement in word recognition by activating Speech Rescue over conventional amplification. Furthermore, consonant discrimination performance improved significantly upon activation of Speech Rescue. It seems reasonable to assume that the improvement in overall consonant discrimination contributes to the improvements in sentence intelligibility in noise. The benefit was furthermore obtained without prior experience with the signal processing strategy, and so the effect of Speech Rescue was immediate.

The potential efficacy of Speech Rescue on both adult and paediatric test subjects with severe losses are currently (Nov. 2015) investigated at Boys Town National Research Hospital in Nebraska.

Figure 6. Word recognition and consonant discrimination performance



Objective: *The aim of the internal clinical test was to investigate the word recognition and consonant discrimination performance of adults with severe-to-profound sensorineural hearing loss using the Dynamo hearing aids with conventional amplification and upon activation of Speech Rescue.*

Design: Twelve Danish adults (average age 54 years) participated in the study. They were tested in an alternative forced choice consonant discrimination test in quiet. Nine consonants b, d, f, g, k, p, s, sh, t were used with "-atu" as the ending e.g. batu, datu, fatu…etc. Only the discrimination of the first consonant was scored. The target word, spoken by a female or male talker, was presented from in front of the subejct.

The word recognition was measured using the Danish matrix sentence material, Dantale II (Wagener et al., 2003). Target speech of 70 dB SPL (C) was masked by unmodulated noise positioned at +/- 110 and 180 degrees. At the beginning of the test the Speech Reception Threshold at 50% correct (SRT-50) word recognition with Speech Rescue Off was determined, and subsequently the conditions were tested at that fixed SNR, ranging from -5.7 to + 13 dB SNR across test subjects. The two conditions, i.e. Speech Rescue On and Off, were randomised for order of presentation. Power analysis prior to testing determined a need to repeat the above test twice, which was done at two visits, summing up to four repetitions for each condition per test subject.

Speech Rescue settings: Test subjects with an audiogram configuration (in at least one ear) that required frequency lowering to achieve audibility were recruited. The Speech Rescue configuration, based on the maximal audible output frequency, was prescribed by default for the individual. The strength was set to medium high (+2 or +4 dB) and the high frequency bands were ON.

Results: The results from both tests showed a benefit of activating Speech Rescue.

On average the word recognition score increases significantly by 3.1 % (Speech Rescue On vs. Off: 59.6 ± 1.7% vs. 56.5 ± 2.0 %, n = 12, p = 0.0098). By combining performance over all consonants in the Consonant Discrimination test across all test subjects, there was an average benefit of activating Speech Rescue of 2.3% from 56.1% without Speech Rescue to 58.4% correct consonant recognition with Speech Rescue activated. Analysing using a Mixed Model ANOVA, p=0.012, showed a difference in favour of Speech Rescue.

Rescue and Guard

Emerging research raises the question of the extent to which the type of wide dynamic range compression system (WDRC) in a hearing aid affects the benefit patients experience from enabling frequency lowering technology. To gain the full effect of frequency lowering requires the preservation of the temporal fluctuations of the lowered signal to the greatest extent possible. It is possible that traditional fast WDRC systems, which diminish the temporal contrasts and more or less smear the speech signal (Plomp, 1988), limit the transmission of otherwise useful frequency-lowered information. Therefore, Speech Rescue frequency lowering holds potential synergies when processed with the Oticon adaptive compression strategy, Speech Guard E. The signal path is designed so that, first, the Speech Rescue processor lowers the high-frequency sound, and then Speech Guard E amplifies the lowered signal. Because Speech Guard E preserves the details in the sound envelope, it "safeguards" the lowered speech cues from degradation due to lack of intensity contrasts in the output speech envelope.

First Rescue, then Guard

Preserving the integrity of the frequency-lowered information

To gain the full effect of frequency lowering requires the preservation of the temporal fluctuations in the amplified speech signal to the greatest extent possible. It is possible that traditional fast Wide Dynamic Range Compression (WDRC), which diminishes the temporal contrasts and more or less smears the speech signal (Plomp, 1988), limits the transmission of otherwise useful frequency-lowered information. Emerging research raises the question of the extent to which the type of WDRC in a hearing aid affects the benefit patients experience from enabling frequency lowering technology (Hariram et al., 20 15). It is well known that fast-acting amplitude compression in hearing aids can negatively affect speech recognition (Souza, 2002), and the perception of high-frequency phonemes is likely influenced by the form of amplification (Davies-Venn & Souza, 2014). Oticon has a long-standing tradition in the adaptive wide dynamic range compression, Speech Guard E. Speech Guard E has proven to be an amplitude compression scheme which better preserves the intensity contrasts in a speech signal for the benefit of both children and adults with hearing loss (Pittman et al., 2014). Therefore, Speech Rescue frequency lowering holds potential synergies when processed with Speech Guard E. The signal path is designed so that, first, the Speech Rescue processor lowers the high-frequency sound, and then Speech Guard E amplifies the lowered signal. Because Speech Guard E preserves the details in the sound envelope, it "safeguards" the lowered speech cues from degradation due to lack of intensity contrasts in the output speech envelope.

