Oticon Medical
Bimodal solutions

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ABSTRACT

We live in a world of sounds, an incredibly complex environment full of dynamic inputs from sources all around us. Our ability to process sounds continues to engage and challenge scientists and clinicians. Cognitive hearing science explores the physiological and mental processes we rely on to make sense of what we hear. Oticon and Oticon Medical have applied the fascinating discoveries of cognitive hearing science in the development of BrainHearing™, an evidence-based approach that supports how the brain makes sense of sound (Hoen et al. (1)). We know that our auditory system, including the brain, is an amazing machine that has been specially designed to process the world of sound through binaural channels. Individuals with untreated bilateral severe-to-profound hearing loss do not have access to much of the world of sound. Fortunately, modern cochlear implants (CI) can restore a significant amount of audibility, providing amazing benefits far beyond what is achievable with traditional acoustic amplification for most users within this group. Optimal hearing requires auditory inputs from both ears, and for most cochlear implant users this means using a bimodal solution, combining a cochlear implant on one side and a hearing aid on the other side. This paper reviews the benefits of binaural and bimodal hearing and explores how Oticon and Oticon Medical, with the principles of BrainHearing, aim to optimize hearing for bimodal users.

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Binaural and bimodal hearing

The importance of binaural hearing

Our ears are designed to pick up sound waves from our surroundings. People with hearing loss in one ear know that it can be challenging to determine where sounds come from and to understand speech in noise. Unilateral hearing, no matter how good, is not optimal for dealing with the variety of sounds present in daily life. Binaural hearing is achieved when the signals from both ears are integrated to obtain an improved listening experience. This enables three-dimensional hearing by very specifically identifying auditory objects from their spatial position of origin.

Double the input

Two heads are better than one for big ideas and problem solving, and two ears are definitely better than one when it comes to processing sounds. In a concept known as **binaural loudness summation,** two working ears mean that the brain essentially receives double the amount of sensory input (at least for sounds coming from the front of the listener, thereby reaching both ears equally). In other words, sounds are louder and easier to detect when you can hear them with two ears instead of one and binaural hearing means using both ears to hear (Fig. 1).

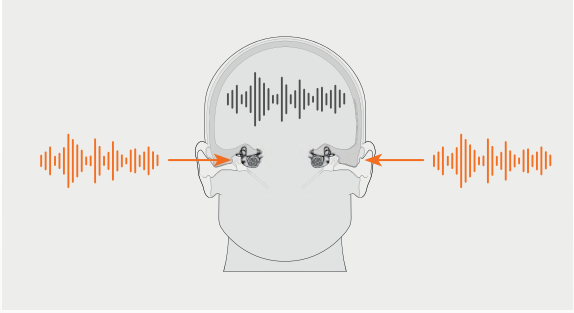

Figure 1: Binaural summation

Sound localization and direction

The use of two ears helps to create a **3D sound landscape.** The time needed for a sound to travel from one ear to the other for an adult is about 500 µs. Our brain is sensitive to temporal delays in the range of 1 µs, so delays between the two ears (ITDs, Interaural Time Differences) can be detected, processed and exploited by the brain to localize sounds and direct attention.

Our heads partially attenuate the sounds reaching the opposite ear. This is known as the **head shadow** (Fig. 2). The head absorbs some of the sound energy, creating a difference in sound intensity (ILD, Interaural Level Difference) between the signals reaching the two ears, that can also be exploited by the brain to localize sounds.

Another binaural ability is the **squelch effect,** which is specific to speech in noise. In a monaural listening situation, the noise and the target speech sound seem to be coming from the same point in space. As a result, it is difficult for the brain to separate the target speech and the noise (Fig.3, situation A). In the binaural situation, the addition of the ear with more noise intensity is enough to create a phenomenon of spatial separation between the noise and the target speech, thereby improving intelligibility (Fig. 3, situation B).

