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If you spend a fair amount of time reading journal articles, you will find a few that are especially memorable. And, of course, catchy titles help.

Many of us became interested in audiology when we learned that one of the required readings was "The Cocktail Party Effect." Who can forget the J. Donald Harris article "My Love Affair With Ruth Bender"? And you have to like this contribution from Marion Downs: "The A.B.C.D.s to H.E.A.R."

Back in 1988, an article by Mead Killion, Laura Wilber, and Gail Gudmundsen caught my eye. It was titled "Zwislocki Was Right..." Prior to seeing this title, it never had occurred to me that Zwislocki could be wrong, so I was hooked.

The reference to Zwislocki related to an article he published in 1953 in *Journal of the Acoustical Society of America*, in which he illustrated that placing an earplug deep in the ear canal significantly reduced the occlusion effect. This was some of the first research supporting one of the benefits of today's insert earphones. What I realized when I started reading "Zwislocki Was Right..." was that there was a lot I didn't know (or didn't remember) about the hearing aid occlusion effect. For example, I didn't know that sound pressure levels for vowels like "ee" were as great as 140 dB SPL in the back of the mouth. I didn't know that vowels like "ah" have much less intensity and cause very little occlusion effect. I didn't know that when the patient is using an unvented earmold, the occlusion effect can add 25-30 dB to the ear canal SPL for a vowel like the "ee," with the resulting ear canal SPL around 100 dB. I didn't know that when Laura Wilber chewed nacho-flavored Doritos that the SPL in her occluded ear canal was nearly 80 dB SPL in the 200-Hz region. And I didn't know how easy it was to measure all this with my probe-microphone equipment.

It's been 15 years since "Zwislocki Was Right..." was published, and in this month's Page Ten, I'll review some of the things we've learned since then. I don't know if Zwislocki said "we haven't made much progress in treating the hearing aid occlusion effect problem," but if he did, he'd be right about that, too!

**Gus Mueller**
Page Ten Editor

# There's less talking in barrels, but the occlusion effect is still with us

*By H. Gustav Mueller*


*Mueller*

**1 The occlusion effect, you say. Can I assume you are referring to the complaint by patients that their own voice sounds "hollow," "booming," or "echoing" when they are using their hearing aids?**

That's it. Those certainly are some of the terms that you might hear from patients who have a significant occlusion effect, which I'll abbreviate as OE. Of course, you might hear those same complaints from someone who doesn't have a large OE, but rather is experiencing unwanted hearing aid gain in the low frequencies.

Another common description of the OE is "It sounds like I'm talking in a barrel." In 20 years or so, we probably won't hear that one much anymore. People just don't talk in barrels as much as they used to.

**2 If you say so. The OE—I'll call it that, too—is an old problem, isn't it?**

Very. As you probably recall, it was because of the OE that Albert Bing and Friedrich Weber had moderate success with their tuning fork tests back in the 1800s. And, we all know how the OE complicates bone conduction and masking procedures. In fact, most research on the OE relates to using a bone-conduction oscillator to present the stimulus. Regarding hearing aids, I suspect that the OE has been a problem as long as earmolds have been used. Who knows, maybe it even occurred for a tightly fitting ear trumpet.

Surprisingly, there really wasn't much written about the *hearing aid* OE until the 1980s. A report by Macrae from the National Acoustic Laboratories in Australia is one of the first I recall on the topic.[1] Wayne Staab, however, recently reminded me that von Bekesy indirectly talked about the hearing aid OE in his 1960 book, *Experiments in Hearing*, where he states, "For maximally useful hearing, it is important to reduce not only the sounds of vocalization but also noises produced by chewing, swallowing, and the like. Even walking produces vibrations of the body that can be heard if the auditory meatus is closed..."[2]

**3 I enjoy history too, but what new information do you have on the hearing aid OE?**

We've learned quite a bit over the past 10-15 years, and today there is increased interest in the topic from both dispensers and manufacturers. There probably are several reasons for this. We fit more CICs than before, and venting, the most common treatment for the OE, is limited with CIC products. We also tend to fit people with milder hearing losses than we did in years past; in general, the OE bothers them more.

Another factor is that market penetration for hearing aid use is declining, which should prompt all of us to examine critically the reasons that people are dissatisfied with hearing aids. Problems with the OE are one reason. Finally, I believe the switch to digital

hearing aids also has had an impact. People purchasing high-end digital products understandably have high expectations, including that their own voice should sound "normal."

