AN INNOVATIVE NON-OCCLUDING DSP DEVICE

"I sound like I'm talking in a barrel." Has any clinician fitting hearing aids not heard those words? What lies behind usually represents a compromise in achieving sufficient gain, limiting tendency to acoustic feedback and providing a cosmetically appealing device. Ironically, the least conspicuous in-the-canal models can end up being the most intrusive for the wearer, as the degree of occlusion needed to provide adequate feedback-free gain creates discomfort, a blocked-up sensation, and a boomy-sounding own voice. While counselling is valuable in helping these patients adjust to the less positive aspects of their new hearing instruments, the ideal solution would be not to create those problems in the first place. This would involve the seemingly simple solution of fitting hearing instruments without occluding the ear canal.

All hearing aid fittings require some form of sound delivery to the ear canal. A non-occluding fitting minimizes how much the ear canal is blocked by the sound delivery system. The least occluding fitting yet described involves delivering the sound from a conventional BTE device to the ear canal with earmould tubing or its equivalent (e.g. Westone earmould #52). Providing amplification without creating occlusion offers the wearer a number of advantages, the most well-documented of which are better sound quality of the wearer's own voice (Kuk, 1991; MacKenzie et al, 1989; Kampe & Wynne, 1996; Courtois, 1988) and reduced gain at low frequencies for patients with good low frequency hearing (McDonald & Studebaker, 1970; Studebaker & Zachman, 1969; Dillon, 2001). Other advantages may include improved speech intelligibility (Cox & Alexander, 1983), improved localization (Noble et al, 1998; Byrne et al, 1998), improved physical comfort (MacKenzie et al, 1989), and reduced risk for external ear irritation and infection (Courtois, 1988).

The most obvious candidates for open fittings are those who are most bothered by occlusion related issues, namely those with mild or high frequency hearing losses. To fit such hearing losses successfully places demands on the hearing instrument physically, electronically and acoustically. First, the device must have some cosmetic appeal. The less it resembles a conventional hearing aid, or the more inconspicuous it can be, the greater the chances that the prospective wearer even wants to try it. Second, the device must provide an adequate amount of undistorted, low noise, high frequency amplification, and the amplification strategy should take into account the recruitment associated with cochlear hearing loss. Finally, the coupling to the ear canal must allow bone-conducted low frequency sound arising from the wearer's own voice, chewing, coughing, etc. to escape from the ear canal to avoid the sensation of occlusion. These goals are at odds, as not occluding the ear canal increases the tendency to acoustic feedback when high frequency gain is increased. In fact, Kuk (1994) found that the maximum usable real ear insertion gain for a completely non-occluding earmould coupled to a high-frequency hearing aid was only 17 dB. Considering that a safety margin of 5 to 10 dB (Dillon, 2001; Bisgaard & Dyrlund, 1991) in headroom is recommended for hearing instrument fitting to ensure freedom from feedback and good sound quality, it is clear that the range of hearing losses which can be fit without occluding the ear canal is quite limited with conventional technology.

A DSP hearing instrument has become available which addresses the fitting requirements of individuals with mild or high frequency hearing losses by allowing non-occluding fittings. This is the ReSoundAIR from GN ReSound. Design goals for this device were:

- To provide high cosmetic appeal
- To maximize wearer comfort by not occluding the ear canal
- To provide sufficient amplification to allow fitting of a wide range of high frequency hearing losses
- To minimize internal noise and distortion of the instrument

The manner in which the ReSoundAIR device meets these goals is discussed in this article.

1. Cosmetics and physical design
Sketches of the device, which is a small BTE, and how it fits on the ear are shown in Figure 1, while Figure 2 shows a photograph of the device on the ear. The device itself comes in such unconventional hearing instrument colors as aluminum, black and pearl white, and is small enough to be virtually invisible on the ear. The coupling of the device to the ear canal is also unconventional and much less conspicuous than any other BTE, ITE or ITC hearing instrument. Sound delivery occurs via an extremely thin sound tube pre-shaped to the right or left ear with a standard sized silicone eartip attached. The eartip is termed "dome" due to its shape, and is available in 2 sizes. The sound tube is available in three lengths and two ear canal insertion depths. A pliable plastic strip, the sports lock, attaches to the sound tube, and is placed in the bowl of the concha to provide added stability of fit. This disposable sound tube and dome are replaced by the user every 2 to 3 months.

