Ampclusion Management 101: Understanding Variables

A tutorial on occlusion, its causes, and how to reduce/eliminate its effects

The term “ampclusion” denotes the occlusion effect experienced during hearing aid use and audiometric testing, when the physical occlusion of the ear canal and the hearing aid amplifier gain are included in the wearers’ perception. Complaints about ampclusion may originate from shell blockage of the ear canal, to sub-optimal amplification settings for amplifying the wearers’ voice, to an over-expectation for hearing aid performance. This article provides a summary of the factors that can contribute to the wearers’ complaint of the ampclusion problem, and a follow-up article details remedies for the various causes of ampclusion.

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Much of the literature on hearing instrument fitting has focused on the wearers’ perception of externally generated sounds. This is reasonable because the primary objective of a hearing instrument is to improve the audibility (and hopefully intelligibility) of external signals. On the other hand, a potential negative side-effect of hearing instrument use—the occlusion or “hollow voice” effect—has been cited by as many as 30% of hearing aid wearers as a reason for their dissatisfaction (or discontinued use) of their hearing instruments. It is reasonable to expect that any methods that can effectively minimize this complaint would significantly improve satisfaction with hearing aids.

Variables Affecting the Wearers’ Own Voice

During audiometric bone conduction testing, the physical occlusion of the ear canals by the headphones (or inserts) improves the low frequency bone conduction thresholds of the test subjects. Tonndorf termed this improvement in low frequency bone conduction thresholds the occlusion effect (OE). Hearing aid wearers experience the occlusion effect when they speak while wearing their hearing aids because the insertion of an earmold or of a hearing aid lowers the bone conducted speech reception threshold (SRT) of the wearer. A difference between the occlusion effect experienced during hearing aid use and that during audiometric testing is that the effect of the hearing aid amplifier is also included in the wearers’ perception.

To distinguish between these two origins of occlusion effect, Painton used the term ampclusion to describe the dual origins of the complaint reported by hearing aid wearers. The term ampclusion will be used in this article to include the contribution of shell occlusion and hearing aid amplifier gain to the perception of unnaturalness in the wearers’ own voice. Other related observations like hearing oneself chew crunchy, crispy food, or the thumping of one’s footstep have similar origins.

Hearing aid wearers express the ampclusion effect by using various descriptors, like “hollowness,” “talking through the nose,” “plugged,” etc. Some of these descriptors may reveal the underlying origin of the wearers’ ampclusion complaint. These variables include shell and amplifier origin and user experience/expectations.

Shell Origin

Occlusion of the ear canal. During vocalization, the vibration of the vocal folds sets the skull into motion along with the air within the ear canal. Much of this sound pressure in the ear canal is eventually transmitted to the cochlea via the tympanic membrane and ossicular chain. In the open ear condition, this transmission is less effective in the low frequencies than in the high frequencies since the open ear canal constitutes a more effective “short circuit” at low frequencies than at high frequencies (i.e., much of the low frequencies dissipate out of the ear canal). When the ear is occluded (as in the use of a hearing aid/earmold), the low frequency sound pressure level (SPL) in the ear canal is “trapped” by the earmold/hearing aid, resulting in increases in low-frequency SPL.

Other changes also occur. The resonance characteristics of the occluded ear canal change from the quarter-wavelength...
resonator to a half-wavelength resonator. The impedance at the tympanic membrane is modified along with the damping characteristics of the ear canal wall. These changes lead to a greater low-frequency output during vocalization in the occluded condition than in the unoccluded condition. Figure 1 shows the real-ear output for an open ear and an occluded ear during sustained vocalization of the sound /i/. The additional low frequency output may have led hearing aid wearers to use adjectives like “hollow,” “echoing,” “talking in a barrel/closed room,” or “boomy” to describe their perception.

**Insufficient venting/leakage.** When the origin of the ampclusion complaint is primarily shell occlusion, minimizing the physical occlusion or increasing the leakage by using larger vents could alleviate the complaint.

Westermann indicated that vents act like acoustic short-circuits in a hearing aid shell (i.e., allowing “trapped” low frequency sound to escape). He estimated that a vent size of 2 mm is sufficient to remove the effect of shell occlusion. Revit, however, showed that a 2 mm vent reduced the occlusion effect by 8.5 dB at 200 Hz but had no effect at 500 Hz. In addition, as the vent size decreases, more occlusion effect is noted. Kampe & Wynne also showed that, as the vent size increased, the low frequency SPL measured in the subjects’ ear canals decreased. However, no correlation was seen between the measured low frequency and the subjective impression of occlusion. Figure 2 shows OE as a function of vent diameter.