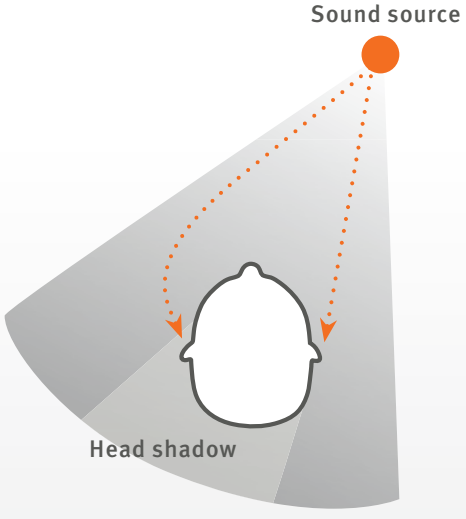

Figure 2: The head shadow effect

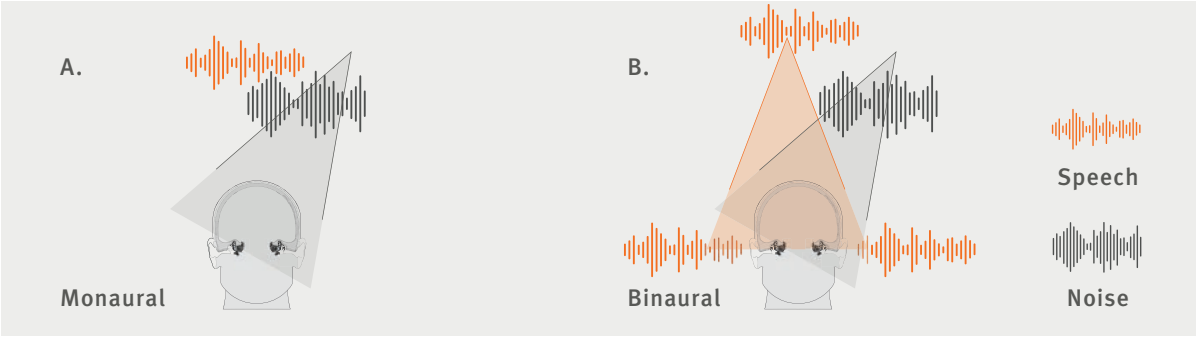

Figure 3: The squelch effect

Binaural hearing and hearing loss

Having two ears comes with obvious advantages, which also apply to situations of hearing loss. For those with bilateral hearing impairment, one hearing aid or cochlear implant is better than none, and two is even better than one. For example, children with bilateral cochlear implants before the age of three and a half have the best opportunity to develop spoken language skills (Sharma et al. (2)), while adults with bilateral aids may have a better experience in social situations and be less subject to isolation and withdrawal as a result of their hearing impairment (Cox et al. (3)).

Bilateral CI

Users with bilateral severe-to-profound hearing loss with limited benefit from amplification are excellent candidates for bilateral cochlear implantation. How much bilateral cochlear implantation restores binaural hearing varies depending on the nature and onset of deafness and the delay between the two implantations. Clinical studies have evaluated spatial hearing abilities in subjects with moderate-to-profound unilateral hearing loss who received cochlear implants, showing binaural benefits in adults early in the postoperative period (Buss et al. (4)).

When acoustic and electric stimulations are combined: bimodal hearing

Bilateral implantation is not for everyone. A CI user may not receive a second CI due to the presence of good residual hearing in the contralateral ear, financial reasons, surgical concerns, or because they wish to preserve one ear for future technologies or treatments. A significant proportion (72% to 85%) of cochlear implant users are now reported to have residual hearing in one or both ears, mostly in the low frequencies (Holder et al. 2018 (5)). Many clinics now recommend the combination of a hearing aid and a cochlear implant in adults, and over the past 20 years, there has been an increasing number of users fitted with bimodal hearing devices (unilateral cochlear implant [CI] and hearing aid on the other ear – Fig. 4). During the same period, there has been an increasing interest and a number of publications evaluating speech recognition in quiet and noise, localization ability, and perceived benefit. For users who have sufficient residual low-frequency hearing in the non-implanted ear, bimodal hearing appears to provide a good non-surgical alternative to bilateral CIs or to unilateral listening. Most unilaterally implanted users, even

Figure 4: Bimodal Hearing: acoustic and electrical stimulations

those with little residual hearing, receive additional benefit with an optimized bimodal solution compared to a unilateral CI (Sheffield et al. (6)). In fact, scientific consensus supports the fact that bilateral hearing (bilateral CI or bimodal configuration) should be the standard of care for implanted users, and that a bimodal solution should be considered for all unilaterally implanted users with contralateral hearing (Offeciers et al. (7), Balkany et al. (8)).

