Zwislocki was right...

A potential solution to the "hollow voice" problem (the amplified occlusion effect) with deeply sealed earmolds

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Over the years, hearing instrument dispensers have listened to patients' complaints about the "hollow" sound of their own voices when wearing their hearing instruments. Earmold venting is normally used to alleviate those complaints, but sometimes feedback problems occur before sufficient venting can be obtained. We have found that a deeply sealed earmold can alleviate this problem even if it is not vented.

In 1953, Zwislocki described the effect which would be created when one inserted an earplug into the ear during bone conduction testing.[11] He showed that placement of the earplug in the fleshy (cartilaginous) part of the ear yielded more sound in the ear canal than if the earplug was inserted more deeply into the bony (osseous) portion of the ear canal. He referred to the process as "obduration" of the ear canal.

Zwislocki showed that an insert earphone ear tip inserted deeply into the canal would reduce, if not remove, this predominately low frequency occlusion effect, and, thus, he recommended the use of insert earphones for masking when testing bone conduction. Subsequently, Khanna, Tonndorf and Queller[3] made probe microphone measurements of the sound pressure developed behind earplugs, confirming that the effect was due to sound transmission into the ear canal from vibration of the fleshy (cartilaginous) portion of the ear canal walls induced by a flesh- or bone-conducted vibration. Berger and Kerivan[2] recently reconfirmed that deeply inserted ear tips (E-A-R plugs, in this case) minimized the occlusion effect for bone conduction.

When hearing instrument wearers complain that their own voices are too loud or sound hollow when they wear their instrument(s), the dispenser often remarks, "That's because you now are amplifying your own speech." The real problem, of course, is caused by the large occlusion effect that occurs when the earmold tip extends only into the fleshy portion of the ear canal. The resulting low frequency amplification of the vibrations from the wearer's own voice creates an unnatural sound. These vibrations are fairly weak for open vowels such as "AH" (/a/) but quite intense for the closed vowels "EE" and "OO" (/i/ and /u/), as they can easily be felt by anyone willing to vocalize with his chin on his hands and his elbows on a table. Probe measurements of the sound pressure levels developed in the back of the mouth show 142 dB SPL (!) for EE, 138 dB SPL for OO and 116 dB SPL for AH, indicating the probable source of the intensity differences.

Traditionally, attempts have been made to control or eliminate the occlusion effect through venting.[5,10] It seemed, however, that another approach might be to use the solution proposed over 30 years ago by Zwislocki and use a deeply sealing earmold or canal instrument.

A couple of years ago, these authors rediscovered the importance of deep ear tip insertion in order to maximize interaural attenuation with insert earphones.[4] In addition, it was known from even earlier measurements, that with a probe tube microphone placed in the ear canal behind an earmold or earplug, one's own voice produced levels close to 100 dB SPL in the ear canal. These data are shown in Fig. 1 for the vowels EE, AH and OO, as well as the similar levels generated while chewing corn chips.

Given these levels, it is not a matter of "not hearing someone when the water is running," but of not hearing them at all because of what might be called the self masking that occurs when eating cereal or chips while wearing a hearing instrument with an unvented earmold. To carry on a conversation at the dinner table, the hearing-impaired person is forced to choose among alternatives, such as wearing no instrument (and thus not hearing the conversation), wearing an instrument and not chewing (to avoid the masking effect of the occluded ear canal), eating only soggy food (to avoid loud crunching) or wearing an instrument with sufficient venting to reduce the occlusion effect (thereby risking feedback).

Recently, a practical, deep canal hearing instrument has been developed,[9] and one of the first things noticed by some hearing instrument dispensers was that fewer patients complained about the sound of their own voices.

