WHITEPAPER
2022

Oticon Own™ Evidence

ABSTRACT

This whitepaper presents the evidence behind the Oticon Own custom hearing aids. It covers the audiological improvements and BrainHearing™ benefits that are now available for custom users. This includes better speech clarity, more speech cues and reduced listening effort. The custom hearing aids are clinically robust and able to prevent feedback even in challenging situations. In addition, the custom styles have been the subject of continuous efforts to improve production, resulting in great audiology now in a smaller and more discreet form.

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Introduction

Our new Oticon Own custom hearing aids are built on the Polaris™ platform and include the latest audiological technology advancements, such as MoreSound Intelligence™ (MSI), MoreSound Amplifier™, and MoreSound Optimizer™ (MSO) – designed to give a superior sound experience. MoreSound Intelligence has already been shown to deliver better access to the full sound scene (Santurette, Ng, Juul Jensen & Man, 2020). Now these capabilities have been added to the Oticon Own custom styles. We tested the performance of MoreSound Intelligence in these new styles using output signal-to-noise ratio (SNR) measurements and pupillometry. MoreSound Optimizer, our feedback prevention technology, was also tested and compared to top competitors for clinical robustness in a challenging situation.

Speech clarity in noise

Background

"Hearing friends and family in noise" was recently rated the most desirable hearing aid attribute by consumers, with more than 88% rating it as "very important" or "extremely important" (Manchaiah et al., 2021). To support hearing in noise and help users follow and participate in conversations, modern hearing aids apply advanced signal processing techniques to preserve access to speech and attenuate unwanted noise in complex listening environments. The newest Oticon hearing technology, built on the Polaris platform, introduced MSI to address this need for enhanced contrast between meaningful sounds and the background, using a novel sound processing approach based on the learnings of an embedded Deep Neural Network (DNN) trained on millions of real-life sound scenes (Brændgaard, 2020a,b). This innovative approach was proven to outperform previous directionality and noise reduction techniques by providing a larger contrast between speech and noise in complex listening situations (Andersen et al., 2021; Santurette et al., 2021). Several research studies showed that such technical improvements translated into important BrainHearing clinical benefits for users, with MSI providing access to a clearer full sound scene at early stages of brain processing, thereby enabling an easier focus on the sounds of interest, improving speech understanding and memory recall, and reducing listening effort (Alickovic et al., 2021; Santurette et al., 2020; Murmu Nielsen & Ng, 2022).

Such benefits of MSI were observed in Oticon More™, for which the hearing aid microphones sit behind the ear. But can MSI also outperform our previous technology when used in Oticon's latest Polaris based custom hearing aid, Oticon Own? To answer this question, we compared the output SNR provided by Oticon Own with MSI to that provided by our previous generation of custom hearing aids, Oticon Opn™ in-the-ear (ITE) hearing aids. The output SNR is a well-established measure for quantifying a hearing aid's performance (Hagerman & Olofsson, 2004; Naylor & Johannesson, 2009; Husstedt et al., 2021). For a given sound scene, a large output SNR indicates a large contrast between a sound of interest such as speech and unwanted background noise, meaning that the brain has more access to the speech in the presence of noise. In complex listening situations, a large enhancement of the output SNR by the hearing aid is thus desirable.

Method

To estimate output SNR, we reproduced an ecologically valid speech-in-noise sound scene in our sound studio (Figure 1). The speech signal was taken from the

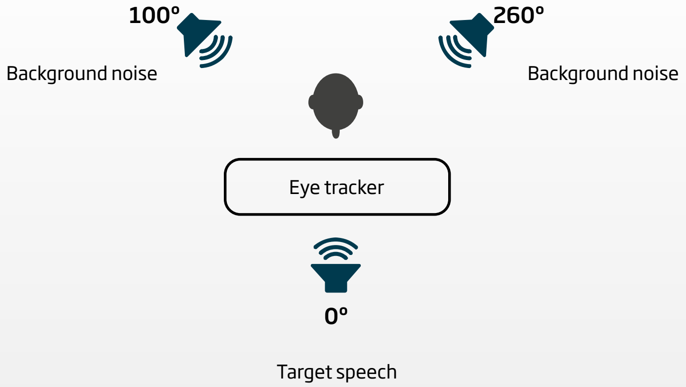

Figure 1: The test setup for SNR output measurements and pupillometry measurements with a target talker from the front and masker talkers. Note that the eye tracker is only used in pupillometry measurements. Background signals each presented combinations of a single interfering talker and speech-shaped noise.

