WHITEPAPER
2019

Introduction to OpenSound Optimizer™

SUMMARY

Since the launch of Oticon Opn, Oticon has taken many new steps in how feedback is managed in the hearing aid and by the hearing care professional. However, up until this point, feedback management has been handled using a reactive approach to feedback, meaning that feedback is detected, and the system reacts to eliminate it using well-known measures.

OpenSound Optimizer is a pioneering new method of handling feedback. It is considered a feedback prevention technology now introduced by Oticon and it has positive ripple effects across the whole hearing aid experience in the form of increased fitting freedom, better target match and access to up to 30% more speech cues. Essentially, it enhances and optimizes the fitting in these areas.

This white paper covers the clinical aspects of introducing OpenSound Optimizer for adults and children. Furthermore, the results of two internal investigations into target match with and without the new feature are presented, and finally, a competitor study evaluating sound access, feedback annoyance, and sound quality.

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Clinical implications of feedback problems

Hearing aid users do not consider feedback a problem or link it to other problems, unless there is audible squealing or whistling coming from their hearing aid. But the fact is that feedback problems indirectly affect other areas of the fitting, such as not being able to match prescribed gain targets or having to opt for more closed acoustics, even if the user prefers an open fitting. The result is that the hearing care professional (HCP) has to make a compromise in the fitting. Either the user is underfit with less access to important speech cues, or the HCP is forced to choose a more closed dome or vent than preferred, causing discomfort or occlusion issues.

After the client leaves the office, feedback problems can manifest as gain reductions when the risk of feedback is high. High feedback risk typically occurs in dynamic environments, meaning situations where the feedback path changes because the person, for example, puts a hand to their ear, wears a hat, inserts/removes hearing aids, chews food, or talks on the phone. The amount of gain reduction is not transparent to the HCP, but complaints may come back to them: "my hearing aid sound fluctuates" or "I can't hear on the phone/while I'm having dinner".

How does OpenSound Optimizer (OSO) improve on these common problems for the HCP (target match, choice of vent, lack of fitting freedom) and the user (more speech access, more comfort, less strange hearing aid behavior)? First, let's understand the important term, loop gain.

What is loop gain?

Loop gain describes the level difference of a signal between the first time it enters the microphone and the second time it enters the microphone, after being amplified by the hearing aid and fed back to the microphone. This happens when the sound was able to leak back out of the ear (figure 1). Ideally, amplified sound re-entering the microphone is softer than the original sound entering the microphone. In this case, loop gain is negative and there is minimal risk of feedback. The more attenuation of leaked sound due to the hearing aid/dome/mold, the smaller the risk of feedback. A problem sometimes arises when a fitting is open, and a lot of gain is needed at high frequencies for a steeply sloping hearing loss. In this case, the sound re-entering the microphone is more intense than the original sound. This is a situation with positive loop gain.

Other examples include power fittings with very high gain and dynamic environments where sound leaving the ear is "trapped" back into the microphone (hand, wall, or phone close to ear). In positive loop gain situations, traditional feedback management systems actively try to reduce feedback using conventional methods such as phase inversion, frequency shift, and gain reduction. In Oticon Opn, the point at which no more gain is given has been 0 dB loop gain (Callaway, 2016), meaning just at the point where positive loop gain is a risk. In Oticon Opn S, OpenSound Optimizer will allow this limit to be set 6 dB into positive loop gain, thanks to new and patented technology.