Perspective

Our brain integrates the stream of speech we hear over time and frequency. With severe-to-profound hearing loss, the loss of inner hair cells leads to a weak or non-existent connection to the auditory nerve. Sound of certain frequencies, often the high frequencies, cannot make its way up through the auditory network, and interpretation of high-frequency speech sounds by the brain is lost. Since the brain is shaped by what we hear, representation of these high-frequency sounds will gradually vanish from the neural networks along with the deterioration of high-frequency hearing. Through Speech Rescue technology, high-frequency sounds are moved to lower-frequency regions, which (again) allows the brain to respond to "high-frequency" sound and start making sense of these speech cues in the context of everything else the patient hears.

25 answers to Speech Rescue

1.	In which products is Speech Rescue available?	*Speech Rescue is available in the new Oticon super power hearing aids in all price points of Dynamo for adults and Sensei SP for children.*
2.	When should frequency lowering technology be used?	*Frequency lowering should only be used if high-frequency speech is not audible through conventional amplification.*
3.	How is Speech Rescue different from SoundRecover and Audibility Extender?	*Speech Rescue is unique because it uses a multi-layered lowering technique that overlaps copied segments from a wide region in the high-frequency input in order to present the information in a narrow region along the border of the severe-to-profound patient's usable hearing. With SoundRecover, sounds above a selected start frequency are compressed (i.e. the frequency spacing in a band is reduced) to fit within the audible bandwidth of the patient. Depending on the position of the start frequency and the degree of compression needed, the low-frequency spectra important for vowel identification are likely to be altered, at the risk of creating vowel confusion. Audibility Extender captures a smaller portion of the high-frequency spectrum and reproduces it at a lower spectral position. Speech Rescue also copies and keeps the original high-frequency sound, whereas for Sound Recover and for some variations of transposition the high frequency there is no output in the high frequencies.*
4.	Is Speech Rescue default ON or OFF?	*Speech Rescue is OFF by default for both children and adults. However, once activated an individual Speech Rescue configuration will automatically be prescribed.*
5.	For whom and how is Speech Rescue prescribed?	*Speech Rescue is made for people with severe-to-profound hearing loss. When activated Speech Rescue is prescribed to patients with a maximum audible output frequency (MAOF) below 6 kHz. The MAOF is defined as the highest frequency at which the patient can hear conversational speech with amplification.*
6.	How does Oticon determine the maximum audible output frequency for prescribing the Speech Rescue setting?	*The maximum audible output frequency calculation is part of the prescribed Genie settings. It includes the audiogram, the output level of the device, the rationale, as well as the average spectrum for conversational speech.*
7.	If the hearing loss is progressive, will Genie change the prescription?	*Yes, any change in the audiogram, which is great enough to result in a shift of the patient's maximum audible frequency, causes an automatic re-prescription of the Speech Rescue configuration.*
8.	What about asymmetric losses?	*The Speech Rescue settings are prescribed individually for each ear.*
9.	Why does Speech Rescue not copy all high-frequency sounds above the maximum audible output frequency and lower this?	*The design goal of Speech Rescue is to provide the patient with as much high-frequency information as possible. This means that, in principle, the source region should cover the entire speech spectrum that is unusable to the patient. However, packing too much information in the low and mid- frequency region likely makes it too dense and hence unusable to the patient. Because Oticon strives for the best sound quality and aims to provide the brain with the cleanest and most intact signal possible, the source region for all configurations covers a 3 kHz range (see further details on page 6).*
10.	Acclimatisation: How long does it take patients to get used to Speech Rescue technology?	*Perceptual adjustment to frequency lowering is likely very individual (Glista et al., 2012). Research done with frequency lowering technology generally allows for a six-week acclimatisation period (Ellis and Munro, 2015). The benefits observed with Speech Rescue on Danish adults (see results in the box, page 10) have been immediate, showing on average no requirement for time to adjust to the technology. Further investigations at independent research sites are ongoing.*