international hearing-in-noise-test (HINT) corpus (Joiko et al., 2020) with a male talker played back from the loudspeaker located at the front. Background signals were played back from the sides at 100 and 260 degrees azimuth. Each of them consisted of interfering speech from a single male talker mixed with speech-shaped noise (SSN). The level of the target speech was set to 65 dB SPL. The level of the noise masker was set to 60, 65, 70, or 75 dB SPL, corresponding to simple, moderate, complex, and very complex hearing-in-noise situations, respectively.

A head-and-torso simulator (HATS) with either Own or Opn ITE hearing aids on both ears was placed in the center of the loudspeaker setup. These dual-microphone hearing aids were fitted with MSI in Own and OpenSound Navigator™ (OSN) in Opn, turned either on or off. Own and Opn were programmed to use MSI with Neural automatic and OSN with Open automatic settings, respectively. Two highly sensitive microphones placed at the end of the HATS' ear canal recorded the output signal from the hearing aids. To ensure the recorded sound was reflecting hearing aid processing, custom ITE molds for HATS with no vents were used. The gain in the hearing aids was provided for a moderate hearing loss and based on an N3 standard audiogram (Bisgaard et al., 2010) using the NAL-NL2 rationale (Keidser et al., 2011). The output SNR was calculated by applying the phase-inversion method by Hagerman & Olofsson (2004). The calculated SNRs in each frequency band were weighted with band importance factors for speech understanding by following the standards from the Speech Intelligibility Index (SII, ANSI S3.5-1997). Note that this standard specifies how to calculate SII both in quiet and in noise. Here we used the calculation for SII in noise. Therefore, the values reported below should not be compared to clinical norms for SII in quiet typically indicated by clinical verification equipment. The SII-weighted output SNRs were calculated and are reported relative to the input SNR, such that graphs show the SNR enhancement provided by the hearing aids.

Results

Figure 2 shows the SNR enhancements provided by Own and Opn in listening situations ranging from simple (input SNR of +5 dB) to very complex (input SNR of -10 dB). We can very easily visualize that Own provides extra SNR benefit compared to Opn. As the complexity of the situation increases, the user will need more help, which is why both MSI in Own and OSN in Opn provide increasingly greater SNR enhancement. At the same time, the extra SNR benefit provided by Own compared to Opn also becomes larger and larger. This illustrates that MSI in Own, with its DNN-based sound processing, clearly outperforms OSN in Opn in complex situations, providing additional contrast between the speech and the background to the user, by up to 2.3 dB, corresponding to a 25% improvement in speech clarity in the very complex situation.

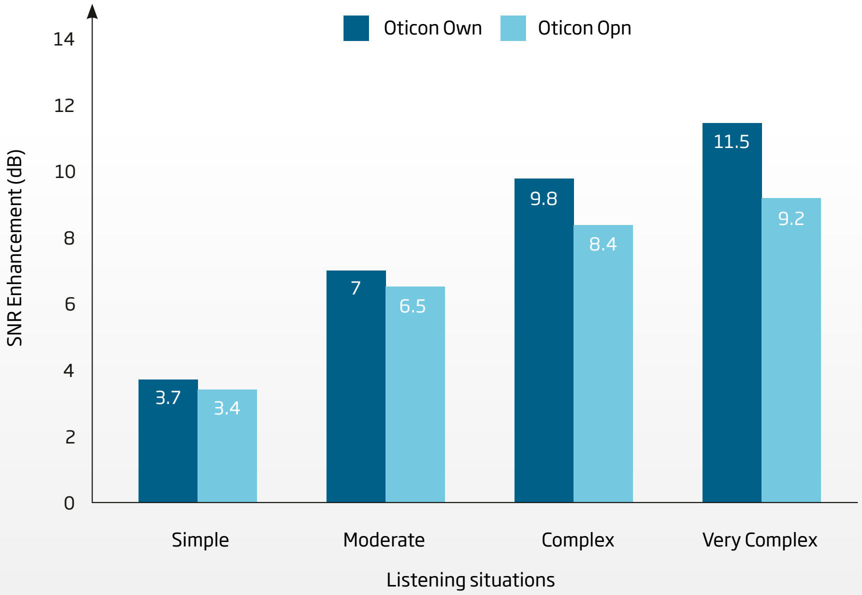

Figure 2: SNR enhancement (output SNR relative to the input SNR) provided by Own with MSI Neural automatic and by Opn with OSN Open automatic, in various listening situations with input SNRs of +5 dB (Simple), 0 dB (Moderate), -5 dB (Complex), and -10 dB (Very complex). Note that these results were obtained with custom hearing aids with two microphones and that the observed benefit may not be as large in hearing aids containing only one microphone.

