Naída CI *Q70* Beamforming Technology:
Unrivalled Performance in Noise

Introduction

For individuals with a severe-to-profound hearing loss, understanding speech in noise remains a challenge for both hearing aid and cochlear implant users (Kochkin 1993, Firszt et al. 2004). When compared to normal-hearing listeners, cochlear implant recipients still require significantly higher signal-to-noise ratios to achieve the same performance. Thus reducing the amount of noise present in the signal is a key focus of hearing instrument and cochlear implant manufacturers today (Schafer et al. 2012).

A number of different strategies have been developed that are designed to act on the signal within the processing pathway to reduce noise without attenuating speech. Examples of such signal enhancement algorithms used with cochlear implants that have been clinically proven to improve performance on speech tests in noise include ClearVoice™* (Buechner et al. 2010) and ADRO® (James et al. 2002). Further improvements are likely to be obtained by improving the signal-to-noise ratio with frequency modulation (FM) systems or directional microphones before the signal enters the processing pathway. FM systems may provide the greatest improvement in the signal-to-noise ratio, but require cooperation between the speaker and the listener and are therefore not practical in many situations (Lewis et al. 2004). Directional microphones, on the other hand, are controlled by the listener to produce the best hearing outcome for a given situation.

Basic Principles of Beamforming

In modern hearing instruments, there are three main categories of microphones available:

- Omnidirectional microphones, which are equally sensitive to sound arriving from all directions
- Fixed directional microphones, or beamformers, which are sensitive to sounds arriving from a specified location
- Adaptive microphones, where the point of minimum sensitivity is adapted to cancel out the dominant sound source(s).

Beamforming is the process by which directionality is achieved through the use of several microphones together. The basic principles of all types of beamforming technology rely on time and therefore phase differences in the signals arriving at two or more spatially separated microphones. In a hearing aid with one back and one front omnidirectional microphone, directionality is based on the assumption that noise will generally come from behind the user and speech from in front. In its simplest form, a single sound wave coming from the rear will arrive at the rear port before travelling onwards to arrive at the front port. This introduces a time delay and a phase difference between the signals arriving at the two ports. If an equivalent time delay is applied to the rear port using a delay filter, the result is zero when the two signals are subtracted. In this way, the signal from the rear is cancelled. The signal from the front is attenuated too, but less than the rear signal. This attenuation is frequency specific and compensated by increasing the gain. The front signal remains therefore virtually unaffected. The characteristics of the directional pattern are defined by the distance between the microphone ports and the applied delay. By varying these parameters, an unlimited variety of differing patterns can be produced **(Figure 1)**, varying mainly by the orientation of the directivity notch, the front sensitivity remaining constant.

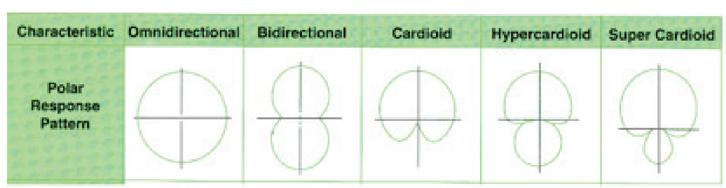

Figure 1. Polar response patterns adapted from Knowles Technical Bulletin 21

Directional microphones with two ports have been successfully used in hearing aids since the 1980s, but they had the disadvantage of not enabling the user to select an omnidirectional characteristic when required (Gnewikow et al. 2009, Hawkins and Yacullo 1984, Nielsen and Ludvigsen 1978). In the 1990s, major advances were made with the introduction of multi-microphone technology, incorporating two or more omnidirectional microphones in an array (Kates 1993, Saunders and Kates 1997, Valente et al 1995, Ricketts and Dhar 1999). Those dual-microphone arrays, along with digital signal processing, provided the opportunity to create an infinite number of directivity patterns. Those patterns, in turn, could be varied adaptively independently of the user, to produce the most appropriate directivity for a given environment (Kompis and Dillier 2001, Kates and Weiss 1996).

Implementation in Cochlear Implants

In 1999, Phonak introduced the Claro hearing aid, which used a combination of digital technology and multiple microphones to produce the first adaptive beamforming system to be implemented in a hearing instrument (Bachler and Volanthen 1995). Clinical trials compared the omnidirectional setting against both adaptive beamforming and a fixed directional cardioid pattern. As expected, when noise came from directly behind the subject, there was no significant difference between the fixed and adaptive directional patterns. However, when noise was at 90° to the side or moved across different speakers, there were significant advantages for the adaptive mode over the fixed directional mode (Kuhnel and Checkley 2000, Ricketts and Henry 2002).

In order for these advantages to be experienced in a real-world environment, a number of different technical issues must be overcome: well-matched and calibrated microphones are essential because even slight differences in phase or sensitivity can cause dramatic directivity losses, especially in the 0.5- 2 kHz range (Peterson et al. 1990). Acoustic head shadow and diffraction effects also can significantly reduce the directional performance, but the use of complex acoustic head models can predict and minimize these effects (Kuster 2013).

