

Thin-tube and receiver-in-canal devices: There is positive feedback on both!

By Stephen A. Hallenbeck and Jennifer Groth

Open-fit, behind-the-ear (BTE) devices have emerged as a new category of hearing instruments. Together with their attractive and comfortable-to-wear design, open-fit BTEs owe much of their success to the development of feedback-cancellation algorithms. Because feedback cancellation can allow up to 10 dB more real-ear gain, this technology has made the open-fit BTE a viable option for a large proportion of hearing aid candidates.

While the first open-fit BTEs were coupled to the ear canal via a thin acoustic tube, a more recent trend has been to relocate the hearing aid receiver from the device housing to the wearer's ear canal. The availability of open products featuring either an externalized receiver or a thin tube

ing aid, can also result in feedback.¹ The sum total of the various transmission lines constitutes the feedback path.

Compared with custom hearing aids, BTEs have some ability to attenuate the direct pathway between the microphone and receiver by physically separating the microphone and receiver, as well as by physical separation of the sound outlet in the ear canal and the microphone.

GAIN BEFORE FEEDBACK

Reports indicate that the maximum available gain before feedback for tube-fit BTE instruments ranges from approximately 17 to 23 dB.^{2,3} Such data illustrate why, without feedback-cancellation algorithms, the use of open devices would be limited to mild degrees of hearing loss.

For example, targets prescribed by the popular NAL-NL1 fitting rationale could not be met in most ears with open-fit BTEs for losses greater than about 50 dB HL. Depending on the chosen fitting rationale, the use of feedback cancellation can increase the fitting range of open-fit BTEs by 20 dB or more, as such processing can make as much as 10 dB in additional usable gain available. It is no wonder that nearly all such products introduced in recent years feature some type of feedback-cancellation processing, although it should be noted that some products may employ gain reduction as well, which causes a reduction of amplification for critical speech frequencies.

The more recent trend in the development of open-fit instruments is to relocate the receiver from a BTE device to the wearer's ear canal. It is widely believed that this configuration is superior in terms of maximum available gain to BTEs that house both the receiver and speaker and are coupled to the wearer's ear via a thin sound tube.

This popular belief may be rooted in the conventional wisdom that a greater distance between the microphone and receiver increases attenuation in the feedback path, thereby allowing for more gain before feedback. Indeed, there is some evidence to support this idea. Ross and Cirimo quantified the difference in frequency response and maximum achievable gain for three BTE devices from different manufacturers measured serially in one ear.⁴

In their experiment, an initial measurement of gain before feedback was obtained by increasing the gain potentiometer of the hearing aid while speech stimuli were presented via live voice at a conversational level (65 dB SPL) for each of the hearing aids coupled to the ear in the conventional manner with tubing and earmolds. A 2-cc coupler measurement of frequency response with a 50-dB input was obtained at the level where feedback occurred.

“...this study investigates the effects of receiver placement on the amount of gain before feedback...”

for sound delivery seems to have created a philosophical divide among audiologists regarding the fitting of open instruments.

At the core of the disagreement is the contention that instruments with the receiver in the canal are superior to thin-tube instruments in terms of available gain and frequency response. However, the applicability of this idea to open-fit BTEs has not been documented. This study investigates the effects of receiver placement on the amount of gain before feedback and frequency response as measured in two matched open-fit hearing instruments.

CAUSES OF FEEDBACK

Feedback in an acoustic system is caused by the re-amplification of sound from the receiver as it is input back into the microphone. This re-amplification can occur along numerous pathways.

First, a direct path is created when the microphone and receiver are in proximity to each other, unencumbered by any damping materials. This is the primary feedback path for open-fit BTEs, one in which the amplified signal escaping from the ear canal is not attenuated by an occluding earmold.

Other pathways arise via leaks in the coupling between the instrument shell and the external ear, as well as between tubing and earmold, earmold and earhook, and earhook and receiver. Emissions from the hearing aid shell, borne structurally or via acoustic transmission within the hear-

Then, the receivers were removed from the devices and placed in full-concha Instamolds, and the measurements were repeated and compared. They reported 2-cc coupler peak outputs of approximately 105 dB SPL with the receiver in the devices. When the receivers were placed in the ear canal, increases of 7 to 13 dB were observed in the maximum achievable output before feedback.

In interpreting these results, it is important to consider how the feedback path was altered. Relocating the receiver outside the BTE housing eliminates several feedback-transmission lines, including structural and acoustic transmission within the device, as well as acoustic leakage at the couplings between earhook and tubing and tubing and earmold.

However, the distance between the sound outlet in the ear canal and the microphone is the same regardless of whether the receiver is in the device or in the canal. This means that the feedback transmission line arising from acoustic leakage from the ear canal would have been the same in both conditions. Thus the observed increase in gain before feedback when the receiver was placed in the ear canal must have been due to the elimination of other components of the feedback path, which the authors also conclude.