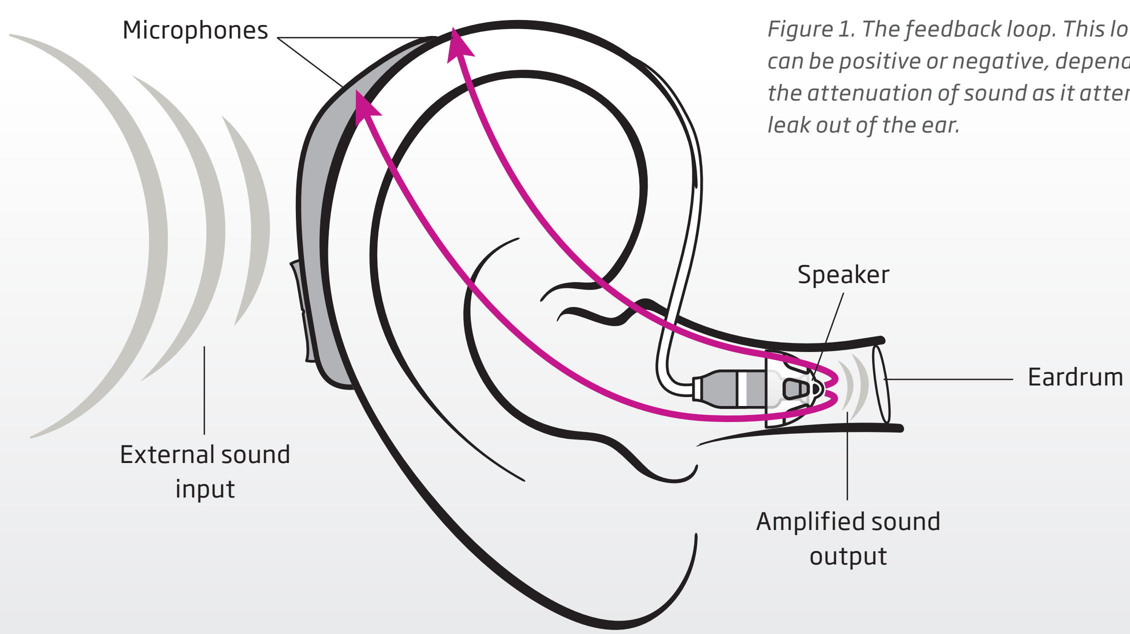

Figure 1. The feedback loop. This loop can be positive or negative, depending on the attenuation of sound as it attempts to leak out of the ear.

What is OpenSound Optimizer?

OpenSound Optimizer is a transformative and multi-patented technology, that controls Feedback Shield LX (Kuenzle & Guo, 2015, Kuriger et al, 2016). It is a new first line of defense against feedback build-up which allows the second line of defense, the updated underlying feedback management system, more time to be precisely deployed when it is needed. Figure 2 shows the OpenSound Optimizer as an added feature in the forward path of the hearing aid.

The OpenSound Optimizer uses spectro-temporal modulation (STM) to disrupt the positive loop gain and break a potential feedback build-up before it occurs. OSO is a proactive system that prevents audible feedback from occurring by monitoring the microphone input sound in 28 frequency channels, 56,000 times per second. A soft and non-intrusive STM is briefly applied in select frequency channels where there is a potential for feedback (Guo & Kuenzle, 2017, Guo et al, 2018) and this effectively stops feedback as we know it before it occurs. Figure 3 shows how OSO is precision-deployed only in a specific frequency range where feedback risk is detected.

Spectro-temporal modulations are modulations or patterns that change over time and across the 28 frequency channels. The modulations can be seen on a spectrogram as a striped pattern in certain frequency regions where dark stripes indicate areas of low energy (figure 3, middle). These stripes show that the output from the speakers is very briefly reduced. The low energy areas are extremely short (16ms) and they are followed by short periods (16ms) of fully restored gain. One low energy and one high energy period is equal to one 32ms cycle. It typically takes around 60ms for audible feedback to be fully detected and prevented in the system. In comparison, a 2010 study showed that it typically took premium hearing aids 500ms to eliminate audible feedback instability in dynamic environments (Spriet et al, 2010). These results are still relevant today because methods of eliminating feedback have not changed significantly.

OSO synchronizes a short burst of spectro-temporal modulation when any feedback build-up is detected in a specific frequency channel. Importantly, STM is *only* applied in the channels affected by feedback and *only* for the duration of risk. In other words, OSO is applied *minimally* and only when strictly necessary. Keep in mind that in between each ultra-fast low energy stripe, gain is fully restored, and this is one of the reasons why OSO preserves speech so effectively. In channels not affected by feedback, sound from the microphone passes through untouched, ready for amplification. If there is a dynamic feedback provocation next to the ear, such as a hand moving back and forth, the STMs will continue for the duration of the provocation. Once the feedback provocation has stabilized, OSO returns to stand-by mode.