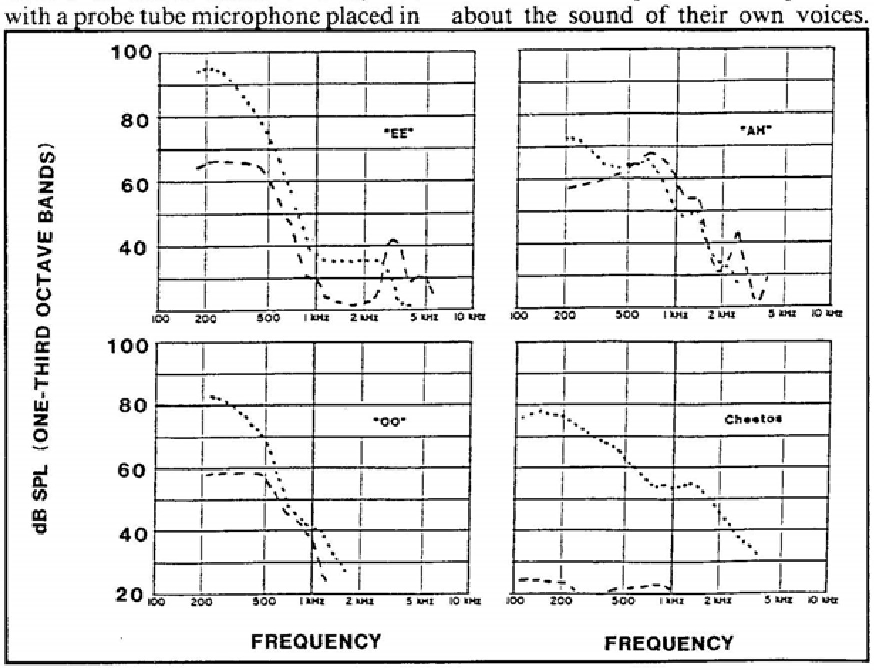

Fig. 1. Ear canal SPLs produced behind a well-sealed, non-vented BTE earmold (hearing instrument turned off) while female subject vocalized vowels or chewed corn chips (....). SPL produced at hearing instrument microphone shown for reference (----).

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The authors realized that this new instrument's deeper placement into the ear canal might be diminishing the occlusion effect.

Experiment 1

In order to explore the practicality of a "deep canal" solution to this "self masking" phenomenon, the authors decided to make a series of measurements similar to those described by Macrae[6] in the ear canals of themselves and of selected hearing instrument wearers. In Experiment 1, a probe tube was inserted into the ear canal through a hole in an Etymotic Research ER-3-14 foam ear tip as a temporary BTE earmold or through the vent hole of a Voroba Technology Associates "105-30-15" modular canal instrument mounted in a #5R shell. These were chosen because in both cases it was possible to compare a shallow and deep ear tip insertion while maintaining an airtight seal. (The E-A-R foam used in the ER-3-14 ear tip expands to fit nearly any canal size, and the soft rubber "bulb" at the tip of the #5R shell expanded to seal two of the authors' ears even with shallow placement.) The authors, as subjects, read the nonsensical sentence "Joe took father's shoebench out, she was sitting at my lawn," followed by two or three repetitions of prolonged vowel sounds EEE, AAH and OOO. The final "sound source" was obtained from vigorous chewing of corn chips (Doritos, Nacho flavored).

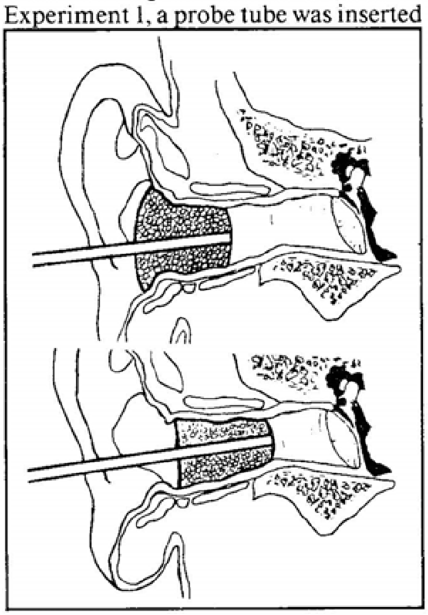

Fig. 2. Shallow and deep insertion of foam ear tips.