For open-fit BTEs, the gain at which feedback occurs is determined primarily by the acoustic leakage of the amplified signal from the unoccluded ear canal to the instrument microphone, and is 15 dB or more lower than that reported by Ross and Cirimo, even with feedback cancellation active. This calls into question the applicability of these results to an open-fit BTE. Since acoustic leakage from the ear canal is the main limiting factor for this type of fitting, perhaps the additional feedback-transmission lines in an adequately designed thin-tube device would not be "stressed" to the point of causing feedback oscillation. If so, relocating the receiver to the ear canal would allow no more high-frequency gain than in the thin-tube device.

As evident in the Ross and Cirimo article, the increase in usable gain before feedback and changes in frequency response are clearly applicable to devices that provide high levels of amplification and use an occluding earmold. However, it is unclear if these findings would pertain to open-fit devices in which lower gain and output are applied.

IMPACT OF RECEIVER PLACEMENT

Given the widely accepted idea that receiver placement can affect open fittings, we designed a study to compare the attainable gain before feedback between two open-fit devices that are virtually the same in every way except placement of the receiver speaker.

The ReSound Pulse houses the receiver in the behind-the-ear portion of the hearing aid. A thin-diameter acoustic tube is connected to the hearing aid, which is then coupled to the ear canal with soft, non-occluding ear domes. The ReSound Pulse CRT (canal receiver technology) has the same housing as the Pulse, except that the receiver is replaced by a small output socket that attaches to the wire receiver assembly. Non-occluding ear domes attach to the receiver assembly, and are available in the same diameters as for the Pulse. The two devices have identical signal processing, although the electroacoustic specifications are slightly different due to the different receivers.

Methods

We fitted 12 subjects (7 male, 5 female) bilaterally with the Pulse and the Pulse CRT. The ear dome size was selected in accordance with comfort for the participant. The same dome size was used to fit both devices. The instruments were programmed using the Audiogram+first-fit rationale based on a mild sloping to moderately severe high-frequency hearing loss.

We disabled the noise reduction and feedback cancellation in order to isolate the mechanical and acoustic effects on stability for each condition. To determine the gain before feedback, the gain for 50-dB inputs from 1000 to 6000 Hz in the Aventa fitting software was slowly increased in one-unit (relative to the Aventa software) increments until the test subject heard feedback.

As the gain of the device was increased, the investigator announced the intensity level (e.g., 10, 11, 12, etc.). The subject used the number to indicate the level at which he or she heard feedback. Typically this level coincided with the level where feedback was audible to the investigator. After an initial provocation of feedback, the gain was reduced several units and was increased again to ensure that a reliable measure had been obtained. The subjects tested were familiar with feedback from

previous hearing aid use. The Aventa displayed gain for 80-dB inputs was kept stable. The simulated insertion gain value in the fitting software at which the subject reported feedback was recorded and used as quantification for maximum gain before feedback. This procedure was performed once for each device and on each ear.

Following these measurements, we reduced the gain in each hearing instrument to a level free from any spontaneous feedback, which in most ears was approximately 3 dB less than the gain before feedback level. At this stable level, the real-ear aided response (REAR) with a 65-dB SPL warble-tone sweep presented at 0° azimuth was obtained using the GN Otometrics Aurical Plus real-ear measurement system.

Results

The average maximum gain before feedback as quantified by the Aventa gain display was 23 dB for the Pulse and 22 dB for the Pulse CRT. A t-test indicated that these values were not significantly different ($p > 0.05$). The mean real-ear aided responses for the Pulse and Pulse CRT are displayed in Figure 1.

We conducted a t-test for audiometric frequencies from 250 to 6000 Hz. Significant differences were observed at only two frequencies, with the Pulse CRT response exceeding that of the Pulse by approximately 5 dB at 2000 Hz and 6 dB at 6000 Hz.

DISCUSSION

As noted earlier, relocating the receiver in a BTE instrument from the device housing to the ear canal can decrease the occurrence of feedback by limiting the number of possible feedback pathways. That is to say that there are fewer potential routes by which sound from a receiver in the ear canal can travel back to the microphone in the BTE portion of the instrument. The possibility for structural vibration due to housing the receiver together with the microphone is also eliminated when the receiver is located in the canal.

For high-gain BTE fittings, eliminating these elements of the feedback path clearly contributes to increased stability and added gain. However, for open-fit BTEs, the primary feedback pathway is acoustic leakage from the open-ear canal to the device microphone, which is not altered by placing the receiver in the canal.