STMs are extremely effective at breaking a feedback loop before it becomes audible, but the question arises whether STMs themselves are audible and if speech

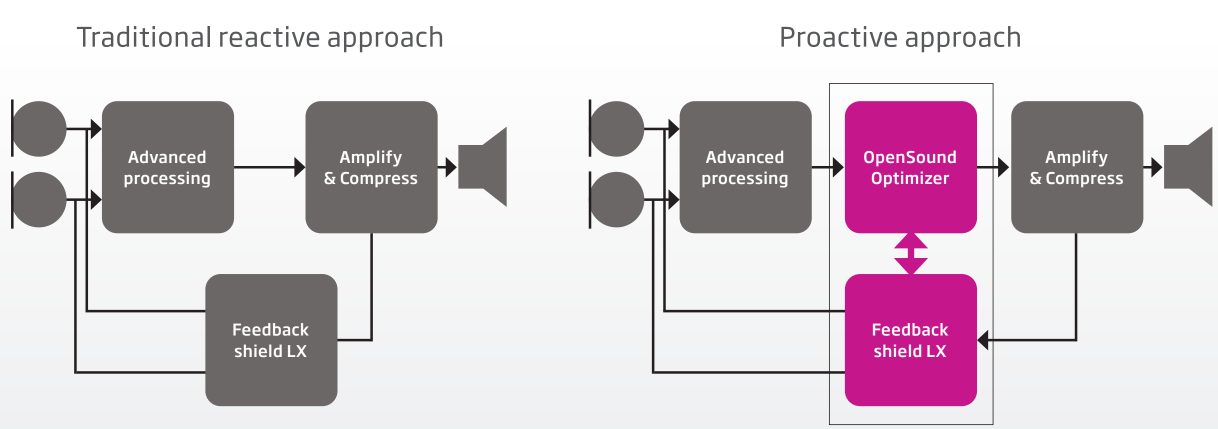

Figure 2. Prior to Oticon Opn S, Feedback shield LX was the feedback management system (left). Now, OpenSound Optimizer is added as feedback prevention technology (right)

perception and understanding are affected? STMs can at times be audible to hearing impaired listeners but even subtle STMs are highly preferable over disruptive and distracting traditional feedback whistling. There is ongoing research in the area of STMs showing that speech-like modifications to signals are even more difficult for people with hearing loss to hear than for normal-hearing people (Bernstein et al, 2013 and Bernstein et al, 2016). (For more information on the topic of STM audibility and annoyance, see results of competitor test below).

Additional benefits of OpenSound Optimizer

OpenSound Optimizer is first and foremost a feedback prevention technology. However, as you will see in the next section, this feature enables the ability to reach gain targets and move clients from being underfit by necessity to being matched to rationale targets. But what if the client does not have a problem with audible feedback and is not being limited in gain due to feedback management? What are the advantages of OSO for this client? There are two distinct advantages, one pertaining to dynamic situations and one pertaining to sound quality:

When using the word dynamic, it refers to situations where the feedback system in the hearing aid is being challenged in real-time by an outside source. This could be the person putting a phone up to their ear or giving someone a tight hug. Although the feedback system normally allows a high level of gain before any action is taken, these situations are different because they represent a sudden large change in the acoustic situation. Hearing aids are designed to eventually limit gain to an extent in these situations, but the level at which this happens differs greatly. OSO allows the hearing aids a 6 dB higher feedback limit (the limit at which no more gain will be given) than before. This is relevant for anyone with hearing aids because dynamic situations can challenge any fitting. A hearing aid is not doing a good job helping the user if gain is reduced every time the user picks up the phone, since they then won't be able to hear the person talking on the other end. *OSO preserves gain to a very high degree in stable and dynamic situations*.

The other advantage of OSO is improved sound quality. When a hearing aid is close to feedback instability (getting close to audible feedback), the sound quality is negatively affected because the response becomes more peaky and these peaks cause a ringing effect, also known as suboscillatory feedback (Dillon, 2012). *OSO contributes to a more stable system at higher gain levels and this leads to fewer incidences of sound quality degradation*.