Phonak has continued to develop its adaptive beamforming technology since the original introduction in 1999. Today's sophisticated UltraZoom beamformer was launched in 2011. UltraZoom is a monaural adaptive beamformer, where the signals of two omnidirectional microphones located along the front-back axis of the hearing aid are processed so as to dynamically attenuate sound originating from varying directions in the back hemisphere in a frequency-specific manner (Hehrmann et al. 2012). Precise microphone matching during manufacturing and automatic in-situ matching procedures ensure robustness of the directivity by continually reducing response discrepancies between the dual microphones.

The new Advanced Bionics Naída CI *Q70* (Naída CI) sound processor for cochlear implant users incorporates the UltraZoom beamforming technology from Phonak.

Clinical Results

Beamforming works best when the speaker is in front of the listener, when speech and noise are spatially separated, and when no reverberation is present (which causes the target and interfering noise to become more spatially diffuse) (Peterson et al. 1990, Kompis and Dillier 2001). In testing the benefits of any beamforming algorithm, the test setup must be carefully considered. The relative locations and types of speech and noise can be selected to produce the optimum level of noise attenuation for a particular directionality setting, but might not be representative of a real-world environment (Hersbach et al. 2012). Noise should be diffuse in nature, not presented only from behind, and at least a moderately reverberant testing room should be used.

Feasibility studies in cochlear implant users were conducted by combining the UltraZoom feature of a modified Phonak Ambra hearing aid with an Advanced Bionics Harmony™ processor. The output of the Ambra was coupled with the Harmony processor via the Direct Connect™ earhook [Hehrmann et al. 2012, Buechner et al. (submitted)]. Preliminary acute data were collected from ten experienced Harmony/HiRes Fidelity 120™* cochlear implant users and showed very positive results, particularly in test conditions that were representative of real-life listening (array of five loudspeakers delivering noise). The combination of ClearVoice™ and UltraZoom was even more beneficial than UltraZoom alone.

A follow-up study was conducted with the Naída CI processor, which includes the UltraZoom beamforming technology. Ten experienced unilateral Harmony/HiRes Fidelity 120 users participated. Several conditions were tested:

- Naída CI omnidirectional microphone only: "Omni"
- Naída CI with T-Mic™: "T-Mic"
- Naída CI with UltraZoom: "UltraZoom"
- Naída CI with UltraZoom and ClearVoice: "UltraZoom & ClearVoice"

Oldenburg sentences were presented from one speaker in front of the subject. Stationary speech-shaped noise, created from the sentence material, was presented simultaneously from five speakers placed around the subject in a moderately reverberant room. An adaptive procedure was used to estimate the speech reception threshold (SRT) (Kollmeier and Wesselkamp 1997). **Figure 2** shows the relative position and angle of the noise sources with respect to the speech source and the subject.

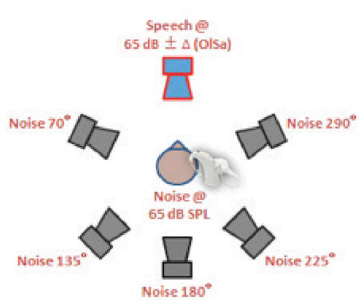

Figure 2. Test setup for Naída CI UltraZoom study. Speech was presented at the front while noise was presented from five loudspeakers located around the test subject (Adapted from Buechner et al., poster presented at ESPCI 2013)

UltraZoom produced a remarkable improvement in the ability to understand speech in noise **(Figure 3)**. A 6 dB improvement in SRT was obtained with UltraZoom compared to the standard omnidirectional microphone. When ClearVoice was switched on, subjects experienced a further 0.8 dB improvement in SRT.

For the Oldenburg sentences, psychophysical research shows that increasing the signal-to-noise ratio by 1 dB could lead to up to 15% improvement in speech understanding in cochlear implant users (e.g., Hey et al. 2003). Thus, the 6 dB SRT improvement seen in this study may potentially translate into considerable benefit for Naída CI users when UltraZoom is enabled.

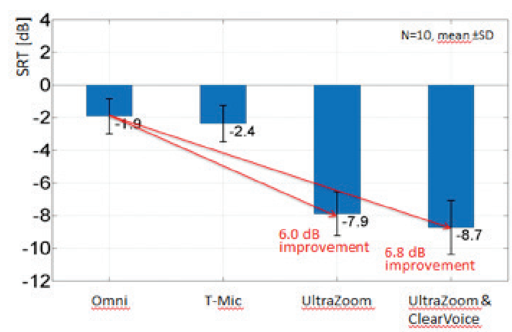

Figure 3. Speech Reception Threshold results with the four different configurations. UltraZoom produced a 6 dB improvement over the omnidirectional setting; adding ClearVoice™ resulted in a further improvement of 0.8 dB. (Adapted from Buechner et al., poster presented at ESPCI 2013)

Summary Statement

The unique microphone technology from Phonak has enabled Naída hearing aid users to have access to a highly sophisticated beamformer, used by more than 8 million people worldwide. With the Naída CI processor, AB cochlear implant recipients also will have access to UltraZoom. Combined with ClearVoice, UltraZoom will provide AB users access to unrivalled performance in noisy real-life situations, such as restaurants, cars, and classrooms.

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*Not approved for pediatric use in the U.S.

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