The speech intelligibility index (SII) is another standard measure that quantifies the proportion of audible and usable speech information for a listener, ranging from 0% to 100%. We calculated the SII from the output SNR recordings obtained above with the phase-inversion method of Hagerman & Olofsson (2004), by following the procedure defined in the ANSI S3.5-1997 standard and taking the hearing thresholds of a standard N3 audiogram (Bisgaard et al., 2010) into account. This way we could estimate and compare the amount of speech cues that MSI in Own and OSN in Open custom devices provide to the user.

Figure 3 shows the calculated SII values in the complex and very complex situations, when MSI in Own and OSN in Opn are turned off, and when MSI in Own and OSN in Opn are turned on. In the complex situation, both Own with MSI off and Opn with OSN off yield the same SII value (24%). Own provides an additional 27% access to speech cues with MSI on, giving an extra 5% benefit compared to Opn with OSN on. In the very complex situation, both Own with MSI off and Own with OSN off yield an SII of 10%. Own provides an additional 32% access to speech cues with MSI on, giving an 8% extra benefit compared to Opn with OSN on.

Note that in similar complex speech-in-noise situations, the SII calculated for normal-hearing thresholds was found to lie around 40-50% (Santurette, Xia, Cosima, Ermert, and Man Kai Loong, 2021). The SII values obtained with MSI on in Oticon Own fall within the same range.

Conclusion

In summary, comparing the performance of Own and Opn dual-microphone custom hearing aids, we found that the DNN-based sound processing of MSI in Own provided more contrast between the speech and the background than OSN in Opn in complex listening situations. This also led to more speech cues being accessible by users when using MSI in Own compared to OSN in Opn. For users, this means better support when following conversations in busy environments.

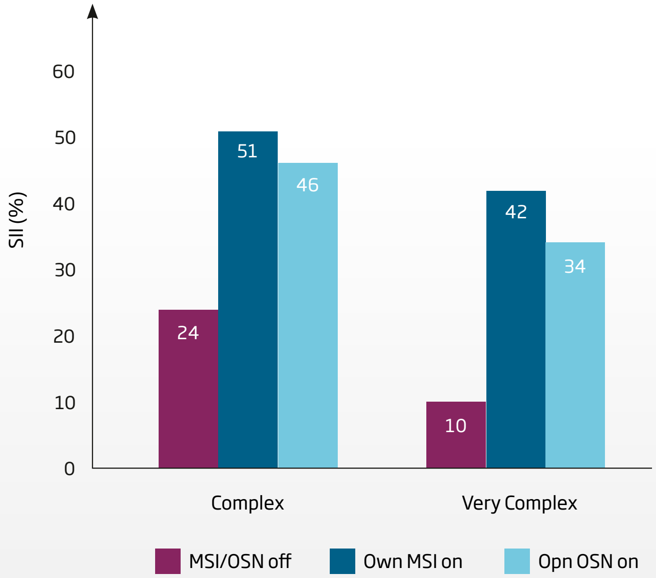

Figure 3: The calculated Speech Intelligibility Index (SII), quantifying the amount of accessible speech cues, in complex and very complex listening situations when MSI in Own and OSN in Opn are turned on vs off. Note that these results were obtained with custom hearing aids with two microphones and that the observed benefit may not be as large in hearing aids containing only one microphone.

Listening effort in Own

Background

The ability to engage in speech communication under less-than-optimal conditions is a primary challenge for people with hearing loss but contains multiple aspects. The difficulty in purely encoding what is being communicated and engaging in a social scene may be viewed as the first and foremost target for hearing rehabilitation efforts. However, the load on cognitive resources such as attention and memory may lead to fatigue, even in the case of aided hearing. From the perspective of the hearing aid user, the mental effort invested in listening may be as challenging as the ability to perceive speech information (Pichora-Fuller et al., 2016).