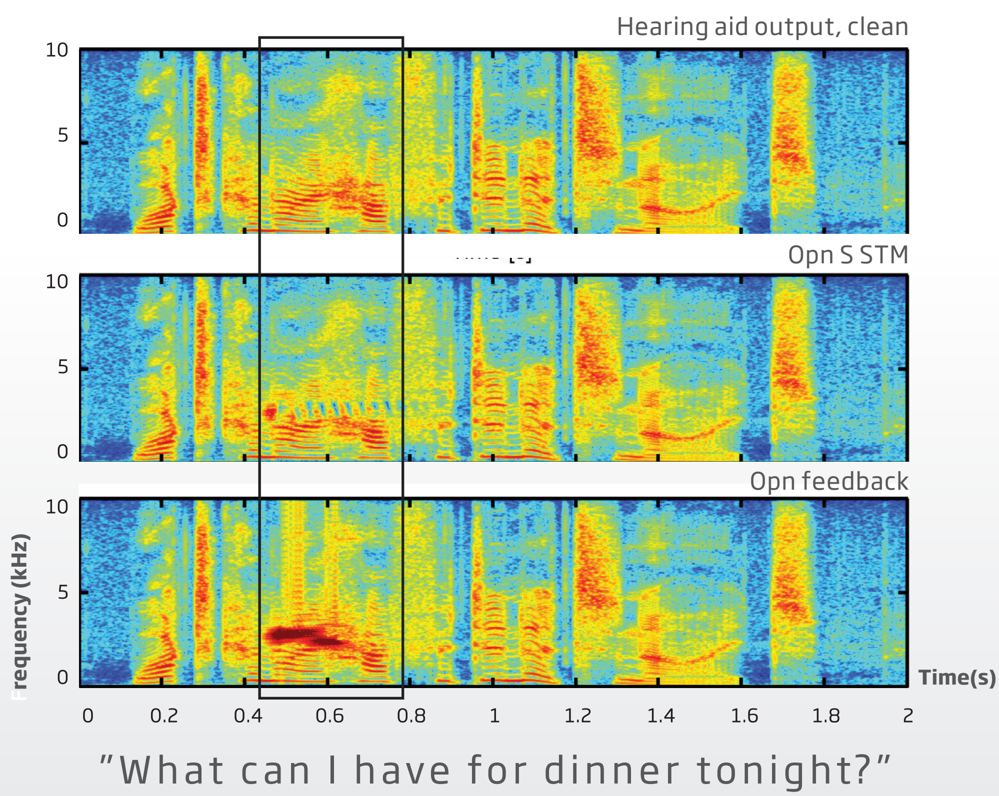

Figure 3. Three spectrograms showing spectral energy over time when a flat hand is placed close to the ear .

The black box highlights the hand on the ear. Feedback distortion is clearly visible across frequencies in the bottom spectrogram.

STMs are visible in the middle spectrogram in a narrow channel but the speech signal is otherwise preserved completely.

Hearing aid behaviors in dynamic situations (gain reduction, large frequency shifts) and when getting close to instability (sound quality degradation) are problematic because they are not easily discovered by the hearing care professional. The client may say, “All sounds seem to have a similar volume”, “sounds seem to get turned down” or “the sound quality is not as good as I expected” and the hearing care professional may not be aware that these complaints are the negative result of feedback management strategies. OpenSound Optimizer helps to minimize these behaviors resulting in a better listening experience for the client.

What happens when your client is underfit?

When an adult or a child does not get the gain prescribed to them, especially in frequency regions with many speech cues, it becomes harder to understand what is being said (Tomblin et al, 2015a, Tomblin et al, 2015b). Unfortunately, both adults, but also children are often unable to attain prescribed gain due to high feedback risk (Dyrlund & Lundh, 1990). For the person who is underfit by a given amount, there are negative consequences for audibility and speech intelligibility. Valente et al (2018) recently showed that when gain is 10 dB or more below NAL-NL2 prescriptive targets for high frequencies, speech recognition for soft speech (G50) decreases by 15%.