For this and the two succeeding experiments, an Etymotic ER-7C probe tube microphone assembly was connected to the earmold/hearing instrument with its output fed into channel 1 of a professional cassette tape recorder. A second probe tube was placed in the non-test ear, and its microphone output fed into channel 2 of the tape recorder. A 94 dB SPL calibration tone from the ER-7C's calibration cavity was recorded on each channel at the beginning of each taping session. The results were analyzed on playback by sending the taped signal through an amplifier and an adjustable bandpass filter to a graphic level recorder.

Fig. 2 illustrates shallow and deep insertion of the foam ear tips. In this case, the ear canal SPLs measured in the 250 Hz octave band during vocalization of the vowel EE were reduced 13 dB for the male subject and 19 dB for the female subject with the deeper insertion.

Fig. 3 shows the ear canal SPLs, in octave bands with center frequencies of 250, 500 and 1000 Hz, produced by the first author wearing the modular canal instrument with shallow and deep insertion. The instrument had been set to 23 dB of high frequency average gain as measured in the 2 cc coupler. Note that there is very little difference between shallow and deep fitting for the vowel AH, but in the octave band around 250 Hz, there is approximately 15 dB more intensity with the shallow than the deeply fitting canal instrument for EE, OO and the sentence.

Recorded comparisons of the difference in amplified sound between the shallow and deep placement of the instrument illustrate the variance between an unpleasantly boomy sound and a clear, crisp sound with good high frequency emphasis. (Not shown in Fig. 3 is the increased high frequency gain that resulted from the deeper canal placement.)

Experiment 2

In Experiment 2, a variety of experimental, unvented earmolds and shells were used to see if a practical, deeply sealing earmold could be obtained. Fig. 4 shows the range in 250 Hz octave band ear canal SPL measurements which were obtained with the various earmolds using vocalization of the vowels EE, AH and OO by a female and male subject. (The authors' previous measurements had convinced them that recording only the 250 Hz octave band SPLs would be sufficient, since that was where the most dramatic occlusion effect is normally seen.)

Fig. 5 summarizes the results of the second experiment. Earmolds which provided a seal in or near the bony portion of the ear canal generally gave minimal occlusion effect. Earmolds without a deep seal exhibited a large occlusion effect regardless of ear tip length, earmold type (shell or canal lock) or material (Lucite, soft vinyl, silicone or foam).

There were some surprises. For example, a Voroba #5R shell in the first author's ear showed little occlusion effect (the data bars fifth from the right in Fig. 4), but a #3R shell showed a large occlusion effect (data bars fourth from the left in Fig. 4), even though both were 14 mm long and provided an airtight seal. The apparent explanation, in this case, was that the straight-walled construction of the soft rubber tip on the #3R shell presumably sealed only near the author's ear canal entrance, while the bulbous configuration of the soft rubber tip on the #5R shell presumably produced a deeper seal.

Similarly, a very deep, soft vinyl shell mold gave a large occlusion effect even though it had a 22 mm long ear tip (data bar third from the left in Fig. 4, male subject). Examination of this mold, however, showed a tapered tip similar to the one shown in the middle drawing of Fig. 5.