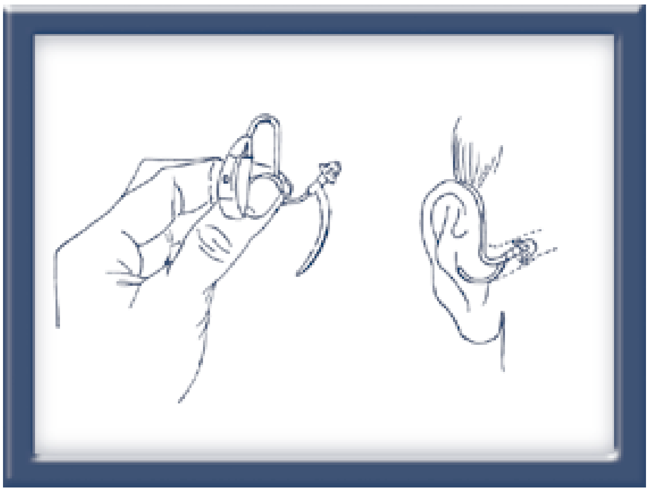

Figure 1.
The ReSoundAIR is a mini-BTE which is coupled to the ear via a very thin sound tube and a silicone dome. The sports lock ensures good retention even in "active" ear canals.

Figure 2.
The device is less noticeable on the ear than conventional hearing instruments.

The comfort, cosmetic appeal and retention of the sound delivery concept were evaluated in a series of in-house clinical trials involving both hearing impaired and normal-hearing participants. Ratings of cosmetics, comfort of fit, and retention of devices were very high and identical for the two groups. Retention was initially of concern, as it was observed that the dome worked itself out of about 20% of the ears in the test. This phenomenon is evidently related to ear canal movement at the temporomandibular joint. The problem was solved by the addition of the sports lock to the sound tube. As described above, the sports lock functions as a kind of hook or brace in the concha to ensure good retention of the dome in the ear canal without sacrificing comfort.

2. Maximizing comfort by avoiding occlusion

Apart from providing an aesthetically pleasing and comfortable fit, the sound delivery system has the added advantage of leaving the ear canal unoccluded. Figure 3 compares average Real Ear Unaided Gain

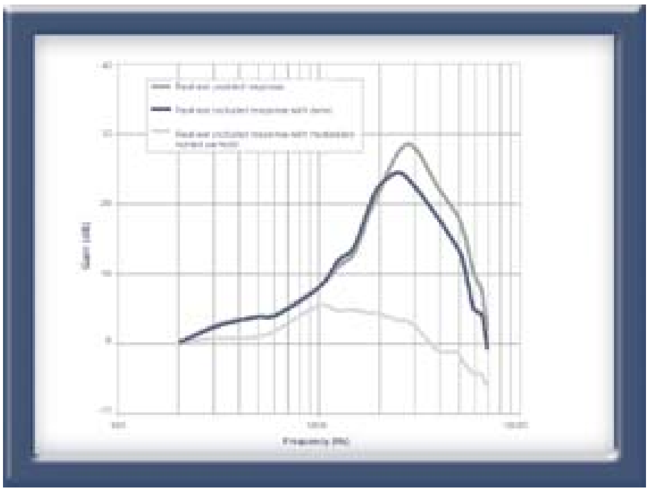

Figure 3.
Average Real Ear Unaided Gain is compared to Real Ear Occluded Gain for the ReSoundAIR and a conventional earmould with a moderate sized vent. The ReSoundAIR occluded gain is nearly identical to the ear's natural response.

with the Real Ear Occluded Gain for the ReSoundAIR sound delivery system and for a conventional earmould with a moderately sized vent. This graph illustrates how little impact the coupling of the ReSoundAIR device to the ear canal has on the natural ear canal acoustics. In contrast, it can be seen that the conventional earmould has a colossal effect on how the ear canal treats incoming sound, as the unoccluded ear canal resonance peak is completely obliterated by the presence of the earmould.