Cognitive exhaustion under challenging listening conditions is commonly reported by individuals with even mild hearing loss (Hornsby & Kipp, 2016). Research within the past decade has linked this experience of effort with objective, physiological measures. Monitoring the eye's pupil response reveals that cognitive effort in encoding even a single sentence may impact dynamic changes in pupil size (Ohlenforst et al., 2017). Any listening task will thus produce a dynamic change in pupil size, indicated by peak pupil dilation (PPD), that increases progressively with task difficulty. If a sentence is presented in noise or otherwise is ambiguous to the listener, or if the listener has hearing loss, encoding the spoken content requires more effort. Higher effort will produce a relatively larger PPD than lower effort. PPD is thus a practical tool for measuring cognitive demands in listening.

Method

To study the effect on listening effort of MSI in Oticon Own, thirteen experienced hearing aid users with symmetrical, sensorineural mild to moderate bilateral hearing loss were fitted with Oticon Own dual-microphone hearing aids with MSI On or MSI Off in random order. With each condition, PPD was recorded while participants completed a speech-in-noise test, in the setup described in the previous section, that required them to listen to a series of sentences and, after each presentation, repeat the sentence as accurately as possible. The target speech signal was presented frontally, while background signals combining interfering talkers and noise sources were presented from two background positions (see Figure 1 for setup). Before the test phase, participants were trained with 20 sentences to ensure that the task was understood. During testing, participants went through 25 sentences with each condition. Speech reception was indicated by the proportion of correctly repeated sentences.

Results

For both conditions, speech reception reached very similar, high levels (Oticon Own MSI On: 98%, Oticon Own MSI Off: 97.3%), suggesting that both conditions efficiently supported encoding of speech.

However, PPD differed across the two conditions, with Oticon Own with MSI On reaching lower pupil dilation peaks than Oticon Own with MSI Off, a difference that was statistically significant (p = .0275). Lower PPD indicates that less cognitive effort was required for the speech encoding task (Ohlenforst et al., 2017).

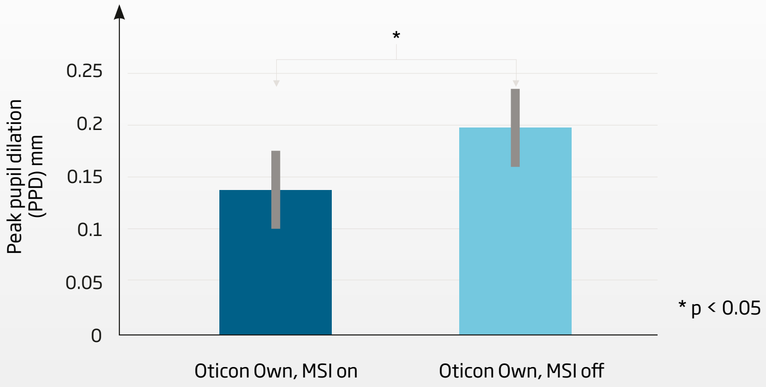

Figure 4: Listening effort indicated by peak pupil dilation (PPD) effort during a speech recognition task. Bars represent mean PPD in each condition. Error bars represent standard error of mean.

In summary, the two conditions provide users with similar support for speech recognition. However, the PPD measurements revealed that the user would need to invest less cognitive resources with Oticon Own to achieve the same listening performance.

Comparing the ability to accurately perceive speech and the cognitive load required to do so revealed interesting similarities and differences between the two conditions. Both conditions provided users with similar, high levels of support for speech reception. Yet this performance was achieved at different costs in cognitive resources, observable in as few as 25 sentences. Generalizing this pattern to extended listening, a larger use of cognitive resources can be linked to higher degrees of listening effort, which may hasten fatigue (Ohlenforst et al., 2017). This further suggests that users engaging in prolonged and more complex listening scenarios, such as dinners or family gatherings, may experience a similar pattern: high support of speech reception is offered by both conditions, but with MSI, less listening effort is required. In turn, this may offer the user the benefit of a longer and more effortless involvement in acoustically demanding environments such as social activities.