## 4 But with today's digital products, we don't have as many OE problems, right?

I hope I'm wrong, but my best guess is that our patients have as many OE problems with today's devices as they did when we were fitting single-channel, linear peak clippers back in the 1970s. Consider that the magnitude of the OE is related primarily to the hearing aid shell, not what's inside it. The enhanced SPL trapped in the residual cavity of the ear canal finds its way there via bone conduction, not through the hearing aid. It doesn't know (or care) what's inside the case that is preventing it from escaping.

Now, *if* the patient doesn't need low-frequency gain for audibility of speech and *if* the adaptive feedback circuit of the digital instrument allows us to fit a larger vent and *if* this vent is large enough to allow the bothersome signals to leak out, then yes, we should be able to make things a little better with today's technology.

It's difficult to track if we've made any progress over the years regarding the hearing aid OE because usually it's not documented if that's what is causing patients' dissatisfaction with the sound of their own voice. For example, a person whose hearing aid goes into saturation when he talks probably will be dissatisfied with the sound of his own voice, yet this has nothing to do with occlusion. Or a wearer could have too much low-frequency hearing aid gain, but this has nothing to do with the OE. Sergei Kochkin includes satisfaction for "sound of voice" on his MarkeTrak surveys. If we assume that for many of the respondents, satisfaction is related to the OE, then there has been no improvement as technology has progressed. From MarkeTrak V in 1997 to MarkeTrak VI in 2000, satisfaction stayed around 60%, and dissatisfaction around 10% (the other 30% were "neutral").[3] In a direct comparison of "non-programmable" to "programmable," Kochkin reports no difference in satisfaction for "sound of voice."[3]

## 5 I tend to use the term "ampclusion?" Are we going to talk about that here?

Not directly, partly because I'm not sure I understand what it is. It seems to be a popular term, as I've seen it used in several articles. I thought it was something that Robert Sweetow[4] made up, but he tells me that he got it from a *JAAA* article by Steve Painton.[5] I looked it up and, according to Painton[5] (page 152), *ampclusion* is "the combination of occlusion and low-frequency amplification that results in the 'hollowness' or 'head in the barrel' complaints." So, if I'm understanding this correctly, if you know that the patient's problem is caused by the OE, then the patient *would not* have ampclusion, as there is no "combined" effect.

I guess I don't use "ampclusion" because I don't view the *combined* effects as the major clinical issue. It's possible that there could be an OE problem at 200 Hz, and too much gain at 500 Hz, but usually the problem is one or the other. For effective treatment and management, we need to determine which of the two factors is the prime contributor to the problem. It's sort of like differentiating cochlear from nerve VIII when a patient has a "sensorineural" hearing loss.

## 6 So, how do I differentiate the OE from "own voice" problems caused by amplification?

That's an easy differential. You conduct testing with the hearing aid in place, but turned off. If the ear canal SPL of the patient's voice is greater with the hearing aid in place than it is for the open ear, you can be quite certain that the SPL increase that you observe is due to the OE. If the difference is large, and greater than the amplified speech signal, then occlusion is most likely the cause of the problem.

## 7 You say "the SPL increase that you observe." Don't you mean the sound quality difference that the patient observes?

You could rely on the patient for this information. One technique is to have the patient read a passage in different conditions, and see if he notices a change in the way his voice sounds. If the problem lies with the OE, then it will exist when the hearing aid is in the ear but turned off. By doing comparisons of "open ear" with "hearing-aid-in-turned-off" with "hearing-aid-in-turned-on" you might be able to isolate the problem. This is probably an okay screening tool, but it's not a very precise measure. My preference would be to conduct probe-mic testing of the OE. Frequency-specific information can be helpful in selecting treatment strategies and, in some cases, determining if your treatment is working.

## 8 Are you referring to the procedure called the real-ear occluded response?

No. The REOR (or REOG if we're referring to gain) is a measurement taken with the hearing aid in the ear and turned off and using an input signal from the loudspeaker of the probe-mic system.[6] This measurement basically tells you how well the hearing aid (or earmold) is working as an earplug. It is *not* a test of the OE.

## 9 But doesn't the REOG tell me if I'm going have an occlusion problem?

Sometimes yes, but mostly no. If the REOG is somewhat positive or at or near 0 dB, it is true that there won't be an occlusion problem. You'll only see this, however, with a tube fitting or with a very large vent. If you see an REOG of –15 or –20 dB, you would probably predict that there would be an occlusion problem. But some people have very little OE regardless of how "plugged" the canal might be. Also, if the fitting is deep and tightly sealed, the REOG could be –25 dB or greater, yet there would be little or no OE.[7,8] There just isn't a straightforward relationship between the REOG and the OE.