A particularly interesting observation in Kampe & Wynne’s study was that, in some subjects, the introduction of a vent increased (instead of decreased) the measured occlusion effect. A possible explanation for these somewhat inconsistent effects of vents may have to do with the phase response of the vent (and its interaction with the phase response of the direct signal and that of the hearing aid). Below the Helmholtz resonance frequency (which is determined by the complex relations between the length and diameter of the vent and the residual ear canal volume) sounds entering through the vent may cancel sounds leaking through the vent. On the other hand, above the Helmholtz resonance frequency, sounds leaking through the vent may add to sounds entering the vent, increasing (rather than decreasing) the measured SPL in the ear canal. This may partly explain the ‘inconsistent’ effects of venting on the occlusion effect and the difficulty in controlling the amount of low frequency gain in hearing aids through venting. This prompted Schweitzer & Smith to propose an “electronic vent” where the dispensers can electronically adjust the phase response of the circuit to cancel out frequencies around 500 Hz where the wearer’s voice dominates.

Despite the occasional inconsistency, the general effect of venting has been positive in alleviating the occlusion effect and improving sound quality. However, it should be recognized that venting could compromise the advantages offered at low frequencies by directional microphones and alter the real-ear compression ratios.

When working with nonlinear directional hearing aids, one may consider starting with the smallest vent size that is just sufficient to minimize the occlusion effect so significant compromise on the directivity index and compression ratio will not occur. The use of a Select-A-Vent (SAV) system may be desirable to achieve this purpose. It is also of interest to note that some preliminary work suggests a possible relationship between the middle ear compliance of the wearers and the minimum vent size that is required for minimal occlusion.

Similarly, leakage of sound from a loosely fitted earmold/hearing aid shell has also been reported to minimize shell occlusion. This may have the same mechanism as venting. Mueller reported that tapering a CIC hearing aid lowered the real-ear SPL relative to a bone-conducted stimulus from 125 Hz to 300 Hz but increased its output at 400 Hz. No change in the response to external sounds was noted. However, Staab reported the opposite finding.

The seal of the hearing aid at the bony section of the ear canal is another variable that may affect the perception of the ampclusion effect. Bryant et al. compared ITEs built in the traditional manner with ITEs that are built with minimal-contact-technology (MCT) but with a deep canal length and total acoustic seal in the bony portion. Their results showed a reduction of the occlusion effect by 10 dB at 200 Hz. While this technique may be effective, Pirzanski estimated that 80% of CIC wearers may not accept such a solution because of potential physical discomfort. **Insufficient canal length beyond second bend.** Tonndorf, in explaining the occlusion effect (OE), noted that the measured OE decreases as the depth of insertion of the occluding device (e.g., insert earphone) increases. He attributed this to an increase in impedance at the tympanic membrane as well as to the modified resonance frequency of the occluded ear canal. This explanation has also been used by Berger who showed that the relative amount of occlusion effect varied as a function of the depth of insertion of the hearing protectors (Figure 3).

Killion et al extended Zwischen’s observation of the occlusion effect into hearing aid fittings. These authors showed a significant reduction in the measured real-ear OE when the canal portion of the custom hearing aid extended far beyond the second bend of the ear canal. A hearing aid that extends beyond the second bend with a tight seal in the bony portion of the ear canal was recommended to overcome the occlusion effect. This observation was supported by subsequent

**Figure 1.** Real-ear response of /i/ measured in an open-ear and an occluded ear condition.
As indicated earlier, a deep canal seal during vocalization.

As indicated earlier, a deep canal seal hearing aid may be physically uncomfortable to some wearers. Unless the amplification effect can only be resolved with a long ear canal, many dispensers would opt for a more comfortable solution. Bongiovanni et al.22 examined the difference in patients’ subjective preference for two versions of a CIC that were matched in target gain (and venting) but differed in canal lengths. In one version, the canal tip terminated 2 mm before the second bend of the ear canal. In the other version, the canal tip terminated 2 mm beyond the second bend. As predicted, the shorter version was more comfortable to the wearers. However, no group difference in the quality of the wearer’s own voice was evident. This suggests that, while canal lengths may affect the amount of shell occlusion within the ear canal, it may not be the sole factor governing the perception of amplification for all wearers.

Manufacturing variation. Pirzanski19 speculated that if the effect of shell diameter is significant on the observed occlusion, then one may expect variation in the observed occlusion effect when using different impression materials, different impression-taking techniques, and different manufacturing processes for the same ear impression/client. Consequently, Pirzanski took ear impressions of one individual in a chewing position, a closed-jaw position, and an open-jaw position. Two types of inserts were made: one with a hard shell and the other with a silicon impression material with a low Shore value. The lengths of the canal inserts ranged from 0-21 mm from the canal opening. Additionally, some of the inserts were vented. Real-ear measures of the occlusion effect were made while the subject produced a sustained /i/ sound. The results showed significant variability in the measured occlusion effect as a function of the canal length, venting condition, how the impression was taken, as well as the manufacturing process (number of coatings).