Most important, however, was the fact that the authors were successful in obtaining soft vinyl, canal-lock style earmolds which gave a minimal occlusion effect (the two right-most data bars for the female subject in Fig. 4 and two

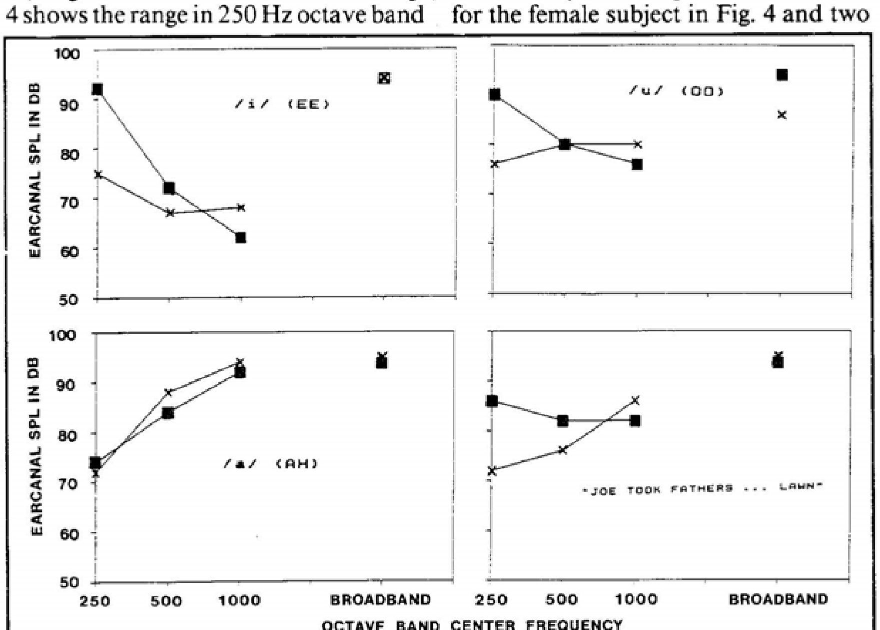

Fig. 3. SPLs measured behind male subject's shallowly (■...■) and deeply (X...X) inserted modular canal instrument while subject vocalized.

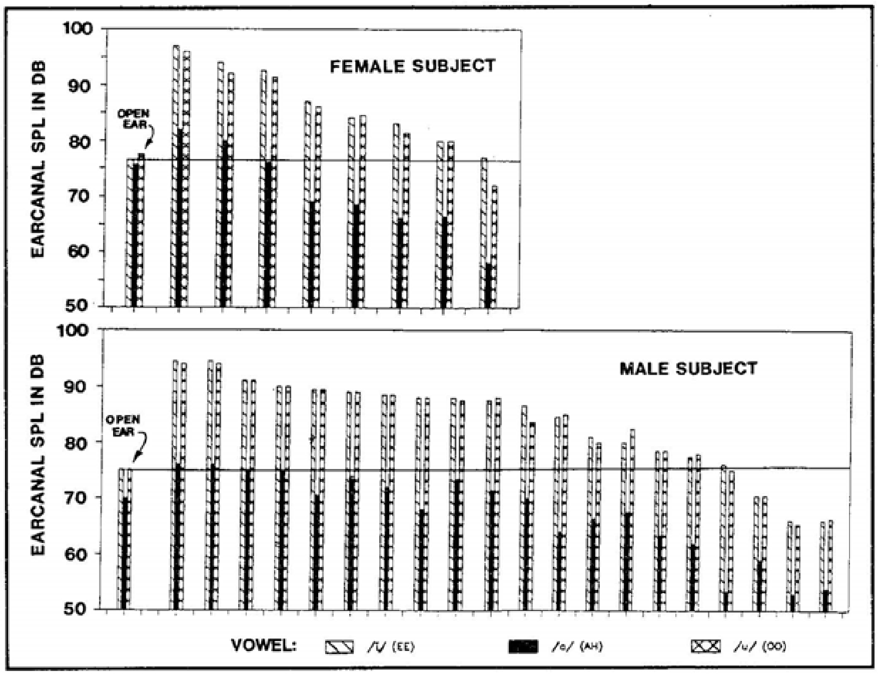

Fig. 4. Ear canal SPLs developed during vocalization behind a variety of unvented earmold constructions investigated in these experiments. Open ear SPLs shown for comparison.

of the three right-most data bars for the male subject in Fig. 4) even though they were completely unvented. How these earmolds were obtained is discussed in a section below.