One way to get a good indication of speech understanding is by using the Speech Intelligibility Index (SII), first introduced in 1997 as part of the ANSI S3.5 standard. The SII is a single number which is shown as a proportion between 0 and 1 or as a percentage (0 to 100%) and it “is highly correlated with the intelligibility of speech” (ANSI S3.5, 1997), although it is not a direct measure of speech intelligibility. It basically measures how many speech cues are available to the listener, either aided or unaided. The SII is a weighted score, meaning that mid-frequencies with more speech information are weighted higher than very low and very high frequencies (Scollie, 2018). SII can be measured in quiet or background noise but in the clinic, it is typically measured in quiet using real-ear verification equipment.

Technical study 1 – Underfitting

At Oticon, we investigated how fitting Opn S to a prescribed target and then underfitting from a prescribed target would affect the SII for the NAL-NL2 and VAC+ rationales. The 6 dB underfit condition was chosen for two reasons. First, the common consensus as of 2018 (British Society of Audiology, 2018, Bagatto et al, 2011) is that a target is matched using real-ear verification if the measured gain is within +/- 5 dB, thus 6 dB is considered to be underfit. Second, OpenSound Optimizer enables 6 dB more gain, compared to the previous feedback strategy and if someone is not reaching target gain, OSO can provide this additional stable gain. Not all clients are of course underfit and not all underfit clients are underfit by the same amount, so this simulation should be viewed as a valid and real example of what can potentially be achieved.

Two conditions were simulated:

1. Opn S hearing aid with 2.4 mm micromold fit to prescribed NAL-NL2 and VAC+ targets at 1-6 kHz for five common hearing loss configurations as represented by standard audiograms N2, N3, N4, S1 and S2 (figure 4)
2. Opn S hearing aid underfit by 6 dB compared to prescribed NAL-NL2 and VAC+ targets for the same five hearing loss configurations.

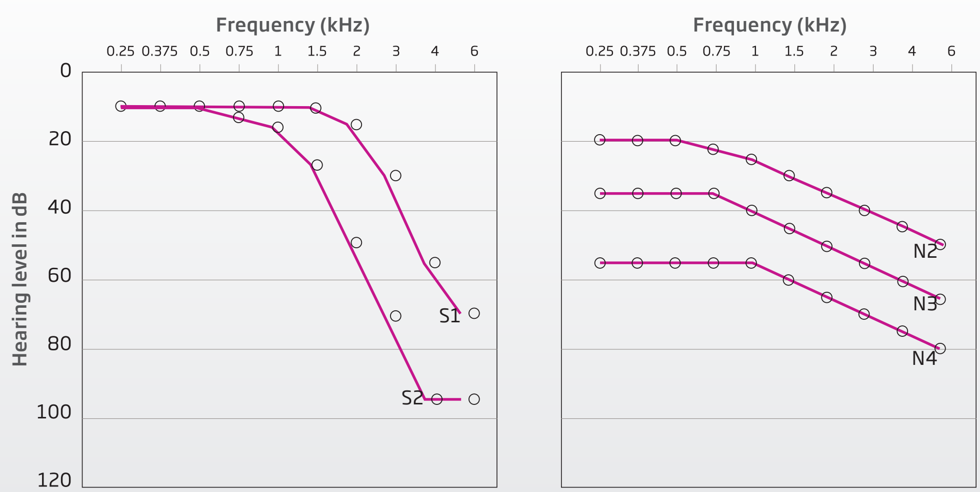

Figure 4. Five standard audiograms used in technical study 1. (Bisgaard et al 2010).

In order to compare to SII measurements that are typically carried out in the clinic in quiet conditions, the insertion gain simulations were carried out for speech at 62 dB SPL level with no noise masker. Measurements were also carried out with a noise masker at 62 dB SPL as stated in the ANSI S3.5 standard.

Results of this investigation showed that providing the prescribed target gain (in noise or in quiet), as opposed to being underfit by 6 dB gives access to up to 30% more speech cues for both the quiet and noise test condition. The amount of access to speech cues depended on type of hearing loss, where greater hearing losses (N3, N4, S2) generally saw greater improvements in access to speech than milder hearing losses (N2, S1).

