OPEN SOLUTIONS – WHY, HOW & WHEN

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Abstract

Open hearing instrument fittings have become quite popular during the past few years. Many individuals with hearing losses appreciate open fittings due to the reduced negative perception of occlusion. This reduced occlusion also increases the potential acceptance by new users of hearing instruments. Thus, more individuals will accept amplification and will benefit from increased audibility.

The foundations of the open fitting concept come from basic acoustics. Advanced signal processing is then combined with the open concept to provide increased gain without acoustic feedback. These two items provide improved audibility and reduced occlusion perception. The open solution can also be applied to hearing instruments with other signal processing, for example directionality. However it is important to realize the implications of such applications and consider the user benefit. This presentation will focus on why there is a need for an open solution, how to implement the open solution, and when to use the open solution.

Introduction

The concept of hearing instrument fittings with open earmoulds has been available for decades. Typically, the fitting was obtained with a behind-the-ear (BTE) hearing instrument coupled to standard tubing. Often an earmould was used to hold the tubing in the ear canal and a minimal amount of material used in order to keep the ear canal open. These open fittings were successful only for individuals with minimal hearing losses. The fitting range was limited as increased gain also increased problems with acoustic feedback. Due to the limited fitting range, individuals with mild hearing losses often rejected amplification as the perceived benefit did not offset the negative cosmetics of a standard sized BTE hearing instrument using standard sized tubing.

The open solution challenge needed to provide appropriate amplification to a larger range of hearing losses as well as be more acceptable to more individuals. This article will deal with the issues that were addressed to have successful open solutions.

Issue Resolved: Occlusion Effect

One of the major complaints from individuals with hearing losses is that of their own voice. When an individual speaks or chews foods, the sound is received by the ear from two paths. The first path is the sound delivered acoustically via air waves that enter the ear canal. The second path is the resonating of the physical components of the individual's head (i.e. bone conduction). This is the reason that our own voice sounds different when we speak compared to when we listen to a recording of our voice. In the recorded presentation, the bone conduction path is not delivered as the sound is generated externally, not internally from the listener.

When the ear canal is plugged or partially plugged (e.g. ear plug, earmould, custom-made hearing instrument) the sound pressure in the ear canal for the internally generated sounds is greater than that of the open ear canal. This occurs because the sound cannot propagate out of the ear canal due to the physical barrier. The individual will often describe the occlusion as their own voice is too loud, boomy, hollow, or like they are speaking in a barrel.

The complaints due to the occlusion effect are typically from individuals with good low-frequency hearing, typically better than 40dB HL (Dillon, 2001). For individuals who have tried wearing hearing instruments, it has been estimated that 27% have been dissatisfied and/or discontinued use due to issues of occlusion (Dillon et al., 1999). Similar findings were reported by French-Saint George & Barr-Hamilton (1978), MacKenzie et al (1989), and Brügel et al (1992).

Why does occlusion need to be addressed? To improve the sound quality of the individual's own voice and thus have more acceptance to amplification.

How can the occlusion effect be reduced? The occlusion effect has often been reduced by increasing the diameter of the vent. This can be done for both BTE and custom-made hearing instruments. As the vent diameter increases, the occlusion complaints typically decrease. This is based on the physical properties of acoustic mass which is directly related to occlusion. The acoustic mass is determined by the following mathematical equation (where k is a constant):

$$\text{Acoustic Mass} = k * (\text{Vent Length}) / (\text{Vent Diameter})^2$$

As vent diameter is inversely proportional to acoustic mass, the increased diameter will decrease acoustic mass and can decrease occlusion. However, the vent diameter is limited by the diameter of both the individual's ear canal and the diameter of the hearing instrument tubing. The individual's ear canal is fixed and cannot be increased for obvious reasons. For custom-made devices, the vent size is also limited by the size of the hearing instrument components that are also placed in the ear canal. For the greatest vent diameter, a BTE device is needed. If thinner tubing was used, the vent diameter could increase more. The outer diameter of standard BTE tubing is 3.3mm; another tubing option is one with a smaller outer diameter of 1.02mm. Using smaller outer diameter tubing will logically decrease the inner diameter of the tube (1.9mm to 0.71mm). This will constrict the sound delivered from the hearing instrument and thus, the hearing instrument will need re-calibration for the new tubing characteristics.

