OpenSound Navigator™ for Ponto

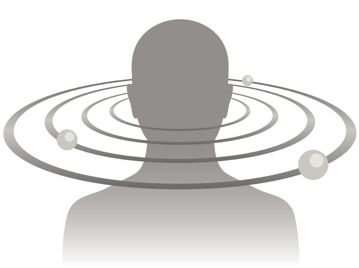
WHITEPAPER

Introduction and evaluation of ground-breaking technology for bone anchored hearing systems

ABSTRACT

OpenSound Navigator™ is a ground-breaking speech-enhancement algorithm that preserves speech and reduces noise in complex sound environments. This integrated directionality and noise reduction system is a Multi-Speaker Access Technology, which was first introduced in Oticon Opn in 2016, and it is now available in the Velox S-based Ponto 4. The first part of this whitepaper describes the OpenSound Navigator technology and its key features.
OpenSound Navigator operates as a holistic system that handles all sound environments from the quietest to the noisiest, by selectively reducing the dominant noise sources while preserving speech in all directions. OpenSound Navigator adapts seamlessly without modes or mode switches. The speed and accuracy of OpenSound Navigator enables selective noise reduction, while offering 360º access to speech sounds opening up to new possibilities for many audiological benefits.

The second part of the whitepaper presents the outcomes of the first clinical study on Ponto 4, investigating the benefits of this ground-breaking technology for bone anchored users. The outcomes of this study showed that the OpenSound Navigator feature not only significantly improved speech-in-noise performance in the laboratory, but was also preferred by the majority of users in real-life sound environments with multiple talkers and/or background noise.
By combining speech intelligibility measures with subjective perception in real-life listening scenarios, this study shows the benefits of the OpenSound Navigator technology, which can support users in the varying and complex listening situations of everyday life.



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Introduction to OpenSound Navigator

The daily challenge of communication in noise

Navigating and communicating in complex acoustical environments is both one of the main challenges and the largest unmet need of people with a hearing impairment (Gatehouse and Akeroyd, 2006).

Communicating in a complex environment can be so demanding that some people with a hearing impairment may choose to avoid the most challenging environments and limit their social participation (Crews and Campbell, 2004). To make sense of a complex sound environment with a mix of both speech and noise, we use a cognitive process to selectively focus our attention on a sound of interest and put other sounds in the background. However, we might want to switch our attention from one signal to another. Therefore, access to all sounds enables us to efficiently navigate a complex sound environment and switch attention when the need arises, e.g., when we hear our name called out (Shinn-Cunningham, 2008, Shinn-Cunningham and Best 2008).

Traditional technology

Current technology in bone anchored sound processors supports communication in complex sound environments creating a focus towards the front of the user, while attenuating noise and other sounds around the user. This is achieved through the use of directional modes and mode switches or categorisation of the environment and a resulting 'set' of settings. The signal processing typically consists of two independent processes: directionality and noise reduction. Both technologies have been used and improved over many years. Directionality systems are well known for improving speech understanding in noise (e.g., Mejia et al. 2015). However, the effectiveness of these technologies in everyday environments, i.e. outside laboratory conditions, has also been criticised (e.g. Bentler 2005). The speed and the accuracy of human sound localisation was also shown to be negatively impacted by directional systems (Brimijoin et al. 2014). Arguably, the limitation of current technology is due to the fact that it reduces context, i.e., it removes information that the brain naturally uses to navigate complex sound environments. Another drawback of current technologies lies in the above-mentioned use of modes or categories. Fast changes between modes can introduce artefacts or distortion, while very slow changes cannot adapt to changing environments.

So, how can a speech-enhancement algorithm better support communication in the dynamic and complex sound environments that we encounter in everyday life?

Such a technology should ideally not only remove noise, but also preserve important speech information coming from all directions to enable the users to navigate the sound scene, follow different talkers of interest and switch between them when relevant.

OpenSound Navigator supports this natural process by maintaining access to all talkers while effectively reducing the noise in complex environments – without isolating the user. We therefore call it a Multiple Speaker Access Technology (MSAT). This has been enabled by several technological achievements and is protected by international patents (Kjems and Jensen, 2015). The MSAT technology is implemented in the new feature, OpenSound Navigator (Le Goff et al., 2016a).