Preventing feedback with MoreSound Optimizer™

Background

With the Polaris platform, we now have MSO in our custom options. MSO is a feedback prevention strategy that uses a patented modulated breaker-signal feature, Spectro-Temporal Modulation, to prevent audible feedback. Preventing feedback is important because it pollutes the output of the hearing aid. Audible feedback is a major obstacle for hearing aid use (Kochkin, 2007) and a key factor associated with hearing aid dissatisfaction (Abrams & Kihm, 2015), making effective feedback prevention a crucial part of the signal processing.

To investigate how our hearing aid behaves when we challenge the feedback system, we completed two investigations, an objective clinical robustness test and a subjective feedback annoyance test. We fit Oticon Own to a hearing loss providing a high level of gain and exposed it to a dynamically challenging situation to see how it behaves when pushing it to the limit. Furthermore, we wanted to compare the behavior to how top competitors handle the same situation.

Objective clinical robustness test

Methods

In this test, we made a comparison between Oticon Own and two other manufacturers, competitor 1 and competitor 2. All hearing aids were matched on closed acoustics and similar fitting level.

To reach a gain-matched foundation we used the Audioscan Verifit2 test box. The hearing aids were gain matched to DSL v5 targets for a modified standard audiogram S3 (Bisgaard et al., 2010), which is a steeply sloping hearing loss; see Figure 5. The hearing aids were fit with this challenging moderate-severe hearing loss, which is still in range of the fitting level of all hearing aids. As the baseline for gain-matching, we used the Oticon Own Invisible-In-Canal (IIC) matched to target in the frequency range from 0.5-8 kHz by +/- 2 dB in the

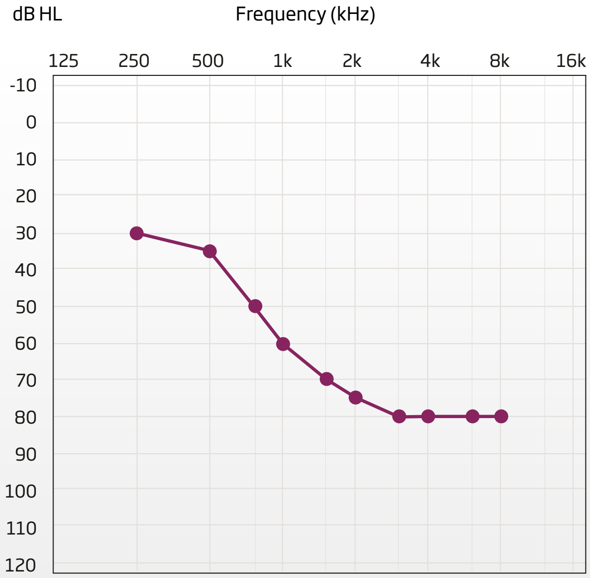

Figure 5: Steeply sloping modified S3 standard audiogram

test box. With the gain-matched custom hearing aids, we tested the behavior across frequencies by using Real Ear Aided Response (REAR) with the International Speech Test Signal (ISTS) on the head mannequin CARL (Clinical Assistant for Research and Learning). As a baseline, we did a standard REAR measurement, where all hearing aids were checked for similar insertion and response by measuring the unprovoked baseline to ensure they still had a similar starting point (within +/- 5 dB from one another). Then we proceeded to do a provoked REAR, which involved dynamically challenging the hearing aid by holding a hand up to the ear. The use of REAR tells us how the response fluctuates across frequencies as perceived in the ear, or internally. Fluctuations can indicate audible feedback. This was the case for the two competitor hearing aids, which had audible feedback problems during the measurement when dynamically challenged. Furthermore, to confirm indications of feedback from the provoked REAR, we analyzed sound recordings from the produced feedback while placing the hand at the ear. These recordings were done with a microphone by the ear, and as such, how it may be perceived externally.

Results

Figure 6 shows the frequency analysis of the sound recordings and illustrates the behaviour of the hearing aid output in quiet across frequencies for Oticon Own, competitor 1, and competitor 2, respectively. When dynamically challenged, both competitors produced audible feedback. For competitor 2, this occurs around 2.5 kHz and for competitor 1, audible feedback occurs at multiple frequencies, and especially around 1.5 and 2.5 kHz. In contrast, Oticon Own did not have audible feedback, meaning this is a clinically robust solution in this dynamically challenging situation.