Experiment 3

In this experiment, ear canal SPLs were measured on three hearing-impaired subjects who had had their ear canals surgically modified to accept a Resound

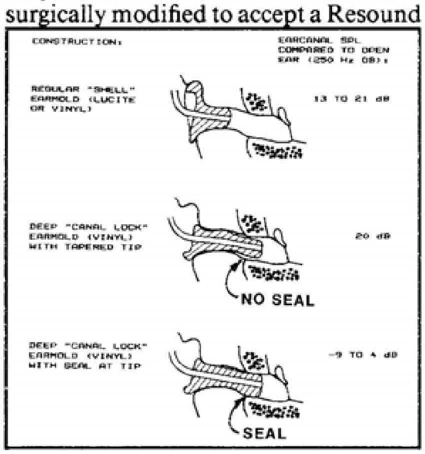

Fig. 5. Illustration of findings from these experiments: earmolds with deep seal gave minimal occlusion effect; earmolds without deep seal gave large occlusion effect.

Corp. deep-seating, custom canal hearing instrument.[7] The experiment was carried out in essentially the same manner as Experiment 1, except that two sentences were added: "Jules, the big fat ape shook and chuckled at many awful things." "Ooo, that hose can wash her feet." In addition, in this case, experimental ITE hearing instrument modules containing only a microphone, a receiver and probe tube passage were employed. For each subject, a shallow ear tip and deep ear tip version of the modules were constructed. (The three subjects had their own custom canal instruments, but these did not permit insertion of a probe tube without drilling into the instruments.)

Fig. 6 shows the measured 250 Hz octave band, ear canal SPLs measured on the three subjects. In each case, the open ear SPLs are shown, followed by the shallow ear tip and deep ear tip results. Note that for the male subject, the measured SPLs with shallow ear tip are greater by approximately 16 dB for EE, 6 dB for AH and 20 dB for OO, but only a small increase is seen with the deep ear tip. Subject EL showed differences which were small, regardless of ear tip length.

Subject DJ had a reverse effect, i.e., the shallow ear tip module gave somewhat less ear canal SPL than the deep ear tip module. Although the differences were not large, this reversal was confusing and surprising, until it was discovered that this subject had a temporomandibular joint problem and had been fitted with a temporary splint, which currently was broken. She reported that when the splint was intact, the hearing instrument fit much more securely. It was speculated that the phenomenon being seen was that referred to by Allen and Fernandez[1] when they investigated bone conduction in a person with an absent temporomandibular joint.

Obtaining the earmold

Not surprisingly, perhaps, it was not easy to obtain deeply sealing earmolds. First of all, a deep impression was made utilizing powder and liquid impression material, and the earmold lab was instructed to keep the finished earmold tip as long and full as possible. This re-

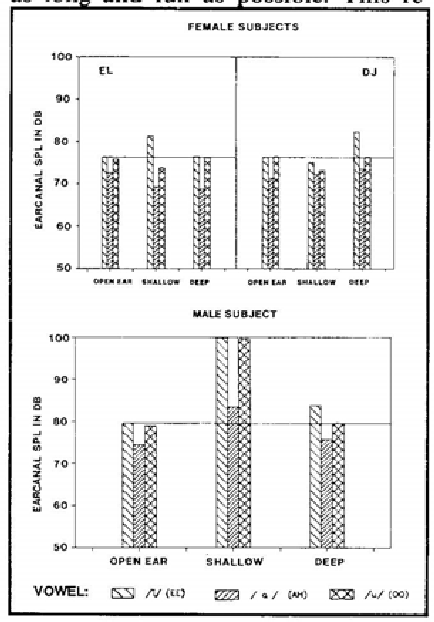

Fig. 6. Ear canal SPLs developed during vocalization behind deep and shallow experimental ITE modules in three subjects with surgically-modified ear canals.

sulted in an earmold that was not as deep as the impression had been. When repeated, utilizing impressions from all three authors and a different earmold lab, again, the resulting earmolds barely reached the bony portion of the ear canal and, in one case, did not look like a similar impression stored at the lab.