OpenSound Navigator

OpenSound Navigator (OSN) replaces conventional directionality and noise reduction systems. These two technologies still exist in an advanced version in the OSN feature, but they are used in a very different way. As shown in Fig. 1, the noise reduction module, here called Noise Removal, is placed after the directionality, here called Balance, and importantly, both modules receive a spatially informed noise estimation realised by a multi-microphone noise estimator in the new Analyse module. The three main modules of OSN (see Fig. 1) and how they interact is explained in detail in the following sections.

Analyse

The Analyse module informs the Balance and Noise Removal modules of the sound environment. It uses a two-microphone beamforming algorithm to create two fixed views of the environment. The first view is realised

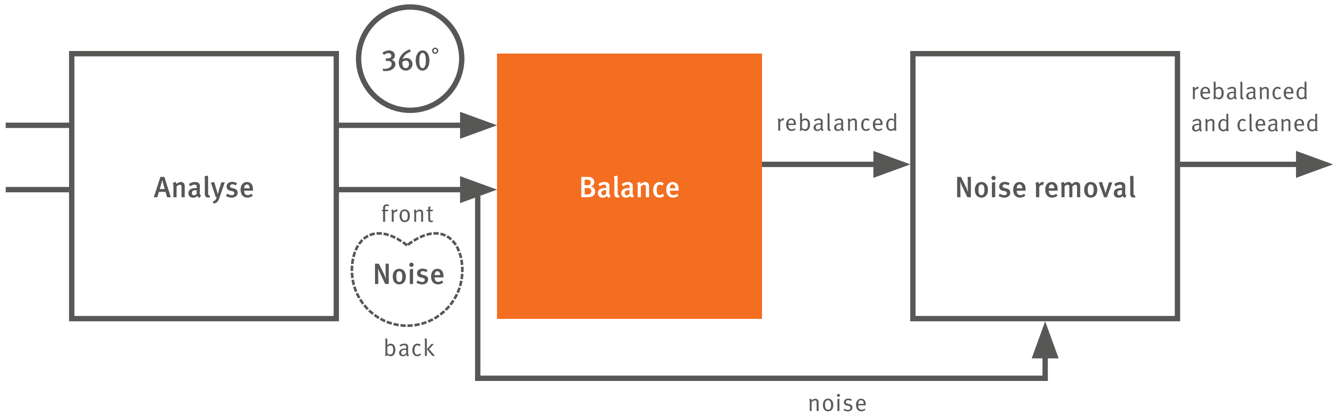

Figure 1. Diagram of the three main modules of OSN. The Balance and Noise Removal modules replace conventional directionality and noise reduction systems. They receive inputs from the Analyse module that ensures an accurate estimation of the sound environment, e.g., noise level and location of noise sources.

by an omnidirectional beam that captures a 360° panorama of the environment. This gives OSN an input that includes all the sounds around the user, both speech and noise, from all directions. The second view is realised by a back-facing cardioid (see Fig. 2) that captures sounds from the side and the back of the user. The sounds captured by the back-facing cardioid are used as an estimate for the noise for both the Balance and the Noise Removal modules. This spatial weighting of the noise makes sense because sound coming from the back is less likely to be the main target for the user. However, speech from the sides and behind is preserved because the listener may wish to move his or her attention. This is secured by the Voice Activity Detector – see the section Voice Activity Detector. Importantly, this "spatially-informed" noise estimate captures not only the level of the noise, but also the direction of the noise (Kjems and Jensen 2012, Jensen and Pedersen 2015). With a noise estimate updated 500 times/s, in each of the 16 frequency bands, this accurate two-microphone technique allows the Balance and Noise Removal modules to be more selective in their noise reduction effect.

Balance

The Balance module is essentially a directionality system that uses a minimum-variance distortion-less response

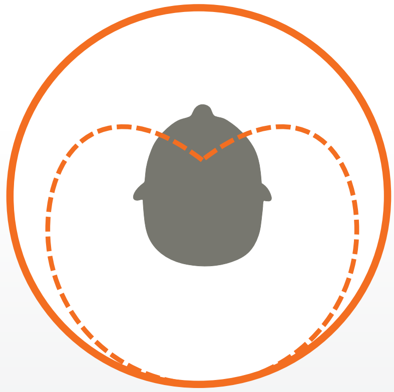

Figure 2. Top view of the user and the two fixed beam patterns obtained by the Analyse module: the omnidirectional beam (solid line) for a 360° estimate of the sound environment and the back-facing cardiod beam (dashed line) used to estimate the noise.