Subjective feedback annoyance test

Methods

In this subjective investigation, test participants rated the annoyance of the sound output. For this test, we used the same hearing aids as in the objective test with the same gain-matched settings for Oticon Own, competitor 1 and competitor 2.

The test included 20 normal-hearing test participants. It was a single-blinded, randomized study where the

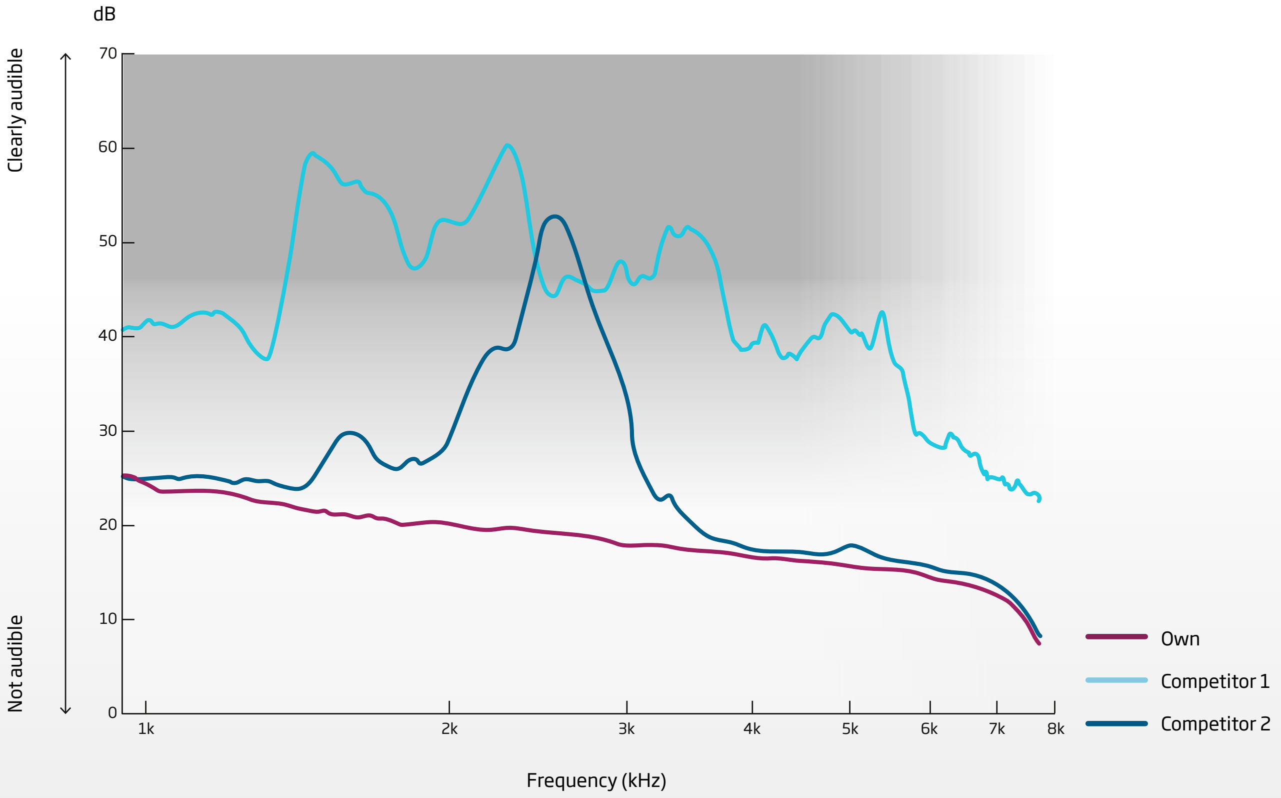

Figure 6: Frequency analysis of the output in quiet from the hearing aids when dynamically challenged for Oticon Own, competitor 1, and competitor 2, respectively. Indicate both frequency and audibility of feedback occurance.

hearing aid manufacturer was unknown to the test participant. While holding the hearing aid in the hand, each test participant was asked to cup it several times to see how it behaves. They were allowed to manipulate the hearing aids to find out how easy each is to provoke. Based on that experience, they were asked to rate the annoyance of this specific sound from the given hearing aid on a visual analog scale, where one end was labeled as not annoying and the other end as very annoying. For a performance comparison between devices, they were asked to rank all three hearing aids on annoyance.