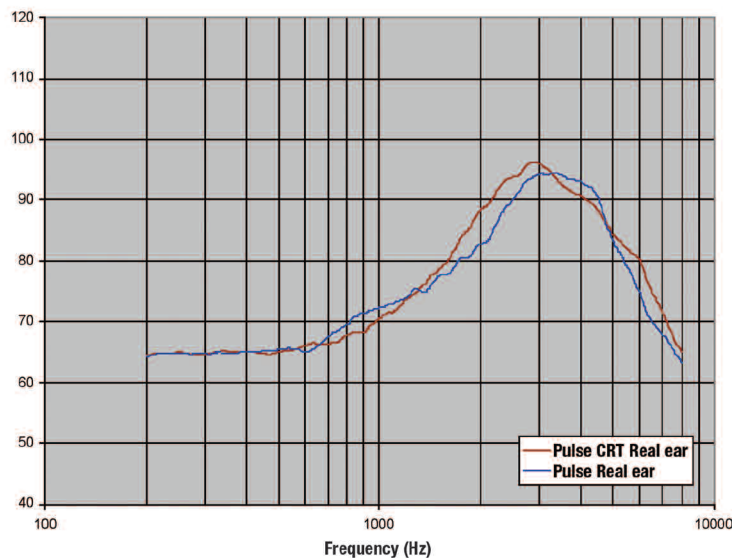


Figure 1. Comparison of the real-ear aided response for a Pulse and a Pulse CRT performed at the maximum stable gain before feedback ($n=24$ ears).

Thus, no advantage in terms of usable gain should be anticipated, and results from the present study support this.

Our study did reveal small differences in limited frequency regions, which are most likely attributable to tube resonances and receiver performance differences. An advantage of placing the receiver in the canal, whether in a custom instrument or a CRT type instrument, is a smoother frequency response. This is because of resonances of the tubing used to couple BTE instruments to the ear canal, and is typically demonstrated by contrasting the response of a receiver driven directly into a coupler versus one attached to the coupler with BTE tubing. Factory calibration of BTE instruments compensates for these tubing resonances as much as possible for the given instrument, including the Pulse.

In our investigation, we were interested in observing the frequency response in the real ear rather than a coupler. When the mean real-ear aided frequency responses for the two devices were compared, certain differences were apparent, although they were much subtler than coupler measurements would suggest.

One difference was additional gain for the Pulse CRT at 2000 Hz. This effect results from a system limitation that precludes full compensation for the tube response at this frequency. For this reason, one would expect the gain at 2000 Hz to be slightly lower for the Pulse than the Pulse CRT.

The other significant difference between the responses from the two instruments was an additional 6 dB of gain for the Pulse CRT at 6000 Hz. This was due to a wider bandwidth associated with this receiver, and may have implications in the perception of improved sound quality of CRT devices, given the correlation of wide bandwidth and high-fidelity acoustic systems. Such a correlation between subjective sound quality and high-fidelity amplification has been observed in normal-hearing individuals.⁵

CONCLUSION

Our study investigated the effect of receiver placement on gain before feedback and frequency response by comparing the Pulse coupled to the ear canal with an acoustic thin tube with the Pulse CRT receiver-in-the-canal device. We found that similar real-ear gain was achieved regardless of whether the receiver was located in the device housing or in the ear canal.

Our findings, while specifically applicable only to these products, cast doubt on anecdotal reports that placement of the receiver in the canal provides increased real-ear gain due to separation of receiver and microphone in open-fit hearing aids. Rather, better real-ear gain with receiver-in-the-canal devices, if present, would more likely be due to elimination of various feedback-transmission lines.

Given these findings, the decision to fit a patient with a device that delivers

sound either via a thin-tube or CRT technology should not be based on any assumption of differences in gain before feedback—assuming that the thin-tube device being considered is well-designed electroacoustically.

Both methods of sound delivery have certain inherent benefits and limitations that may be factors either for or against their selection by the clinician. As this study demonstrates, CRT devices potentially offer a smoother, wider frequency response. In addition, by their nature, CRT devices have no issues with moisture in the tube. Also, as technology progresses, manufacturers will be able to make smaller, more cosmetically appealing BTE devices or to add more options given the physical space gained from an externalized speaker. The obvious disadvantage of CRT devices is that, should a malfunction occur in the receiver, the CRT component is significantly more expensive to replace than a thin tube.

In summary, the findings of this laboratory investigation of the differences between an open-fit, thin-tube device and a CRT instrument with identical signal processing indicate that the maximum available real-ear gain does not justify selecting one instrument over the other. Both devices can be expected to perform similarly in the patient's ear, except for possible fluctuations in the smoothness of the frequency response. From that vantage point, the decision to select one of these technologies over the other should be based on other factors, such as cost/benefit analysis, ease of use, and personal preference.

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