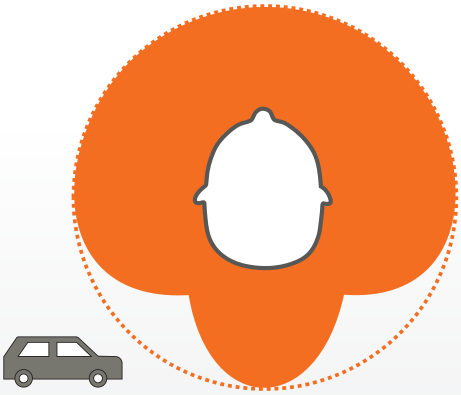

Figure 3. Illustration of how null directions can attenuate localised, dominant noise sources. Thanks to the spatially informed noise estimate, the depth of a null direction is stronger for sounds placed further towards the back.

(MVDR) beamformer. This algorithm is widely used in different systems to improve signal-to-noise ratios (SNRs). Here, it increases the SNR by rebalancing the soundscape. This re-balancing is obtained by seamlessly combining the two fixed views to obtain different beam patterns – from fully omnidirectional to strong attenuation at the back. This specifically targets the dominating noise sources. The key to effective performance of this type of systems is how they receive information about the sound environment. This is obtained via the Analyse module.

The most important sound, the target speech in front of the user is only present in the omnidirectional signal. However, disturbing sounds are present both in the omnidirectional and in the noise signals. The MVDR algorithm subtracts the noise signal from the omnidirectional signal to minimise the dominating noise and obtain a rebalanced signal. In effect, this subtraction creates strong attenuations, called null directions, towards the dominant noise sources (see Fig. 3). The null directions are updated according to the sound environment 125 times per second independently in each of the 16 frequency bands. The speed and the precision at which this processing is executed allows OSN to selectively attenuate noise sources between speech sources.

Noise Removal

In many sound environments, the target speech in the rebalanced signal will still contain some noise. This happens for instance in environments with diffuse noise, environments where noise reverberates over hard surfaces, or when a noise source is located behind or next to the target. To reduce this residual noise, the Noise Removal module operates as an additional step to clean the signal from noise. It is fundamentally a very fast noise reduction system operating independently in 16 frequency channels. The purpose of noise reduction systems is to attenuate a specific frequency band if the noise dominates the signal in that particular moment. With an accurate estimate of the SNR, a high resolution of 16 frequency bands and 500 updates per second, the Noise Removal module is capable of accurately removing noise between words (up to 9 dB attenuation) while preserving the speech. The Noise Removal module receives two inputs: the spatially-informed noise estimate from the Analyse module and the re-balanced signal from the Balance module.

As a result, the signal and the noise estimates in OSN are simply more accurate than in conventional systems, with OSN capable of estimating SNRs accurately even at low SNRs.

Voice Activity Detector

To prevent the system from attenuating speech information from the side and the back, OSN is equipped with a Voice Activity Detector that operates independently in each of the 16 frequency bands. If speech is detected in one frequency band, the state of the Balance and the Noise Removal modules in the corresponding band is “frozen” to preserve the speech information regardless of the position of the talker. The detection of speech and the resulting freeze and release of Balance and Noise Removal modules is updated 500 times per second.

Summary and perspectives

The ground-breaking technology of OpenSound Navigator marks a breakthrough in the development of speech-enhancement systems – as it belongs to the MSAT class. It is not only designed to improve acoustics at the user’s ears, but also to facilitate the brain’s own processing. It does not isolate the front talker but preserves access to all talkers. Its accurate and fast spatially-informed noise estimator allows the Balance module to selectively attenuate noise sources at given locations. The Noise Removal module removes the remaining noise even between words. OSN opens up many possibilities for new user benefits.

OpenSound Navigator in Genie Medical BAHS

In Genie Medical BAHS, OpenSound Navigator (see Fig. 4) is automatically active and set to default settings (Medium transition). OpenSound Navigator can also be fine-tuned on a dedicated screen that offers separate adjustments to the transition of the Balance module and the Noise Removal.