Finally, after lengthy discussions with representatives from various earmold labs, the "Byron McKellips" procedure evolved. A cotton block was prepared with one end of a soft rubber probe tube inserted into the middle of the cotton and sewn into place with the normal thread, taking care that the tube remained open. The cotton block then was inserted as deeply as possible into the canal, and a deep silicone impression was obtained. The cotton block was used because it squeezes easily into a smaller size and still prevents the impression material from oozing through. (Foam blocks take up too much room to allow a really deep impression unless cut in half in length.) The rubber tube allows air to flow out while the impression is being taken and, more importantly, air to flow back in when the impression is being removed. Without the tube, the suction that is created when removing the impression can be painful, if not potentially dangerous. The use of silicone impression material helps assure that it will not lose shape during shipment.

Using this impression technique and asking for "soft vinyl, canal-style earmolds with ear tip to the full length of the impression (20 to 22 mm in this case) and a seal at the tip end only," four earmolds were ordered from two different earmold laboratories. All four were a success. The figure at the bottom of Fig. 5 illustrates these earmolds. Their SPL data were previously discussed in this article.

Comments

As can be seen from Figs. 3 and 4, the proper balance between vowels is not preserved even when the excess ear canal SPL is minimized. The complete solution to the "my voice sounds hollow" problem, however, requires only that the low frequency output of the hearing instrument exceed the residual ear canal SPL build-up due to the occlusion effect. Here again, in keeping with the findings of Punch and Beck,[8] some low frequency output from the hearing instrument provides a more pleasing sound and, when combined with true high frequency emphasis, greater intelligibility.

Several questions remain. First of all, it is not known how deep an earmold tip actually is required. It may be that most of the relief can be obtained when a seal is obtained deep enough to shield the ear canal from the vibration of the walls in the cartilaginous portion as long as the earmold itself does not vibrate and pump sound into the ear canal. The only way to be sure of success is to make probe tube measurements with a system that includes low frequency analysis capability. The best of such equipment is often the human ear. Listening to the probe output with a good monitor earphone quickly will reveal the exaggerated SPL on the EE and OO vowels, if a serious occlusion effect is present. (The earmold should be ordered with a probe tube hole.) The most important requirement for success, though, is probably the willingness to take a second impression, if the first earmold fails to provide a low occlusion effect. It also is not known how comfortable deeply sealed earmolds would be for prolonged wearing, although early experience with the new, soft vinyl material was good. A good fit is especially important with such earmolds, however, because the skin over the bony canal is quite tender.

Warning

It is extremely important that an adequate cotton block be used and that care be used in removing the impression. Rumors of earmold impressions having been mailed in with ossicles attached are frightening, whether true or not. Moreover, it is impossible to obtain an adequate impression deep in the ear canal without a block for the impression material to push against. In these authors' experience with these deep impressions, allowing the subject to remove the impression will ensure that it is removed slowly enough to allow any "vacuum" to be relieved. Taking a deep impression in an ear (such as the first author's left ear) which on visual examination exhibits a collapsed canal is not recommended, since it will be difficult (and uncomfortable for the subject) to pull the large, bony canal portion of the impression through the narrow collapsed canal portion of the ear canal, even though the latter tissue is soft. □

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AUTHORS' NOTE: A cassette tape containing comparisons between shallow and deeply sealing ear tips can be obtained by sending $4.00 to Etymotic Research and requesting the Occlusion Effect Tape. These comparisons were recorded from the ear canal of male and female talkers wearing BTE, ITE and canal instruments. The address is: Etymotic Research, Inc., 61 Martin Lane, Elk Grove Village, IL 60007.