Results

Based on the marking of the scale, the ratings were converted to percentage numbers from 0-100 %. Figure 7 shows the result of the annoyance rating. The average rating for Oticon Own, competitor 1 and competitor 2 was 14.4 %, 55.7 % and 62.3 %, respectively. Oticon Own is rated highly significantly better compared to competitors ($p < 0.001$). While competitor 2 is rated slightly higher on the annoyance level compared to competitor 1, this difference is not statistically significant. The rating results are also reflected in their ranking. Here, Oticon Own was the best-ranked hearing aid for 20 out of 20 test participants, showing a clear preference on performance compared to competitors 1 and 2.

Conclusion

These two studies were designed to show how clinically robust Oticon Own is when placed in a challenging situation, as well as how it effectively eliminates feedback annoyance as a complaint from hearing aid users.

In the objective test, all hearing aids were put under technological stress. However, when the hearing aids were in this situation, Oticon Own was simply more clinically robust than competitors. This was clear as it did not produce audible feedback where competitors did.

This was further supported in the subjective test where the Oticon Own annoyance rating was excellent compared to competitors, and highly significant in terms of being much lower. As a matter of fact, 20 out of 20 test participants ranked Oticon Own as their preferred choice when asked to rank performance.

Discreetness and production optimisation

In addition to strong audiology, our current custom styles reap the benefits of the combination of state-of-the-art machinery, miniaturization techniques, training protocols and great craftmanship. All of the efforts into continuous improvement and optimization have produced great results for the custom hearing aids and reduction in size.

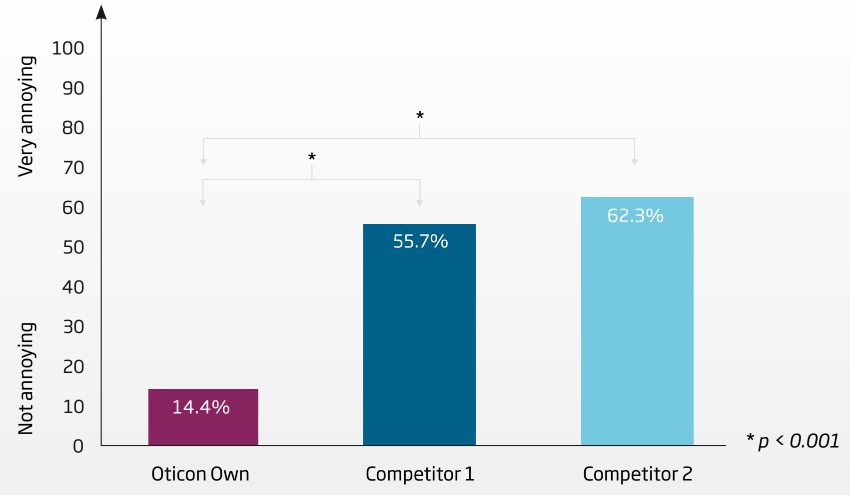

Figure 7: Annoyance rating of sound produced by hearing aid when dynamically challenged in percentage for Oticon Own, competitor 1, and competitor 2, respectively.

Firstly, it means that 9 out of 10 of our IICs are truly invisible. Modeling and invisibility assessment is performed by an experienced modeling operator, who assesses whether the hearing aids are truly invisible by being placed hidden behind the tragus. This assessment is an ongoing evaluation done on a global scale to ensure the consistency across production sites, which enables us to confidently claim that for 9 out of 10 ears the IIC is truly invisible.

Secondly, the efforts of optimization have allowed for more flexibility in the integration of Bluetooth® Low Energy technology in our In-The-Canal (ITC). This flexibility in production means that hearing aids can be built smaller so that more patients can be fit with custom hearing aids offering the possibility of connectivity.

These size optimizations are done without compromising on the audiology and connectivity options as they apply to these individual styles, so we continue to deliver strong audiology and connectivity in a smaller package.

Summary

In Oticon Own, we now have custom hearing aids on the Polaris platform, allowing for the audiological improvements that come from commitment to audiological features. This includes MSI, which provides clearer speech in noise and improves access to speech cues while showing a reduction in listening effort. The introduction of MSO provides the user with a clinically robust system to prevent feedback while handling the dynamic world in which we live. Our audiological improvements are accompanied by optimization in our production, allowing for smaller hearing aids and more options for more people.

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Notes

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