OpenSound – Transition

The Transition control lets you choose how much help is needed in the stage between simple and complex environments. In other words, how early in this transi-

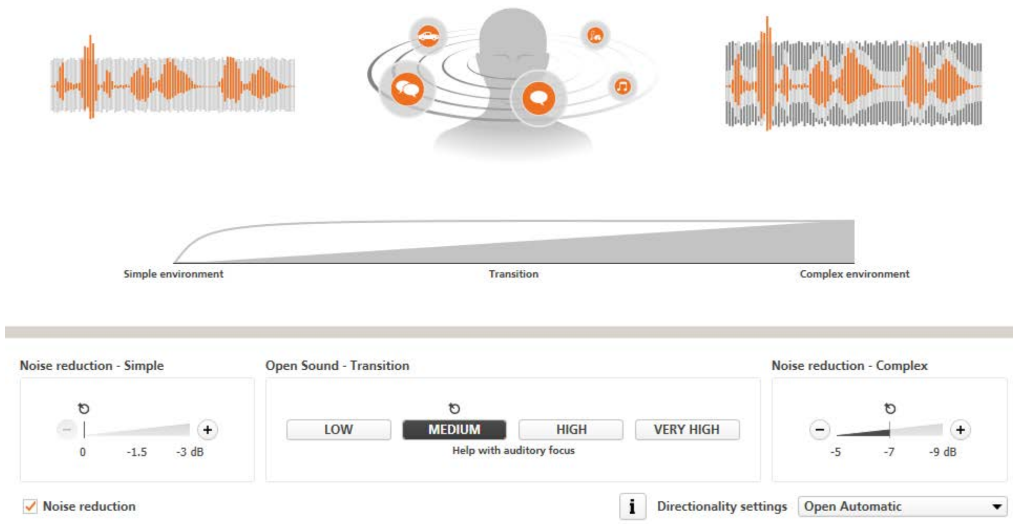

Figure 4. The OpenSound Navigator tab in Genie Medical BAHS 2019. Visualisation at the top and controls at the bottom.

tion will the user want the sound processing to provide more help? When using the Open Automatic directionality setting, you can choose between a Low, Medium, High, and Very High amount of help. As an example, when choosing High, the sound processor will step in more aggressively to reduce the dominating noise, even if the environment is not yet complex. OpenSound Navigator has a default setting (Medium) that we recommend using for the first fitting (see Fig. 4 and Fig. 5). After trialing the sound processor in different situations, the setting can be revisited.

For pediatric fittings of children under 1 year old wearing Ponto on the forehead, the omni-directional setting is automatically applied (i.e., the automatic setting of OpenSound Navigator is deactivated).

Noise reduction controls

Adjustments to noise reduction are divided into Noise Reduction for Simple and Complex listening environments. As default, no noise reduction is applied in Simple situations and a medium level of reduction is applied in Complex situations. Simple environments are here defined as environments with low to medium overall sound level, low reverberation effects, and few disturbing sound sources. Usually, there is a high SNR making it easy to hear target speech. If there are multiple sound sources, they are spatially separated, making them easy to tell apart from each other. Complex listening environments are here defined as environments with a low SNR or a fluctuating SNR, and high sound levels. Multiple sound sources are present and these are difficult to separate spatially. Reverberation might be present and there might be noise sources, which make it difficult to hear and understand target speech.