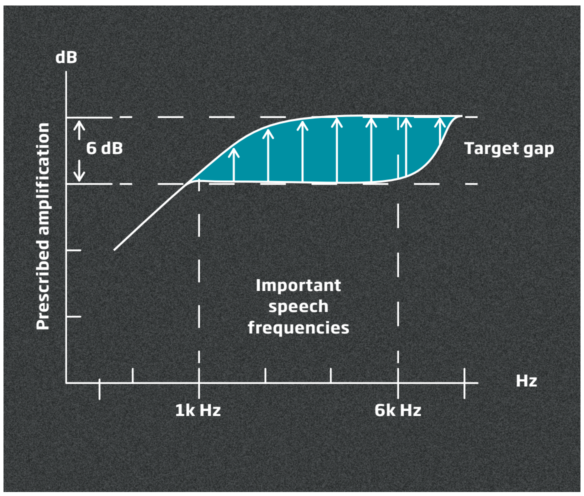

Figure 5. Simple illustration of added gain or headroom in Oticon Opn S, enabled by OSO.

What is the significance of adding up to 30% more speech cues? Small improvements in SII can have a great impact on the audibility of speech. The goal of the SII is not that every person with hearing aids now has 100% SII. Folkeard et al (2018) investigated what the normative ranges of SII scores are for adult hearing aid fittings when using DSL v5.0 targets. This way, clinicians can compare compare their clients' SII scores to the norm for pure-tone averages (PTA) across the range of hearing loss. For mild hearing loss, SII should be 75% or higher and then the percentage drops as the PTAs increase. It helps the clinician understand that for a high PTA, an SII of 50-60% is a good result. In the context of OpenSound Optimizer, access to more speech cues can thus make a big difference in a client's performance with hearing aids.

Technical study 2 – Oticon fitting accuracy

With the OpenSound Optimizer freeing up an additional 6 dB of gain, it made sense to investigate the effect this might have on initial fitting accuracy for Oticon Opn S hearing aids. In this investigation, fitting accuracy was defined as the percentage of fittings that can successfully match rationale targets using prescribed acoustics and prior to any fine-tuning.

The hypothesis was that OpenSound Optimizer in Opn S will enable greater first fitting accuracy than possible with Oticon Opn. Simulations were carried out, based on Genie 2 fitting data. The data included seven feedback analysis measurements and they were all fittings where 2.4 mm vents or open domes were prescribed (mild to moderate hearing losses). The hearing aids used in the simulations were Oticon Opn and Opn S with level 85 speaker units. The hearing aids were fit according to the Oticon VAC+ proprietary rationale.

The results of this investigation showed that for Oticon Opn, the fitting accuracy for this group of hearing aid users was 62%, prior to any fine-tuning. In reality, this means that for 38% of clients, some fine-tuning was needed to reach the VAC+ targets. For Oticon Opn S, the initial fitting accuracy rose to 84%. The added fitting flexibility provided by the OpenSound Optimizer in the form of 6 dB of additional available gain was the reason for the large improvement in first fit accuracy (figure 5). This shows us that the benefits of the OpenSound Optimizer go beyond simply eliminating audible feedback and feedback related artefacts and distortion.

Oticon and competitors

In November 2018, a competitor test was conducted to determine feedback performance among the six major competitors using the most recent premium products on the market at the time of the study. Feedback performance was evaluated on three parameters: Ability to match high gain targets between 1500-8000 Hz using the manufacturers' own open dome, feedback performance (presence and annoyance), and sound quality.

All hearing aids were programmed on the principle, "matched target, matched acoustics". All hearing aids were programmed with a modified standard audiogram, S2, corresponding to a steeply sloping mild to profound hearing loss configuration. This audiogram was chosen in order to stress the openly fitted hearing aids in terms of feedback performance. Real-ear measurements were conducted to verify NAL-NL2 gain target match. All six hearing aids were able to meet NAL-NL2 targets within +/- 2 dB between 1500 and 8000 Hz.