What does this imply in terms of sound quality for the wearer? Seventeen normal-hearing subjects who wore the ReSoundAIR without amplification for 2 weeks to evaluate a number of factors, including occlusion, reported no perceived differences in the sound of their own voices or other sounds when wearing the devices. This means that complaints from the hearing instrument wearer about his hollow-sounding own voice, the unbearably loud crunching sounds when eating, and the unpleasant cacophony of toothbrushing are just not an issue with this device.

3. Providing sufficient amplification

There are three important elements, that together ensure that appropriate amplification can be provided to the individual ear. These are the unique WarpOpen compression system, the Stabilizer digital feedback suppression system, and the novel mechanical and acoustic design of the device.

WarpOpen compression system

The ReSoundAIR utilizes the WarpOpen compression system, which provides fast wide dynamic range compression in 3 bands. The compression scheme includes expansion to reduce internal noise from the device. This system is fundamentally different from existing systems in commercial DSP hearing aids, which use multi-channel filter banks with characteristics most often chosen to emulate critical bands in the auditory system. Because digital processing is intrinsically uniform in terms of frequency analysis, these systems employ varying techniques to reproduce the non-uniform frequency resolution of the auditory system. The WarpOpen is the first hearing instrument compression system to employ frequency warping technology (Rabiner & Gold, 1975) and minimum-phase FIR filtering to achieve frequency resolution equivalent to a traditional hearing instrument filter bank system containing many times the number of bands, but with much greater processing efficiency and lower compressor noise, thereby matching the specific demands placed by the open nature of the fitting (refer to Pedersen & Groth, in press, for a detailed description of the WarpOpen compression system used in the ReSoundAIR).

Stabilizer digital feedback suppression
Because the ReSoundAIR does not occlude the ear canal, there is little attenuation in the pathways by which the amplified sound escapes from the ear canal and returns to the hearing instrument microphone. This means that the amount of amplification available to the wearer will be severely limited by acoustic feedback unless some measure is taken to manage the feedback. The ReSoundAIR includes Stabilizer digital feedback suppression, which builds on GN ReSound's extensive experience with Digital Feedback Suppression (DFS) technology.

Stabilizer utilizes feedback cancellation filters as described by Kates (1999). Briefly, such a system consists of two filters whose coefficients are determined to mirror the feedback path. The first filter is set up by a calibration procedure during fitting of the hearing instrument, and is intended to represent relatively stable characteristics of the feedback path, such as sound tube and dome acoustics, and responses of the microphone and receiver. This part of the system is advantageous in that it means that the system does not "start from scratch" each time the device is switched on. For an open fitting, the lack of this filter would mean that many users would be blasted by several seconds of feedback each time they turned on their hearing instrument. The system's second filter is adaptively updated by the hearing instrument software during use of the hearing instrument to account for rapid changes in the feedback path, such as when a hat is put on. This system has the potential of increasing headroom – or maximum achievable gain without feedback – by 10-15 dB (Kates, 2000).

While the rationale for application of DFS technology has been to provide added headroom to hearing aid fittings, thus freeing the user for feedback in nearly all situations, the rationale for Stabilizer is to provide more usable insertion gain. In other words, Stabilizer intends to make possible fitting more severe hearing losses than the acoustics of the open fitting would otherwise allow. This places extreme demands on the robustness of the system. To meet these demands, Stabilizer has been tuned to model the feedback path more accurately than any other feedback cancellation system. In addition, the frequency with which the system's adaptive filter is updated has been increased compared to previous implementations to better track changes in the feedback path. Based on clinicial trials, it is estimated that one third of ears in the fitting range for this device would have spontaneous acoustic feedback at use gain settings without Stabilizer (Groth & Olsen, in press).

To guide clinicians in optimum use of Stabilizer, the Maximum Stable Gain software fitting tool presently used in fitting GN ReSound Canta hearing instruments is employed. This tool utilizes the feedback path measurement performed during calibration to derive a shaded area which appears on the insertion gain graph in the NOAH-based fitting software, as illustrated in Figure 4. The Maximum Stable Gain display can be easily interpreted by clinicians as a "safe zone" for gain settings, and is crucial in finding the best balance between amount of gain and risk for feedback when carrying out open fittings.