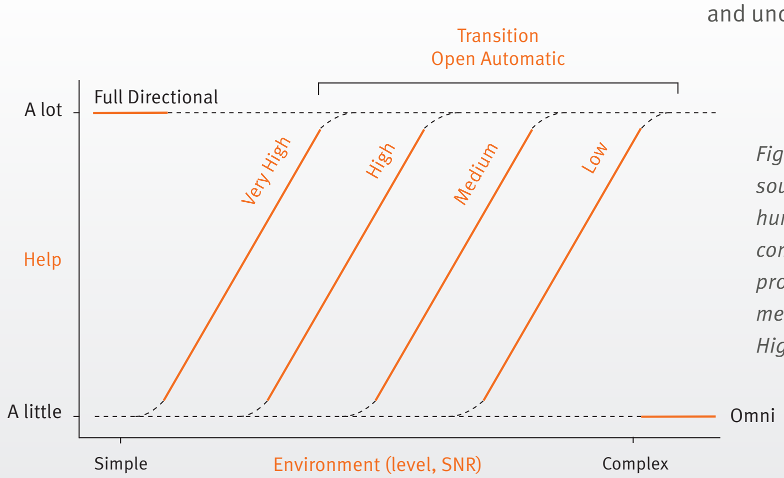

Figure 5. OSN directionality settings. In Omni, the sound processor mimics sound as received by the human ear. In Full Directional, the focus is on sounds coming from the front. In Open Automatics, the sound processor automatically adapts to the sound environment, based on one of the four help profiles, Very High, High, Medium, or Low.

Clinical evaluation of OpenSound Navigator

Several studies have evaluated the benefits of OpenSound Navigator for hearing aid users (e.g., Lunner et al., 2016; Wendt et al., 2017; Ohlenforst et al., 2018; Browning et al., 2019). These studies showed that OpenSound Navigator led to improved speech understanding in noise, decreased listening effort, and improved recall performance (for an overview, see Le Goff et al., 2016b). These results highlight that OSN is a BrainHearing technology. Not only does it improve speech understanding, but it also reduces the effort required to understand speech. The reduction in effort means that cognitive resources are freed up and can be used for other cognitive tasks, such as remembering conversations.

With the release of Ponto 4 in June 2019, the OpenSound Navigator feature is now also available, for the first time, for bone anchored users. A clinical study was conducted to investigate whether bone anchored users would obtain a similar benefit to hearing aid users.

In this study, the OSN feature was evaluated in terms of speech recognition performance in the lab as well as users' self-reported performance in everyday life. The purpose of this study design was to capture the full potential of OSN, which is believed to be mostly reflected in the complex interactions of the users' everyday life.

Methods

This prospective study consisted of two lab visits and a field-trial period (see Fig. 6).

Participants

Twelve listeners (5 male, 7 female; mean age 59 years [32-72 years old]) participated in this study. All participants were already Ponto 3 users. The patients had a conductive hearing loss (N = 8), mixed hearing loss (N = 1), or single-sided deafness (N = 3). All patients had average bone-conduction pure tone thresholds (BC PTA) within the fitting range of Ponto 4. Nine patients were tested unilaterally with one Ponto on the implanted side and three patients were tested bilaterally.

Procedure

The participants were fitted with Ponto 4 and speech recognition thresholds at 70% correct (SRT70) were obtained with the OSN feature activated (OSN ON) and deactivated (OSN OFF). Target sentences (Danish matrix test; Wagener et al., 2003) were presented from a loudspeaker positioned at 2m distance in front of the participant (0° azimuth) and speech-shaped noise was presented from three loudspeakers positioned behind the participant (±110° and 180° azimuth; Fig. 7). The level of the noise was fixed at 70 dB SPL, while the level of the target speech started at 75 dB SPL and was then adaptively varied. A set of 30 sentences was used to obtain the SRT70 for each condition (OSN ON and OSN OFF).

During the field-trial period (9 days on average), the participants were instructed to use Ponto 4 as the main sound processor and Ponto 3 as a reference device. The participants were asked to complete a direct-com-

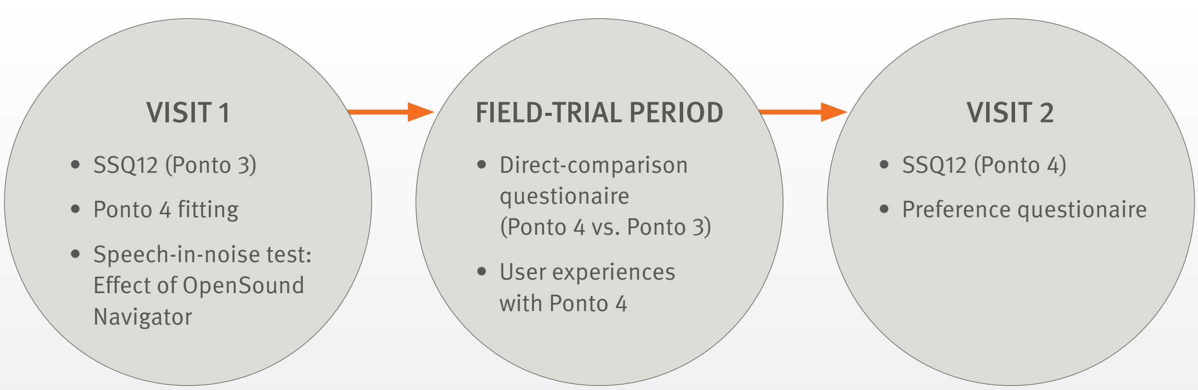

Figure 6. Study overview with outcome measures performed at each visit.

parison questionnaire, where they had to rate the two devices in the same sound environment.