Another variable that can be adjusted to decrease acoustic mass is the vent length. The vent length can be reduced by decreasing the length of the earmould. To decrease issues of acoustic feedback and for cosmetic reasons, the thinner earmould should be positioned deep within the ear canal. New earmould solutions have been developed where vent length is very short and a thin supporting structure holds the earmould in position. Open earmoulds are now available in standard sizes and thus, do not need to be custom made. In these cases, the open solution can be fit at the initial visit.

For individuals who need more gain than can be provided without feedback using standard open solutions, a custom earmould could be the solution. One example of a custom open earmould is a FlexVent. The FlexVent has either an equivalent 1.6 or 2.4 mm vent diameter and a length of 1.0mm. Combining the short length and large vent diameter will result in reduced occlusion. For further description and rational regarding the FlexVent, refer to Jespersen and Groth (2004). Kiessling et al (2005) reported occlusion measurements for 19 subjects with various venting options. One procedure measured the sound pressure level difference between the open ear canal and various earmoulds. During the measurements, subjects sustained the vowel /ee/. The average measured occlusion (250, 400, and 750 Hz) were around 7dB less for the FlexVents compared to the standard earmoulds with parallel vents and equivalent vent diameters. The data also reported that an open dome coupling option can provide occlusion measures that are not significantly different than an open ear canal.

By increasing the vent diameter and decreasing the vent length, the negative effects of occlusion are reduced. However, the solution also increases the probability for acoustic feedback and thus, limited gain will be available for amplification. This is the next issue that needed to be addressed.

Issue Resolved: Acoustic Feedback and Adequate Gain

The open fitting solution is focused on individuals with good low-frequency hearing when the risk of occlusion complaints are high. However, these individuals need appropriate high-frequency gain to provide audibility of sounds, especially speech. Increased gain will result in the desired increased sound pressure in the ear canal but also increased signal will pass out of the large vent. If this amplified signal reaches the microphone with enough energy, the hearing instrument will become instable and acoustic feedback will occur. When this happens, a disturbing whistle sound occurs and the hearing instrument will not provide the necessary output for audibility.

Why do the issues of acoustic feedback and adequate gain need to be addressed? To provide individuals with the required gain necessary for audibility.

How can acoustic feedback be reduced to provide adequate gain? Acoustic feedback suppression algorithms cancel the feedback signal and thus, provide more available gain. These systems were first introduced over 10 years ago. These algorithms are unlike the common notch-filter feedback management system where the hearing instrument gain is reduced in the frequency region of instability. While this will reduce acoustic feedback, it also decreases the audibility of signals in that frequency region.

Advanced feedback suppression algorithms typically incorporate two filters. The first filter focuses on the static properties of the fitting. Examples of these properties include the vent size and position, hearing instrument microphone and receiver orientation, and ear canal size and shape. The static filter characteristics are determined by a calibration signal that is presented during the fitting of the hearing instrument. A second dynamic filter will adapt the filter characteristics dependent on changes in the daily environment. Examples of these events include placing a telephone at the ear, wearing a hat, or cupping the hand at the ear.

While most hearing instrument manufacturers have feedback suppression algorithms, all are not equal. Two areas are of critical concern: increased headroom and artifacts. Headroom refers to the increased gain provided from the feedback suppression algorithm. For example, an individual wearing a hearing instrument might get 20dB of feedback-free gain with feedback suppression deactivated and this could increase to 35dB of feedback-free gain with feedback suppression activated. This 15dB of increased headroom will provide substantial improvement in audibility.

The second area of concern is that of artifacts. These artifacts occur when the feedback suppression algorithm fails to accurately determine the acoustic feedback characteristics. For example, when listening to flute music, keys jingling, or bells, some systems will classify these sounds as acoustic feedback. In these cases, the hearing instrument will produce a signal that is opposite in phase to the signal to cancel it. As the signal occurs in the listening environment and not due to an instable hearing instrument, these phase-reversed signals will be undesirable audible signals or artifacts.

As stated above, acoustic feedback occurs when the hearing instrument output reaches the hearing instrument microphone at a great enough level. For dual-microphone hearing instruments, this creates an interesting problem. Dual-microphone hearing instruments were introduced to increase the understanding of sounds (i.e. speech) from the front. As the hearing instrument has two microphones, two feedback paths will occur in these instruments. The first is between the receiver and the front microphone and a second is between the receiver and the rear microphone. To ensure maximum feedback-free gain, both feedback paths need to be addressed. One way to accomplish this is by using two feedback suppression algorithms that are independent for both microphones.