The hearing aids were placed in randomized order on a Knowles Electronics Manikin for Acoustic Research (KEMAR) and 23 normal hearing test persons were asked to rate feedback presence and annoyance for each hearing aid for five different dynamic feedback provocations (insert hearing aid, hand to ear, phone to ear, remove hearing aid, cupping in hand). The dynamic feedback provocations were done by the test leader on the KEMAR and the test persons listened to the provocations blindly using headphones. This served as the basis for the feedback performance parameter of the test.

To test sound quality, four recordings (two speech, two music) were made with each hearing aid as programmed using the matched gain method. Each normal hearing test person listened to these four recordings and was asked to rank the recordings by sound quality preference in a MUSHRA test setup.

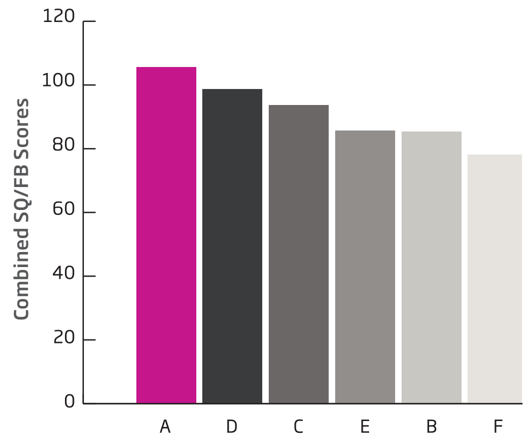

Figure 6 Combined feedback annoyance and sound quality measures for six competing hearing aids in order of performance. "A" is Opn S.

Feedback elimination often comes at a cost in the form of either gain reduction or sound quality degradation. In this test, all hearing aids were able to meet target gain, at least for non-dynamic environments. In terms of feedback presence and annoyance, it does not make sense to judge it in isolation, but rather factor in whether or not sound quality is also well preserved.
Combined results for feedback annoyance and sound

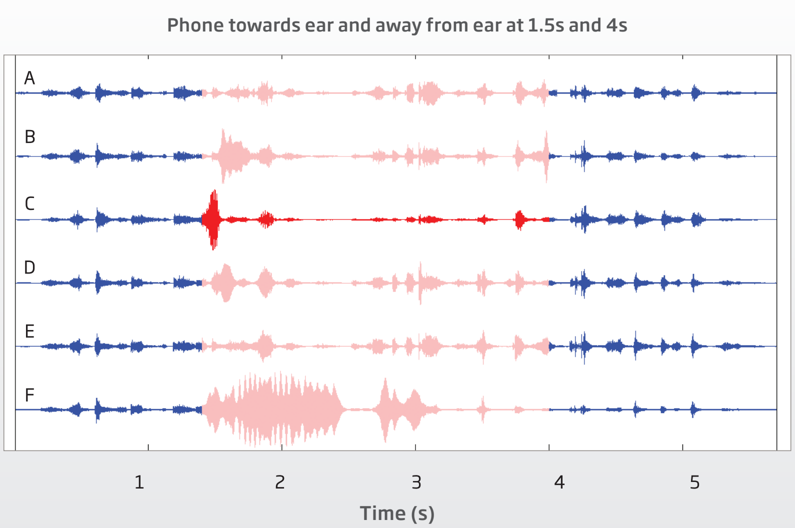

Figure 7. Speech amplitude over time for the six competing hearing aids. The reduced gain of competitor C is highlighted in red. The pink/red section indicated the hand to ear feedback provocation.

quality, are shown in figure 6. As visualized in the graph, Oticon Opn S preserves good sound quality while maintaining the lowest annoyance rating of all six HAs. Competitors D and C also performed well, however, competitor C employed high gain reduction for every dynamic feedback provocation and no gain equals no feedback. This also meant that competitor C gives little to no help when a person with a hearing aid is talking on the phone for instance. This is shown in figure 7 where the speech amplitude during a hand to ear provocation shows drastic reduction after an initial short distortion. Once the hand is removed, the amplitude normalizes. For competitor F, severe feedback occurs in dynamic situations such as a hand to the ear. It helps to show us that methods used to curb feedback in dynamic situations are often not transparent to hearing care professionals. In the case of C, the client may complain that they cannot hear well on the phone. The hearing care professional probably does not start by thinking that this is possibly a gain reduction caused by the feedback system.