The participants completed the abbreviated version of the Speech, Spatial, and Qualities of Hearing Scale (SSQ12; Noble et al., 2013) to evaluate the perceived performance with their own sound processor (Ponto 3, at visit 1) and with Ponto 4 (at visit 2). A preference questionnaire was also completed at visit 2 to evaluate the device preference in specific sound environments (four conversation types in order of increasing complexity), as well as in general (sound quality, listening comfort, loudness, speech intelligibility, and overall preference).

Results

Speech recognition thresholds

Mean speech recognition performance was of -3.07 dB with OSN OFF and -5.43 dB with OSN ON (Fig. 7), with more negative values indicating better performance. The difference between OSN ON and OFF, averaged across participants, was of 2.37[1] dB. The obtained improvement was significant (paired t-test; $p < 0.0001$).

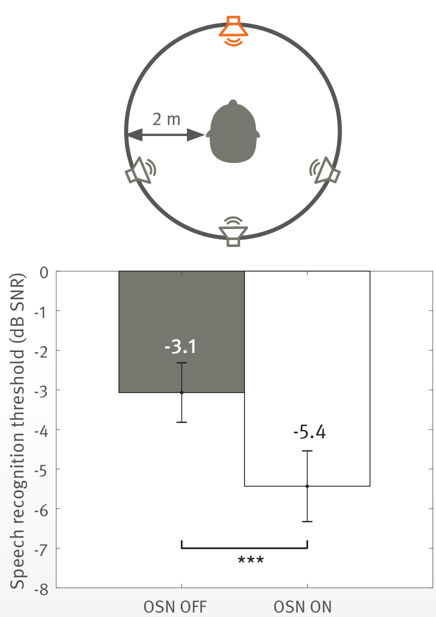

*Figure 7. Top figure: Sketch of the loudspeaker set up for the speech intelligibility test. Bottom figure: Mean speech recognition thresholds (dB SNR) to obtain 70% correct (N = 12) with OSN OFF and OSN ON (*** $p < 0.0001$). Error bars depict the standard error of the mean.*

[1]Note that the difference between -3.07 and -5.43 dB equals 2.37 and not 2.36 dB because of rounding errors.

SSQ12

The mean scores obtained in the SSQ12 questionnaire are shown in Fig. 8. Note that the mean scores are calculated across 11 patients since one patient did not complete the questionnaire. A mixed model ANOVA, with question and processor as fixed factors and participants as a random factor, revealed a significant main effect of sound processor ($p = 0.003$). Since the interaction of sound processor and questions was not significant, we can conclude that the patients rated Ponto 4 significantly better than Ponto 3 across questions.

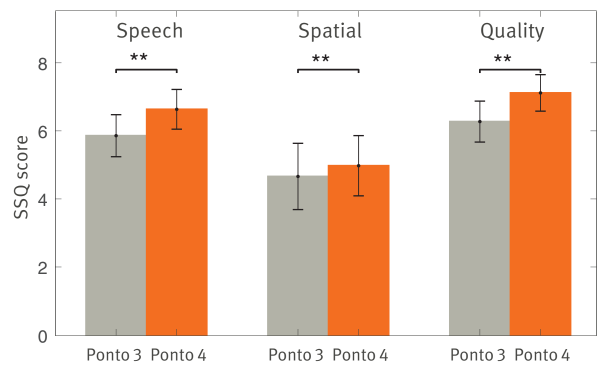

*Figure 8. Average scores for each scale of the SSQ12 questionnaire (N = 11). The scale ranges from 0 ("Not at all") to 10 ("Perfectly"). Error bars depict the standard error of the mean. The main effect of sound processor was significant (** $p < 0.01$).*

Direct-comparison questionnaire

The results from the direct-comparison questionnaire are shown in Fig. 9. The strength of these results lies in that they reflect a comparison between the two sound processors in the same sound environment during the field trial. These results show how 70% or more of the patients that rated conversations in noise preferred Ponto 4 over Ponto 3 when there were multiple talkers and/or substantial background noise. These results show that the perceived benefit of OSN increases together with the increasing complexity of the sound environment.