## 10 So is there *any* reason to measure the REOG?

There's one reason I can think of, and it's related to our topic—could be it would fall into your "ampclusion" category. Sometimes, when the hearing aid (or earmold) is placed in the ear, there will be a vent-associated resonance. It usually occurs around 500 Hz when the vent is around 2 mm and can be 10-12 dB or larger.[9,10] The low-frequency gain also will show up in your REAR (and REIG); however, you may think it's related to amplifier gain and turn down gain to try to make things better. If you see this gain in the REOG (with the hearing aid turned off), you can be assured

that it is not an electroacoustic event, but rather an acoustic event, and turning down hearing aid gain will provide no benefit.

As you would expect, this is most bothersome for patients with normal hearing in the low frequencies. It could make their voice sound "hollow," and you might think that complaint is related to an OE problem. Conducting an REOG probably adds 15-30 seconds to your verification protocol. Is the extra information worth the time? Your call.

## 11 Let's go back to measurement of the OE. What do you recommend?

I prefer to use traditional probe-mic equipment and measure the patient's ear canal SPL for their own voice for the open canal and then with the hearing aid (earmold) in place. I usually use the vowel "ee," but other speech sounds would work too. This is pretty much the protocol that has been talked about for the past 10-15 years[6,11-14] and is similar to what was used as early as the mid-1970s.[15] The set-up of the equipment varies somewhat for each manufacturer, so it's difficult to give you a generic step-by-step procedure. Check your manual for details. If your probe system is not equipped to monitor the patient's voice, you will need to use a sound level meter to ensure that the SPL of each vocalization is the same. Some probe systems let you "listen in" and hear the OE in the ear canal when the patient vocalizes.

If the patient has trouble with the vocalization task, you can use a bone-conduction oscillator and deliver a pure-tone stimulus.[7,12] Measuring the OE for pure tones at 250 and 500 Hz will provide an estimate of the degree of the problem, and these results should be in good agreement with the OE for speech vocalizations.[12] If possible, however, I prefer using patients' own voice, as it helps them understand the purpose of the testing.

## 12 Okay, that works for me, but not all my colleagues own probe-mic equipment. How can they conduct these measures?

There is an alternative. Etymotic Research manufactures a product called the ER-33 OE Meter.[16] As the name suggests, this device, which is about the size of a deck of cards, is designed specifically to measure the OE. It's very portable, easy to use, and costs no more than a few bottles of good wine. It does lack some of the frequency specificity that you can obtain with traditional probe-mic measures, since the ER-33 only calculates rms energy in the bandwidth between 180 and 460 Hz. (For most patients, this is the most important frequency range to observe.) Limited research has shown that OE measures with the ER-33 are reliable and that, in general, your clinical impression using this device will be the same as when standard probe-mic equipment is used.[17]

## 13 Just how big is the typical hearing aid OE?

It's hard to say what is typical, as venting has a big influence. If we consider results from hearing aids (or earmolds) that have an average canal length and have little venting (maybe some slit leak or a pressure vent), then you can expect the *average* OE to be around 12-16 dB in the range of 200 to 1000 Hz.[17,18] There is a large variability among patients, however. On a given day you could see anything between 5-8 dB and 25-30 dB.[18]

## 14 I'm guessing that males have more occlusion problems. Is this correct?

Research on the hearing aid OE has found no difference between men and women.[17,18] That wasn't your question, however. You asked who has the most problems. Some people have 25 dB of OE, but don't consider it a problem.

In general, the greater the hearing loss in the low frequencies, the less the problem. This is due to two factors: First, if the loss is severe enough, the patient will not hear the enhanced output of his voice; secondly, as the loss becomes more severe, we add in more gain and amplified speech exceeds the enhanced speech signal caused by the OE. Given that women tend to have flatter hearing losses than men, it could be that although their OE is the same, they experience fewer "own voice" problems.

## 15 You mention low-frequency amplification. If the OE is 20 dB or more and I also provide considerable low-frequency gain in the hearing aids, won't the patient say his voice is really booming?

It's not as bad as you're suggesting. For the most part, since it's unlikely the two signals will be the same intensity, the "loudness" perception will be determined primarily by the louder of the two signals. The greatest summation will occur when the two outputs are the same. For example, if the patient's voice is 70 dB SPL, which because of the OE results in 90 dB in the occluded ear canal, and you add amplified speech in the same region (which also is 90 dB SPL), the net SPL will be around 93 dB —not 180 dB!