The open fitting solution has incorporated a large and short vent and combined it with feedback suppression algorithms to increase useable gain. The next issue addresses the user concerns of cosmetics and physical comfort.

Issue Resolved: Cosmetically Acceptable and Comfortable

For many individuals with hearing impairments, cosmetics of the hearing instrument are very important. People often do not want to appear different than others or be seen as having a hearing problem. For this reason, completely-in-the-canal (CIC) custom hearing instruments are popular. The device was worn deep in the ear canal and thus, is more discreet than a larger device. However, the CIC instrument is often uncomfortable in the ear canal; is difficult to make for smaller ear canals; causes occlusion complaints and vents can not be enlarged; are prone to clogged or damaged receivers (e.g., from cerumen); and are often difficult to insert and remove. Thus, a new solution was necessary.

Why do the issues of cosmetics and comfort need to be addressed? To provide the individuals with a solution that will be acceptable to wear for both cosmetics and comfort.

How can these issues be resolved? The vision of the open solution was that the device should be an extremely small BTE case that is unique compared to hearing instruments of the past. The small size would be more cosmetic and it would also provide a more modern, high-tech feel for the audience that is typically younger in age. The thin tube used to deliver the hearing instrument output into the ear canal would allow for a larger venting as discussed previously. It is also often difficult to see and thus, is more cosmetically acceptable.

An additional benefit to this small, sleek design is the decreased weight of the device. The device is only 1,4 grams. Figure 1 displays the weights of six different typical hearing instrument options. The weights include the required components (i.e. tubing, earmould, battery). The smaller open solution is five times lighter than a BTE device that was considered small. This will decrease the feeling of wearing a device on the ear.

The open solution now has reduced occlusion, increased feedback-free gain, and improved cosmetics and comfort. The next issue addresses the processing delay of the instrument.

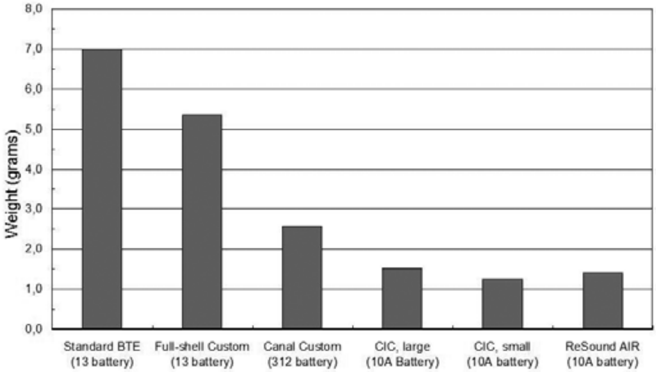

Figure 1. Weights (grams) for six different typical hearing instrument options including required components (i.e. tubing, earmould, battery).

Issue Resolved: Hearing Instrument Processing Delay

Hearing instruments modify (e.g. amplify) the acoustic signal before it is delivered to the ear. The time it takes to complete this processing is referred to as the processing delay. If the processing delay is very long, the acoustic signal delivered to the ear can follow after the visual signal is received. This is unacceptable. Shorter delays will integrate with the visual system but, they might still be delayed compared to the unprocessed acoustic signal.

The risk of audible timing differences between acoustic events (unprocessed vs. processed) is more likely when using an open coupling option and the individual has audibility of unprocessed sounds. For open fittings, the direct sound mixes with the amplified sound in the ear canal and this increases the risk that the individual will perceive the timing delay. This perception, often described as an echo of the acoustic signal, may lead to rejection of the hearing instrument.

Why do the issues of processing delay to be addressed? To provide individuals acoustic input that does not have a perceived echo.

How can the issue be resolved? Processing delay is inherent in all real-time digital processing systems. Fortunately, as Stone and Moore (1999) reported, the auditory system can tolerate some timing differences and still hear a natural sounding signal. The key to delivering the natural sound is to ensure that all processing delays are below this perceptible difference.

Processing delay is dependent on two items: algorithm speed and micro-processor speed. In order to provide minimal delays, efficient algorithms and fast micro-processors are required. It is important to also realize that these processing delays can be frequency dependent. While two hearing instruments might both have delays less than 5ms at 2000 Hz, one might be greater than 6ms in the low frequencies (see figure 2). Thus, it is important to have similar processing delay across frequencies and always inaudible to the user. Another signal processing issue has to do with noise.