Preference questionnaire

The outcomes of the preference questionnaire are shown in Fig. 10 (N=11 patients filled in the questionnaire). In general, there was a high preference for Ponto 4 or no preference between the two sound processors. Panel A

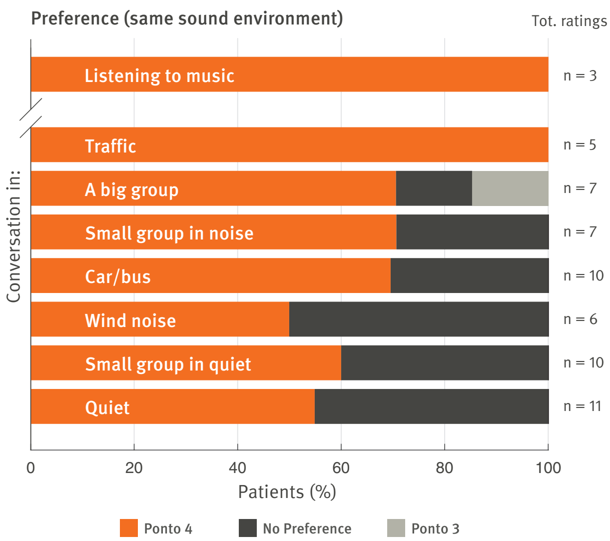

Figure 9. Percentage of patients that prefer Ponto 4, Ponto 3, or have no preference between the two sound processors, as obtained from the direct-comparison questionnaire. Note that the number of ratings differ across situations and percentages are calculated from the total number of ratings obtained in each situation.

shows the preference results for four different conversational scenarios (in order of increasing complexity). These results confirm that the preference for Ponto 4 over Ponto 3 increased together with the increasing complexity of the sound environment. When having a one-to-one conversation in a quiet environment, 45.5% of the patients preferred Ponto 4 and 45.5% did not have a preference for one device over the other. However, in the presence of a big group of talkers, 81.8% of the patients preferred Ponto 4. Panel B shows the preference results for more general aspects, such as sound quality and comfort. For all aspects except for loudness, more than 70% of the patients preferred Ponto 4. No clear preference was obtained for loudness, as anticipated. The loudness preference can be considered as a sort of "control condition" since Ponto 4 and Ponto 3 were individually fitted with similar gain settings and, therefore, the two sound processors should have resulted in similar loudness – as confirmed by the majority of the patients rating 'No preference'.

The outcomes of the preference questionnaire form a consistent and solid dataset, the strength of which lies