25 answers to Speech Rescue		
11.	Is it possible to activate/deactivate Speech Rescue independently for each program? What about the settings?	*Yes, programs where Speech Rescue is ON or OFF, respectively, can be set up in Genie to allow the patient to trial Speech Rescue in an extra program. However, you cannot make different programs with various Speech Rescue settings, e.g. a strong vs. a subtle setting.*
12.	Does turning the Speech Rescue ON cause an additional delay in signal processing?	*No.*
13.	What are the 10 configurations for Speech Rescue and why are there so many?	*A configuration is a pair of a source and a destination region. The source and destination regions are linked, and move in concert. Toggling between configurations with the Genie tool allows for movement of the lowered sounds in discrete steps. Oticon has designed 10 configurations to allow for high precision when fine-tuning the Speech Rescue setting to the individual patient's needs.*
14.	What is an ERB and how does that relate to the Speech Rescue configurations?	*The equivalent rectangular bandwidth (ERB) is a measure used in psychoacoustics, which gives an approximation to the bandwidths of the filters in human hearing (Wiki). The specific Speech Rescue settings complement the natural frequency selectivity of the cochlea (for detail, see page 6)*
15.	Does the destination region for Speech Rescue always have the same width?	*In Hz it is different, but in the ear's own logarithmic scale it is similar.*
16.	What is the strength of Speech Rescue?	*The strength defines the level of the lowered input signal at the destination region. You can call the strength the "How much do you want to hear that S?" button. The AVERAGE total output level does not change when the strength is turned up or down. This is because the high-frequency sound is first lowered, then added to any existing sound at the destination region and subsequently amplified to the level of the output defined by the rationale.*
17.	What are the consequences of increasing/decreasing the Speech Rescue strength?	*Turning the strength up will give more emphasis to the high-frequency cues; turning the strength down will make the high-frequency cues more subtle.*
18.	How should the audiologist find the appropriate strength of Speech Rescue?	*The goal when setting the strength is to balance the perceptual saliency of the lowered signal (that is, is it audible enough for the patient to hear it and to integrate it into the speech stream) and its distractibility (that is, is it so loud that it segregates out of the speech stream). It requires clinical judgment to find the preferred strength for the individual patient since it may depend on the configuration and severity of loss, the interaction with compressive amplification, and the patient's motivation and ability to cognitively handle the additional information provided by the lowered signal. If time allows, find the preferred strength level of your patient by letting him/her listen to running speech while you adjust the strength. If in doubt, leave the setting at default (in the middle position).*
19.	Why activate/deactivate the high-frequency bands in the Speech Rescue Genie Tool?	*Oticon believes that keeping the wide bandwidth amplification when using frequency lowering is the safer choice, in particular for children. There is always that possibility that some information can be extracted from the high frequencies. Thus, the high-frequency bands are on by default. Choosing to turn off the high-frequency bands may reduce internal perceptual distortion in some patients and will increase the battery life of the hearing aid.*
20.	What does Speech Rescue sound like?	*Connect headphones to your test box and try listening to it. Generally, normal hearing individuals find the sound of Speech Rescue quite subtle, only slightly increasing the lisp in speech. In studies done so far with hearing-impaired individuals, no negative perceptual effects on sound quality have been found.*

25 answers to Speech Rescue		
21.	Does the Speech Rescue Processor maintain the harmonics?	*It is important to preserve low frequency harmonics for speech quality, for perception of pitch cues, and for transmission of low-frequency speech cues. Therefore, Speech Rescue does not alter the natural relationship between the low-frequency harmonics in the destination band. In addition, 1600 Hz is the lowest possible frequency for the destination band in order to minimise interference with low-frequency harmonics during the occasional instances when high-frequency harmonics from the source region are simultaneously present. In addition, within each sub-region of the source region local harmonics are preserved.*
22.	Verification: How do I verify Speech Rescue using the test box e.g. the Verifit?	*Follow the guidelines developed by the PedAmp Lab at Western University: http://www.dslio.com/?page_id=166*
23.	How does Speech Rescue interact with Speech Guard E?	*Speech Guard E is Oticon's approach to provide gain and compression to the speech signal in a way that makes the speech signal audible but also preserves the details of the speech signal. Speech Rescue replicates speech information in the high frequencies and moves it down into the usable hearing range. Speech Guard will then take the lowered sound and place it within the narrow range of the patient in a way that fully preserves the lowered signal.*
24.	Why are some features disabled when Speech Rescue is ON?	*When enabling Speech Rescue significant resources are used within the instrument to drive this advanced algorithm. Thus, certain features are disabled to make way for Speech Rescue. This means that Transient and Spatial Noise Management (Dynamo only), Music Widening, Power Bass and Voice Priority i cannot run simultaneously. If Speech Rescue is On in one program, the features will be disabled in all other programs. A choice of feature priority for the individual patient is needed.*
25.	What clinical evidence exists for the Speech Rescue technology?	*The potential efficacy of Speech Rescue on both adult and paediatric test subjects with severe-to-profound loss is currently (Nov. 2015) being investigated at Boys Town National Research Hospital in Nebraska.*

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