Mechanical and acoustic design
The sound tube which must deliver the amplified sound has an inner diameter of only 0.86 mm. This is less than half the diameter of the standard sized tubing used for coupling to a conventional BTE. As a consequence, the device must be capable of delivering much more gain than if the larger diameter tubing were used in order to overcome the greater acoustic impedance. This in turn necessitates extreme mechanical stability of the device to ensure that internal feedback will not limit the available gain. Not only this, there must also be a great degree of flexibility in calibrating the system in order to achieve the desired flat frequency response in the ear. One of the ReSoundAIR design engineers likened the problem to playing a rock concert through a drinking straw.

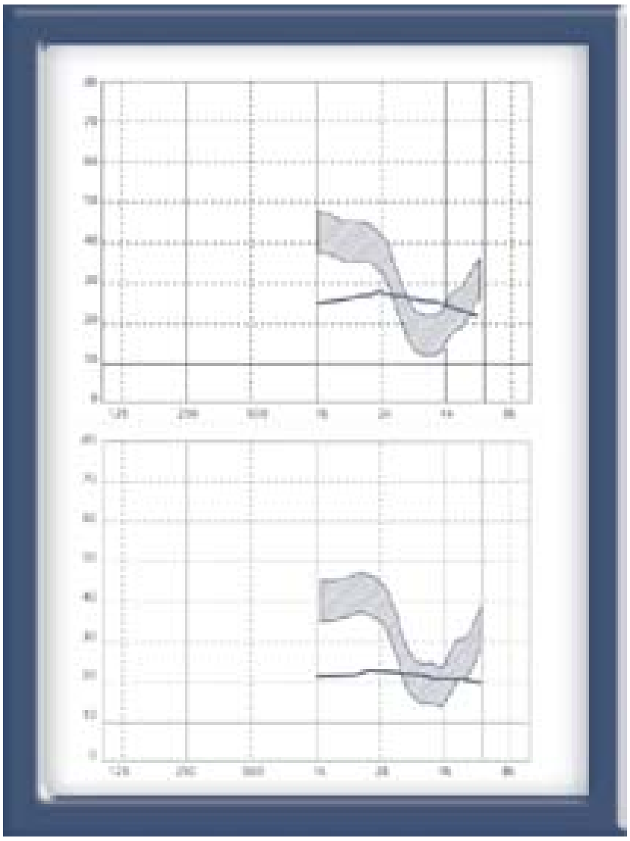

Figure 4.
The shaded green Maximum Stable Gain display in the software fitting screen guides the fitter in determining the optimum gain settings to avoid feedback problems with the non-occluding ReSoundAIR. In the example on the left, the hearing loss was at the limits of the fitting range. It was necessary for this individual to reduce the gain for soft inputs (dark grey curve) slightly relative to the prescribed gain (light grey curve) in order to ensure a stable fitting. For the hearing loss in the example shown on the right, the prescribed gain was available for the fitting.

One example of how added stability is accomplished is that the casing consists of 2 parts which slide together to form one structure rather than the usual approach of screwing 2 casing halves together like nutshells. Not only does this make the device easy to assemble and service, it increases the resistance to structural vibration, which translates to less risk for internal feedback. Because of inventive thinking in the construction, choice of materials and packaging of the device components, the gain available for fitting is not limited by mechanical stability constraints.

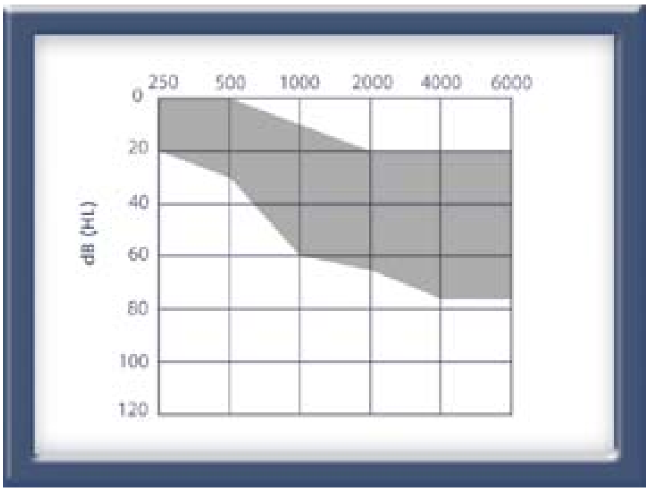

Figure 5.
The fitting range for the ReSoundAIR extends well beyond what might be expected for non-occluding fittings due to the effective combination of signal processing and mechanical design. (fitting range from data sheet or dispenser brochure)

Fitting range

The combination of the WarpOpen compressor, Stabilizer and the unique mechanical design result in typical usable insertion gain of 20 to 25 dB in the frequency region where feedback occurs. More gain is attainable in the 1000 to 2000 Hz region. This translates to a fitting range extending to 60 dB at 1000 Hz and 75 dB at 2000 to 6000 Hz, as shown in Figure 5.