OpenSound Optimizer in Genie 2

The OpenSound Optimizer is a hardware feature in the hearing aid and it is therefore not dependent on settings in the fitting software. However, it will be visible in Genie 2 as a new tool for the HCP. The goal with the introduction of OSO is that the HCP has to take as little action as possible in terms of feedback management. This is possible now because OSO handles dynamic feedback provocations proactively and puts the client at a lower risk of feedback, even if the HCP takes no action in the fitting software. As our internal technical investigation shows, the vast majority of fittings (84%) experience no heightened risk of feedback when fit to prescriptive targets using prescribed acoustics. Therefore, for most best practice fittings, there is no need to take any extra feedback management precautions. For the small group of fittings where feedback can still pose a risk, a new tool is introduced: the Unstable Gain Indicator (figure 8).

The Unstable Gain Indicator is a small symbol which appears when relevant in the status bar at the top of most screens within the Fitting part of Genie 2. The biggest change in the fitting software is that the feedback risk in the client's ear is measured in real-time. Once every second, the feedback risk in the ear canal is measured and the fitting software is able to inform the HCP if there is a problem. If the client puts their hand up to their ear at the fitting (slowly), or gain is increased by a lot, then it is possible to provoke the indicator to appear.

The hearing aids must be connected and unmuted for this ongoing measurement to take place which is why the indicator is not active during in-situ audiometry. The indicator appears when the gain exceeds +6 dB loop gain at any frequency in one or both ears. Importantly, a feedback risk does not influence match to gain targets. Target match takes priority and if matching target poses a risk, then the HCP is informed so they can make the choices that they find most appropriate for their clients.

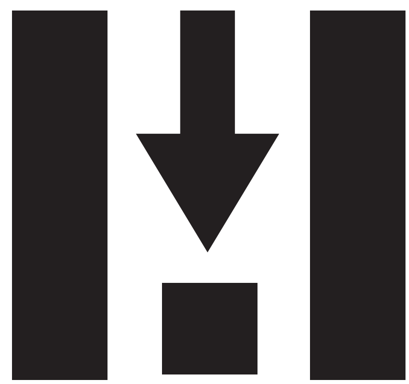

Figure 8 Unstable Gain Indicator symbol in Genie 2

The predicted feedback limits known from previous Genie versions can no longer be seen, but can be reactivated in Preferences if desired (not recommended). The reason these limits are gone is that the HCP need not even consider feedback management, unless the Unstable Gain Indicator appears. Until OSO, this has not been possible, since Feedback shield LX on its own is not fast enough to prevent feedback in its initial stages. The predicted limits show a limitation of gain that is no longer necessary to have. If a risk is indicated, the HCP is prompted to visit the Feedback Management tab in the left task pane, in order to run a feedback analysis and/or take other precautions.

The new OpenSound Optimizer in Genie 2 gives the HCP the freedom to fit hearing aids to their clients as they find most appropriate to be successful with hearing aids.

Conclusion

The new feature in Oticon Opn S, OpenSound Optimizer, is a technological and audiological newcomer that utilizes multi-patented Optimizer, is a technological and audiological newcomer that utilizes multi-patented methods of preventing audible feedback before it occurs. Not only does it prevent audible feedback from occurring, it enables more fitting flexibility for the hearing care professional because they can now focus on providing comfort in terms of more open fittings, or matching prescribed targets more easily. The hands-off implementation of the OpenSound Optimizer in Genie 2 means that for vast majority of fittings, the hearing care professional does not need to worry about feedback handling and in the situations where they do experience feedback issues, they have the tools to fix the issue easily and without compromise.

Two technical studies and a competitor study show that OpenSound Optimizer can provide access to more speech cues for those who have previously been underfit. For Oticon Opn S first fit target match with the VAC+ fitting rationale has improved from 62% to hearing aids, 84% for open dome fittings. For those clients who have not had feedback or target match issues, the OpenSound Optimizer gives more headroom for dynamic listening environments and better sound quality overall. Compared to competitors, Oticon Opn S outperforms other hearing aids and takes the lead with yet another technological break-through.

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