Expected benefits of bimodal solutions

Research studies have demonstrated that bimodal stimulation in adults provides a wide variety of benefits over unilateral cochlear implantation in adults such as:

- Better outcomes in speech recognition in noise (e.g. Blamey et al. (9), Hoppe et al. (10), Morera et al. (11))
- Localization benefits (contributing to the recovery of the 3D sound landscape) (Potts et al. (12))
- Improvements in the perception of patient's own voice (Flynn et al. (13))
- Better music and pitch perception (Ching et al. (14))
- Improved sound quality and a more 'natural' perception (Ching et al. (14))
- Improvement in quality of life and social activities (Farinetti et al. (15))

Bimodal hearing can help restore binaural effects, especially the head shadow and the summation effect (Kokkinakis et al. (16)). The largest improvement is observed in the summation effect: Speech Reception Thresholds improved by 7.5 dB compared to the unilateral CI condition. This large summation effect is due to the complementary cues in the acoustic and the electric inputs. Most bimodal users have residual hearing restricted to the very low frequencies. However, this low frequency content is full of very detailed information about pitch, melody and intonation. The CI efficiently conveys the main speech cues over a large frequency range but is unable to provide this amount of detail in the low frequencies. In a bimodal configuration, the brain fuses information from the two devices to offer a fuller listening experience. Improvements in pitch, music, speech in noise, and sound quality, are strongly related to this complementarity (Ching et al. (14)).

Bimodal hearing is not restricted to the adult population. For children, in addition to better speech recognition in noise, localization and musical perception (e.g. Ching et al. (14); Shirvani et al. (17)), bimodal stimulation has been demonstrated to improve language acquisition and quality of life (Moberly et al. (18), Nittrouer et al. (19)).

A bimodal solution should provide clear, minimally distorted acoustic cues which complement those provided by the CI, making listening to complex signals less effortful and supporting the brain's natural ability to make sense of the world of sound. This represents the goal of BrainHearing and the philosophy behind Oticon and Oticon Medical's bimodal solutions.

The Oticon Medical approach and bimodal solutions

Bimodal BrainHearing

Oticon Medical and Oticon, as part of the Demant group, use the principles of BrainHearing to deliver devices that provide rich and undistorted sound that supports the brain's natural hearing processes. That means helping users invest their cognitive resources in understanding, remembering, interacting, and enjoying, rather than 'just' hearing. To develop solutions that truly help the brain, we need to understand how the listening brain works and how cognitive processes can be supported in the best way possible. That is why with every new generation of products, we take another step towards definite BrainHearing: a hearing solution that makes the process of listening as effortless as possible for our users in their everyday lives and listening environments, supporting an active and rewarding social life.

Cochlear implant systems and hearing aids operate in different ways when transmitting sound signals to the brain. While the hearing aid amplifies soft, medium and loud sounds, a cochlear implant and its electrical stimulation needs to respect the highly limited neural dynamic range. Bimodal BrainHearing takes this difference into account in the design of the signal processing. It aims

at providing optimal complementary stimulation resulting in a rich, full and balanced perception of these two inputs where they reach and combine in the auditory pathways.

Designed for clean speech with minimal distortion
Voice Guard™ for Oticon Medical CI and Speech Guard™ for Oticon hearing aids are patented technologies that were developed with similar processing objectives and are individually optimized to deliver a clean electrical and acoustical sound with minimal distortion respectively. Voice Guard and Speech Guard are designed so the best possible inputs from both ears are reaching the brain.

Speech Guard in Oticon hearing aids preserves the speech cues more efficiently than a fast-acting compression system while providing comfort in all environments even in the presence of loud transient sounds. Speech Guard's adaptive compression system only changes gain when necessary by combining linear amplification (for minimal distortion) and adaptive compression (for comfort). Research has shown that Speech Guard provides better speech understanding, especially in complex listening environments. The better the details of the speech waveform are preserved, the easier it is for the brain to fully understand the speech signal (Pittman et al. (20)).