Minimizing noise

Candidates for fitting with the ReSoundAIR have good hearing in the low frequencies. This means that they are more likely to be annoyed by internal instrument noise arising from the compressor or microphone. Part of the rationale for implementing the WarpOpen compressor in this device was that it is inherently low in noise. Moreover, the low level expansion is effective in ensuring that microphone noise is not amplified.

The ReSoundAIR also utilizes amplitude modulation based fast-acting noise reduction. This processing is effective in preventing amplification of stationary noises that the wearer may find annoying. The implementation of this processing is similar to that in the

Canta hearing instruments, and contributes to increased listening comfort for the wearer. Participants in clinical trials with the ReSoundAIR rated the devices to be less noisy when listening to stationary noise with the noise reduction processing than without. In addition, many reported greater listening comfort in the presence of various types of background noise compared to their own hearing instruments (Groth & Olsen, in press).

Summary

The ReSoundAIR represents a unique opportunity for clinicians to remove the obstacles which prevent patients with mild or high frequency hearing loss from enjoying the benefits of amplification. Not only is this device cosmetically appealing and comfortable to wear, its innovative combination of features allow fitting an astonishing range of high frequency hearing losses without occluding the ear canal.

Refenrences

Bisgaard, N. & Dyrlund, O. (1991). Acoustic feedback part 1: Traditional feedback suppression methods. Hearing Instruments, 42, 24-26.

Byrne D, Sinclair S & Noble W. (1998). Open earmould fittings for improving aided auditory localization for sensorineural hearing losses with good high-frequency hearing. Ear & Hearing 19(1): 61-71.

Cox RM & Alexander GC. (1983). Acoustic versus electronic modifications of hearing aid low-frequency output. Ear & Hearing 4:190-196.

Courtois J, Johansen PA, Larsen BV, Christensen P & Beilin J. (1988). Open moulds. In Jensen JH (ed.) Hearing Aid Fitting: Theoretical and practical views. p, 175-201.

Groth J & Olsen SØ. (in press). Clinical evaluation of a non-occluding DSP hearing instrument.

Kampe SD & Wynne MK. (1996). The influence of venting on the occlusion effect. The Hearing Journal 49 (4): 59-66.

Kates, J.M. (1999). Constrained adaptation for feedback cancellation in hearing aids. Journal of the Acoustical Society of America, 106, 1010-1019.

Kates, J.M. (2000). Room reverberation effects in hearing aid feedback cancellation. Journal of the Acoustical Society of America, 109, 367-378.

Kuk F. (1994). Maximum usable real-ear insertion gain with ten earmould designs. Journal of the American Academy of Audiology 5: 44-51.

Kuk F. (1991). Perceptual consequences of vents in hearing aids. British Journal of Audiology 25: 163-169.

MacKenzie K, Browning GG & McClymont. (1989). Relationship between earmould venting, comfort and feedback. British Journal of Audiology 23: 335-337.

McDonald FD & Studebaker GA. (1970). Earmould alteration effects as measured in the human auditory meatus. Journal of the Acoustical Society of America 48: 1366-1372.

Noble W, Sinclair S & Byrne D. (1998). Improvement in aided sound localization with open earmoulds: observations in people with high-frequency hearing loss. Journal of the American Academy of Audiology 9: 25-34.

Pedersen BD & Groth J. (2003). GN ReSound's WarpOpen: A high definition compression system for open fittings.

Rabiner LR & Gold B. (1975). Theory and application of digital signal processing, Prentice-Hall, Inc. Englewood Cliffs.

2903-GB-03.02

GN ReSound as • Mårkærvej 2A
P.O. Box 224 • DK-2630 Taastrup • Denmark
Tel.: +45 72 11 11 11 • Fax: +45 72 11 11 88
gnresound@gnresound.dk • www.gnresound-group.com