This is a reasonable thing to think about, as some people treat the occlusion problem by increasing low-frequency gain to "blend in" amplified speech in the same frequency region as the OE. The amplified speech usually sounds more pleasant to the patient than the enhanced loudness from the OE.

Your probe-mic measures will assist you in determining how much gain is enough, and where frequency-specific adjustments are needed. However, even when this procedure works, the approach does not solve *all* the occlusion problems. More importantly, you need to consider that this additional low-frequency gain could have a negative effect on speech intelligibility.

## 16 You bring up increasing low-frequency gain. I thought one of the most popular treatments for the OE was to reduce low-frequency gain.

You could be right. Next to venting, that might be the most "popular" treatment. Maybe that's part of the problem.

I fail to see how reducing hearing aid gain can affect the ear canal SPL of a speech signal that found its way to the canal via a pathway other than through the hearing aid. If turning down hearing aid gain makes the problem go away, then I doubt that it was the OE causing the problem. Recall from our previous discussion, the additive nature of hearing aid gain plus OE is less than it might appear.

## 17 So what about venting? I've found that sometimes it works and sometimes it doesn't. What do you think?

I think sometimes it works and sometimes it doesn't. But it's usu-

ally quite predictable. We know that some people have most of their OE for speech around 200 Hz. Others have much less OE around 200 Hz, but might have a large effect at 500-700 Hz. If you review the expected effects of venting across vents of different sizes, it's fairly easy to conclude that a 2-mm vent probably would be quite successful in "leaking out" OE with primarily 200-Hz energy, but not successful in eliminating the OE complaint if the OE was around 500-700 Hz. By comparing your probe-mic measures of OE with expected vent effects for different vent sizes,[19,20] you can develop a systematic treatment plan. You just have to hope that the patient with the big OE above 500 Hz does not have her heart set on a pair of CICs.

## 18 You mentioned that CIC fittings might lead to more occlusion problems. I remember hearing a few years back that CICs were the solution. What's the deal?

It's certainly possible that you heard that. In fact, a fellow named Mueller stated that this was a *potential* advantage of CICs right here in *The Hearing Journal* back in 1994.[7,21]

Deeply fitting hearing aids (or earmolds) *will* reduce the OE. We know this from several research studies, and this is a well-accepted alternative (or supplemental) strategy to venting.[7,11,22,23] This approach can be accomplished using a long canal on *any* style of custom instrument; it doesn't have to be a CIC.

When CICs were introduced, they tended to have long canals and fit fairly tightly in the ear canal. The reduction of the OE was a pleasant dividend of this type of fitting. Today, though, many people seem to be more interested in how the CIC product looks "in-the-hand" than "in-the-ear," so, in some cases, the canal length on CICs is shorter than on many ITEs. The only way a short canal can reduce occlusion is if it increases slit leak—and it usually will. This, of course, frequently leads to a new problem—acoustic feedback. For people with significant OE, it just isn't possible to achieve the vent size necessary in a CIC product to eliminate the problem. I don't have a magic number, but usually it's necessary to reduce the OE to below 10 dB before it is considered "acceptable."

## 19 With all of today's digital technology, isn't there a way to do some type of phase cancellation of the OE?

That seems like a reasonable thing to do. There has been some research in this area,[24-26] and there probably are researchers working on this as we speak. As you know, this technique works fairly well for feedback suppression. Canceling out the OE is much more difficult, however.

First, unlike acoustic feedback, the OE for speech (the primary complaint) usually occurs over a fairly large frequency range. The peak of the OE varies significantly among hearing aid users, so the hearing aids might need to be "tuned." Additionally, for many patients, the OE cancellation would have to be 10-15 dB or more across frequencies before their own voice would sound "normal." Nevertheless, I suspect that we'll see some progress in this area before too long.

## 20 So, what are your bottom-line recommendations for dealing with patients who have the "hollow voice" complaint?

First, do no harm. This basic principle of the practice of medicine also applies to addressing the "hollow voice" complaint. To develop effective treatment strategies and to make sure you do not apply the wrong strategy, it's necessary to determine what is causing the problem. To determine what's causing the problem, you'll usually need to conduct testing of the occlusion effect. Probe-mic measures are the standard for this.

If the problem *is* the occlusion effect, you really only have five treatment options: venting, a deep canal fitting, counseling, counseling, and counseling. Counseling when you are ordering the hearing aids, during the fitting of the hearing aids, and during post-fitting visits. And, keep your eye out for new hearing aid technology and venting techniques that might be assistive. Finally, just for fun, try talking in a barrel now and then!

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