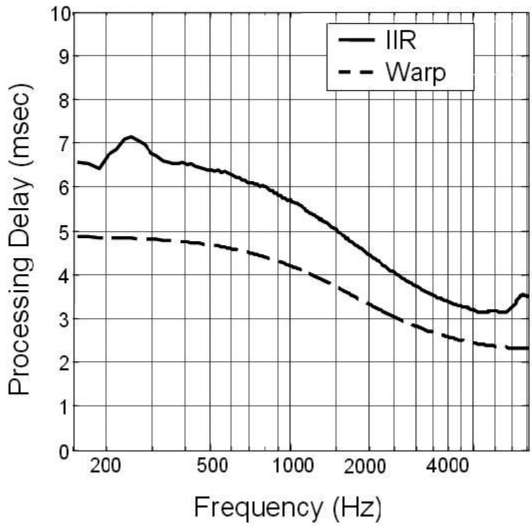

Figure 2. Processing delay across frequency for Warp and IIR processors.

Issue Resolved: Noise

Noise can be generated internal or external to the device. An example of internally generated noise is that of the microphone or receiver. These noises can have low sound pressure levels but, for individuals with good low-frequency hearing these noises can be audible. This is an issue when the environment is quiet and higher gain is applied for audibility. Externally generated noises originate from many sources, such as the hum generated by the refrigerator. These noises can be bothersome to the hearing instrument user.

Why do the issues of noise need to be addressed? Individuals can be bothered by these noises and thus, reject the hearing instrument based on sound quality.

How can these issues be resolved? The noises mentioned are typically low intensity sounds and are heard in quiet environments when other sounds do not overpower them. In these situations, the hearing instrument is providing the most gain for audibility of important acoustic signals, such as whispered speech. Modern hearing instruments often implement expansion for these low-level input signals. The gain characteristics are programmed so that very soft speech sounds are audible with maximum gain from the hearing instrument. However, for input signals that are below this input level, the gain is reduced. This reduces the audibility of low-level internal and external sounds. The expansion characteristics typically have a steep slope so gain is quickly reduced for these inputs. This increases the sound quality for individuals who are bothered by hearing these noises. The final area that will be discussed is that of improving speech understanding in background noise – a common problem for individuals with hearing losses.

Issue Resolved: Open Directionality
One of the most difficult listening environments for individuals with hearing instruments is that of understanding in background noise (Kochkin, 2000). The use of directional microphones in the hearing instrument has been shown to provide the greatest improvement in speech understanding in noise (Agnew & Block, 1997; Preves, 1997; Ricketts & Dhar, 1999; Valente, Fabry & Potts, 1995). In these situations, the hearing instrument will amplify sounds from the front more than sounds from the sides and back. However, when using an open solution, the processed directional-benefit signal will mix with the unprocessed non-directional signal and the benefit might be reduced. Further, it is important to ensure that the directional microphone system provides benefit across the entire frequency range.

Why do the issues of hearing instrument directionality need to be addressed? To provide the individuals with improved speech understanding when using an open solution.

How can these issues be resolved? The issues can only be resolved with improvements to the directional microphone performance. This can be accomplished by focusing the maximum listening angle to 0° azimuth when the device is worn on the head, decreasing the listening angle so more sounds from the sides are reduced in amplitude, increasing the reduction of sounds originating from the sides and back, and ensuring these benefits are realized across the entire frequency range. It is important to note that not all directional instruments provide the same benefit.

In an internal trial, GN ReSound compared the Canta7 Open hearing instrument in omnidirectional and directional modes. Speech was presented from the front (0° azimuth) and noise was presented from the sides (90° & 270°) and back (180°). Subjects repeated sentences when listening in a speech-babble background noise. Noise was presented at 65dB SPL and the speech level was adjusted until 50% performance was obtained. The directional benefit was the difference between the omnidirectional and directional modes. The result indicated a 3.4dB benefit. In other words, when in directional mode, subjects maintained performance with 3.4dB less intense speech level relative to the background noise.

When to Use an Open Fitting

Now that the open solution has been solved, when can it be used clinically? The open solution can be beneficial for individuals with up to a 40dB HL hearing loss in the low frequencies and up to 80dB HL hearing loss in the high frequencies. The individual's specific needs also need to be addressed. For example, a progressive hearing loss might dictate the use of a hearing instrument that is larger and can provide adequate gain with a classic sized vent when needed. The open fitting solution has provided another option for individuals with mild-to-moderate hearing losses who would find traditional amplification solutions unacceptable for sound quality and comfort.

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