Voice Guard in Neuro 2™ is based on the same philosophy as Oticon's well-renowned Speech Guard. In daily situations, speech can exhibit an extremely variable distribution of loudness, depending on who is talking and on the environment. Compression systems designed for cochlear implants must account for this variability while always prioritizing the optimal representation of speech information. Voice Guard is the automatic multiband output compression system used (building on the XDP signal processing strategy, Bozorg-Grayeli et al. (21), Segovia-Martinez et al. (22)), which maximizes the transfer of speech information in every listening situation. Voice Guard will automatically adapt compression settings to the intensity of the sound present in the environment to guarantee maximal audibility and sound clarity in every listening situation, thereby avoiding reduced intelligibility in difficult situations (soft or loud speech).

Neuro 2 bimodal solutions

All founded on BrainHearing principles

Each hearing condition needs to be addressed individually taking lifestyles and individual preferences into consideration. That is why Oticon Medical proposes different solutions all founded on the BrainHearing concept.

Oticon Xceed and Neuro 2
Oticon Xceed targets even the most challenging severe-to-profound hearing loss and gives users more access to important speech cues and more gain based on the latest technology. Like other members of the Oticon Opn™ family, Oticon Xceed uses the ultra-fast OpenSound Navigator™ to offer users 360° access to speech. Oticon Xceed also features the OpenSound Optimizer™ that delivers optimal gain and prevents feedback.

Figure 5: Neuro 2 with Oticon Xceed

Benefits with Oticon Xceed

- Latest as well as established BrainHearing technologies designed to provide clean speech with minimal distortion
- Better access to speech for even the most challenging hearing loss
- Access to speech-supporting features like OpenSound Navigator and OpenSound Optimizer
- Bimodal connectivity options based on T-coil technology in the hearing aid and CI.

Oticon Xceed Play™ is the pediatric counterpart to Oticon Xceed that can be used with Neuro 2.

Oticon Dynamo and Neuro 2

The Oticon Dynamo hearing aid covers most users' need for power and gain, giving the clarity they need. Embedded in Oticon Dynamo, Speech Guard delivers high-quality sound while preserving the dynamic variations in intensity and the nuances of the speech signal to support the users' brain in making sense of sound. In severe-to-profound hearing losses, this is even more crucial because every single speech cue counts. Oticon Dynamo and the Neuro 2 cochlear implant (Fig. 6) can both be controlled wirelessly via the Oticon Medical Streamer XM, which additionally provides a dedicated bimodal connectivity solution, compatible with virtually all Bluetooth® devices.

Figure 6: Neuro 2 with Oticon Dynamo

Benefits with Oticon Dynamo

- Established Brainhearing technologies designed to provide clean speech with minimal distortion
- Covers the majority of severe-to-profound users' need for power and gain
- Dedicated bimodal connectivity solution with Oticon Medical Streamer XM

Oticon Sensei SP™ is the pediatric counterpart to Oticon Dynamo that can be used with Neuro 2.

Full bimodal connectivity

With both Oticon Xceed and Oticon Dynamo as part of the bimodal solution, users can enjoy full connectivity.

Oticon Xceed offers direct Bluetooth streaming from external devices to Oticon Xceed, and bimodal streaming with the Neuro 2 using loop technology. With a Bluetooth neckloop system and T-coil technology in both the hearing aid and CI, each device individually receives the same input.

Users with Oticon Dynamo and Neuro 2 can have dedicated bimodal streaming and remote control with the well-established Oticon Streamer technology and can enjoy the benefits of the ConnectLine app for easy control from their smartphone.

Conclusion

A bilateral cochlear implantation is not for everyone. In a bimodal approach, one ear is stimulated electrically and the other acoustically. Candidates for bimodal fitting are people with severe-to-profound hearing loss who receive a cochlear implant in one ear and have residual hearing in the non-implanted ear. While a cochlear implant provides good speech understanding, especially in quiet listening situations, a bimodal fitting provides complementary acoustic amplification in the non-implanted ear and restores transmission of some binaural cues. Oticon and Oticon Medical know how to optimally combine their expertise based on BrainHearing principles with the aim to provide efficient bimodal solutions.

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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 15,000 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.

Oticon Medical

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