On the other hand, some of the variations observed in Pirzanski’s study19 were not easily explained on theoretical grounds. More data would be needed to define how each variation could affect the measured occlusion effect. Nevertheless, the study points to the complexity of managing the occlusion effect.

Amplifier Origin

Excessive low frequency output in the ear canal. While physical occlusion increases the low frequency SPL in the ear canal during vocalization, such is not the only source for the increase in low frequency SPL. The input level of one’s own voice at the position of the hearing aid microphone, assuming a normal vocal effort, is higher than that measured at a conversational distance of 1 meter. This is due to the shorter distance between the speaker’s mouth and his/her own ears compared to the typical conversational distance.

In addition, the radiation characteristics of the mouth also affect the SPL measured at the ear level.21 Indeed, if one measures the SPL at the ear level, it is frequently 15-20 dB higher than that measured at a distance of 1 meter. Figure 5 shows the difference in the long-term speech spectrum measured at a distance of 1 meter and at the ear level. An increase in the low frequency and a slight decrease in the high frequency are seen. This knowledge is important when it comes to fine-tuning the acoustic parameters of a hearing aid to minimize the amplification effect.

A second factor that increases the low frequency output in the ear canal is the low frequency gain provided by the hearing aid. These two factors (i.e., increase in low frequency input and available low frequency gain) further increase the low frequency energy in the wearers’ ear canals during vocalization.

In order to determine if the amount of low frequency output plays a role in the wearers’ perception of their own voice, Kuk24 instructed hearing aid wearers to select their preferred frequency-gain responses on a programmable hearing aid while they listened to their own vocalization and to externally presented speech. The results showed that the average preferred frequency response for the listening task had significantly more low frequency gain than the preferred frequency response selected for the vocalization task.

In a follow-up study, Kuk et al.25 demonstrated that a hearing aid that adaptively changed its low frequency gain according to input levels resulted in a reduced perception of hollowness.

Excessive sound pressure level in the ear canal. On the other hand, some individuals with high frequency hearing loss who were wearing what is essentially an open mold with no low frequency gain on the hearing aid still reported the amplification effect.25 This suggests that low frequencies per se may not be the only contributor to the amplification effect. Rather, it may be the overall loudness that contributes to such a perception.

The low frequency effect is more noticeable because low frequency sounds contribute more to loudness than mid and high frequency sounds. In the absence of low frequency, the amplified mid and high frequency sounds may contribute to the overall loudness and thus to the amplification effect. Wimmer26 reported that the amplification effect was diminished by a reduction of overall gain. In Kuk’s study,24 the average subject also preferred a lower overall gain for the speaking condition than the listening condition.

Insufficient output SPL. It is not infrequent to find hearing aid wearers whose
ampclusion complaint is due to insufficient output. This may occur in an under-fit situation where the insertion loss created by the physical occlusion of the hearing aid is not overcome (or is only partially overcome) by the gain of the hearing aid, or the hearing loss in the low frequency is not adequately compensated.

An example of circumstances where this may occur is the use of a minimally vented completely-in-the-canal (CIC) hearing aid for a mild-to-moderate hearing loss. Sweetow & Valli28 explored this possibility in 10 CIC wearers (15 ears) and found that almost half of their subjects required a gain increase to minimize the ampclusion effect whereas half required a gain decrease. Frequently, wearers whose ampclusion complaint originates from this cause may describe it as “talking through the nose,” “closed,” “plugged,” “can’t hear own voice,” “unnatural,” “own voice too soft,” “muffled,” or “distorted.” Ampclusion complaint that originates from insufficient output requires more low frequency gain than the settings on the hearing aids provide.

**Imbalance of sound pressure output at different frequencies.** One possibility for the unnatural voice during vocalization may be a tonal imbalance between high and low frequency output during vocalization where such balance is achieved for listening to external sounds. Killion29 improved a hearing aid fitting from the occlusion effect by increasing the mid and high frequency gain on the hearing aid.

Wearers may comment that their vocalizations sound “unnatural,” “muffled,” “too loud,” “too much bass,” “boomy,” or “too tinny.” Although the same comments may be made for external sounds, it is important to recognize that these comments are made relative to a high input level. Under this hypothesis, remediation may be difficult because tonal balance for vocalization may disrupt the tonal balance for listening to external sounds. Wearer counseling and re-training may be necessary.