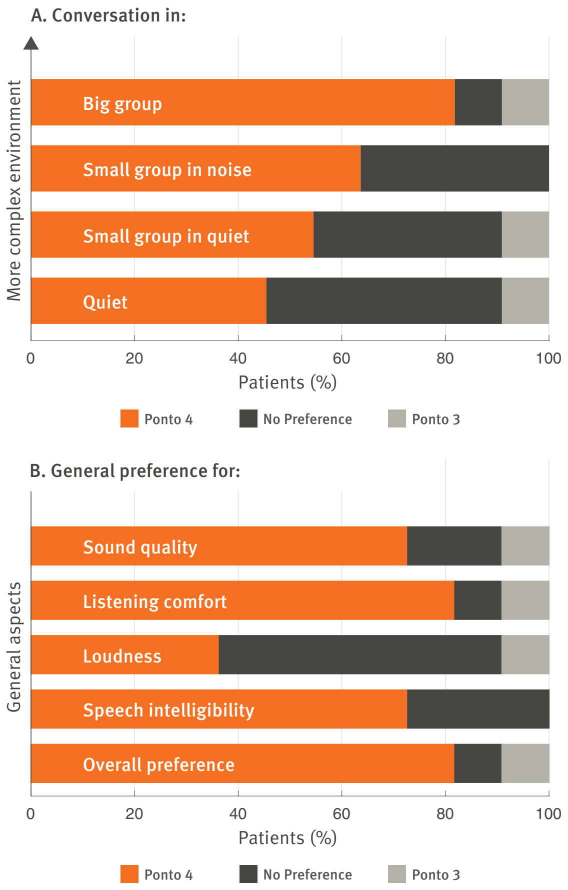

Figure 10. Percentage of patients (N = 11) that prefer Ponto 4, Ponto 3, or have no preference between the two sound processors, as obtained from the preference questionnaire. Panel A: Sound processor preference during a conversation in different sound environments (in order of increasing complexity). Panel B: Sound processor preference for general aspects.

in that the same 11 patients rated the same sound situation after a complete experience with OSN in real life.

Discussion

The speech recognition results show how bone anchored users can significantly benefit from the OSN feature. When the OSN feature is active, the users can understand speech at a sound pressure level that is about 2 dB lower than with OSN OFF. To put this result into context, a 2 dB difference in SRT50 corresponds approximately to a 30% increase in speech intelligibility performance in a matrix test (e.g. Hagerman, 1982; Wagener et al., 2003).

These results obtained for BAHS users are similar to those obtained for hearing aid users wearing Oticon Opn (Ng et al., 2016; Le Goff et al., 2016a). Using a similar matrix test in a spatial setup, Ng et al. (2016) obtained an improvement in SRT80 of about 2 dB with OSN ON relative to OSN OFF.

Measuring speech intelligibility in the lab via traditional and well-established tests is a necessary step in validating the introduction of a new technology. However, we know that the OSN feature is a Multi-Speaker Access Technology (MSAT), whose strength is primarily reflected in more complex and realistic sound environments than a lab setup.

Therefore, what better way to test the MSAT technology than in the patients' everyday life? Interestingly, both the direct-comparison questionnaire and the preference questionnaire showed how the perceived benefit of OSN increased with increasing complexity of the sound environment. During a conversation in a quiet environment about half of the patients preferred Ponto 4 and the remaining half had no preference for one sound processor over the other. This makes sense: we do not expect the advanced signal processing of OSN to make a big difference in the presence of only one speech signal in a quiet environment. However, when more than one talker comes into play and there is substantial background noise, more than 80% of the patients showed a clear preference for OSN.

Conclusion

Having access to speech from all directions is a prerequisite to facilitate the user's natural process in following different talkers and selectively focusing on one of them. The unique signal processing of OSN supports this process via a seamless and continuous analysis of the sound environment that identifies and preserves the speech information regardless of the talker's position. The results of this study clearly show that bone anchored users benefit from this technology in terms of better speech intelligibility. This study also shows that patients perceive the benefit of the OSN technology and have a strong preference for it in the varying and complex listening situations they encounter in everyday life.

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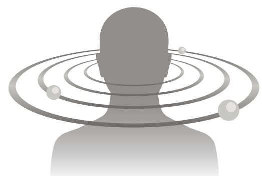
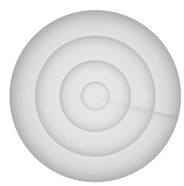
OpenSound Navigator™



– 3 steps in a split second

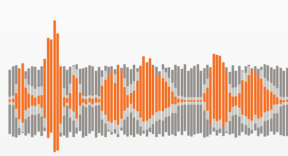


1: Analyse

Scans the 360° sound environment
more than 100 times per second to identify
and separate noise from speech.

2: Balance

Rapidly reduces the levels of loud noise
coming from specific directions,
while preserving speech.



3: Noise removal

Rapidly attenuates remaining diffuse noise,
even between individual words.

Because sound matters

Oticon Medical is a global company in implantable hearing solutions, dedicated to bringing the magical world of sound to people at every stage of life. As part of the Demant group, a global leader in hearing healthcare with 14,500 people in over 130 countries, we have access to one of the world's strongest research and development teams, the latest technological advances and insights into hearing care.

Our competencies span more than a century of innovations in sound processing and decades of pioneering experience in hearing implant technology. We work collaboratively with patients, physicians and hearing care professionals to ensure that every solution we create is designed with users' needs in mind. We share an unwavering commitment to provide innovative solutions and support that enhance quality of life for people wherever life may take them. Because we know how much sound matters.

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