**Distortion of input/output.** Although not truly a possibility for the ampclusion effect, some wearers may report distortion from their hearing aids during vocalization as “unnatural.” The high input level at the microphone opening during vocalization suggests the possibility that the wearers’ voice may saturate the hearing aid at the input stage.

Saturation may be especially likely for individuals who speak at a higher than normal volume. Another possibility is saturation distortion at the output stage when the output limit of the hearing aid does not increase with gain settings. This would be especially true for linear hearing aids that use peak clipping as the output limiting method. Subjective comments like ‘distorted,” “unnatural,” “static” are frequently used to describe voice problems with such origin. Gain reduction at high input levels and the use of a compression limiting circuit at the output stage may solve such complaints.

In contrast, some wearers react negatively to gain reduction at high input or to a compression limiting circuit. They may say that their own voice sounds “muffled,” “unnatural,” or “not loud enough.” This is especially a possibility for those who are accustomed to linear hearing aids with peak clipping. The dispensing professional may need to increase gain at high inputs (i.e., increase MPO setting or decrease compression ratio) to satisfy these wearers.

**Multichannel specificity.** A concern in minimizing the ampclusion effect is that any gain reduction should not affect intelligibility. This should not be a major concern because the ampclusion effect is primarily below 500 Hz where minimal intelligibility information is available.

In practice, it is often impossible to achieve complete ampclusion reduction without accompanying intelligibility reduction. This is because conventional single-channel aids lack channel specificity (or channel independence), so that low frequency gain reduction also leads to gain reduction in the nearby frequencies. To preserve intelligibility, one may have to compromise the effectiveness of ampclusion reduction by limiting the amount of gain reduction.

Historically, this fact has fueled the popularity and use of some multichannel hearing instruments. Due to the independent compressors, a multichannel hearing aid has a higher potential for allowing specificity in low frequency adjustment without affecting intelligibility. On the other hand, a multichannel aid with highly overlapping filters (shallow filter slopes) may not improve the situation because gain adjustment to one frequency region may “spread” to nearby frequency regions. Consequently, there is no guarantee that a multichannel device will provide better management of the ampclusion effect. Rather, one may hypothesize that the multichannel devices with narrower bandwidths (especially in the low frequencies) and steeper filter slopes may offer more specificity (and thus more effective occlusion management) than ones with a broader bandwidth and shallower filter slopes.

**Artifacts of some DSP hearing aids.** In contrast to analog and programmable hearing aids, digital signal processing results in a delay of the processed signal (relative to the unprocessed signal).

The exact amount of delay (or group delay) varies from one DSP design to another. (For an example of how to test for this phenomena, see Frye.29) While short delays are not noticeable to the wearers, longer delays are noticeable and result in an echoic sensation when the wearers listen to external speech and to their own voice, depending on the earmold/shell condition. This echoic sensation occurs when there is a mixture of processed sounds and direct sounds in the wearers’ ear canals.

In a completely occluding earmold, group delay may only produce an echoic sensation of one’s own voice because there is no vent to provide a direct sound path for external sound. The wearer’s own voice that is trapped within the ear canal via bone conduction interacts with the hearing-aid-processed sounds in the ear canal to produce the echoic sensation. By contrast, in a vented earmold/hearing aid shell, the direct acoustic signal enters the ear through the vents/leakage in the hearing aid shell/earmold. When this signal is mixed with the processed sound from the hearing aid, the partial overlap could result in an “echoic” or “hollow” sound.

Stone & Moore30 and Agnew & Thornton31 showed that a group delay as little as 5-10 ms could result in perceptible artifacts. This perception is less like-
ly in the severe losses because these wearers are less likely to use large vents in the earmolds. Obviously, to minimize such perception, the choice of DSP hearing aids with minimum group delay is important.

**Inexperience and Expectations of the Wearers**

It is a common observation that new hearing aid wearers complain of the occlusion effect more frequently than experienced hearing aid wearers. One reason for such an observation may be that new wearers are not familiar with their hearing aids, whereas experienced wearers have resided to the experience that amplification is a necessary side effect of hearing aid wear.

Compared to experienced wearers, new wearers are exposed to a new set of challenges when they wear their hearing aids. They may not expect the occlusion of the ear canal to bring such changes in the quality of their own voice. This raises the importance of pre-fitting counseling for hearing aid wearers so that proper and realistic expectations can be set. Poqash & Williams* have also indicated such possibility.

**Clinical Implications**

Because of its myriad nature, resolution of the occlusion complaint would necessarily need a precise identification of its origin so that proper and efficient solutions can be applied. The next article will consider a systematic approach to managing occlusion effects in hearing aid wearers.

**References**


