A low frequency emphasis open canal hearing aid

By Mead C. Killion, PhD, Charles I. Berlin, PhD, and Linda Hood, PhD

The relatively rare individual with a "reverse ski slope" hearing loss has long presented a problem in hearing aid fitting. This paper describes a newly designed hearing aid that appears well-suited to those individuals who have normal or near-normal hearing in the 2 to 4 kHz region, but who have 40 to 65 dB of low frequency hearing loss. This new aid leaves the ear canal open to normal (unamplified) high frequency sounds, while providing 20 to 30 dB of amplification in the 250 to 1500 Hz region.

The problem

An individual with normal or near-normal high frequency hearing would presumably do best with an open canal fitting, which should provide the most natural sound and allow him to make maximum use of the normal external ear resonances and the directional cues provided by the pinna. However, an open canal or "tube" fitting allows most of the low frequency output of the hearing aid to leak out of the ear canal, so that such a fitting is normally used to give high frequency, not low frequency, emphasis. Lybarger's "vent response" graphs,[1] for example, show a 30 dB loss at 300 Hz for an open canal fitting with the tube inserted halfway down the ear canal, compared to a sealed earmold fitting. A hearing aid having a maximum output of 100 dB SPL at 300 Hz could thus produce only a 70 dB SPL output at that frequency in an open canal fitting, an output that would be inaudible to someone with a 55 dB loss at that frequency. Not surprisingly, therefore, a sealed earmold is normally required for low frequency emphasis amplification.

Thanks to high-efficiency, push-pull amplifiers and the recent CI-series of Knowles receivers designed by Stuart Ewens, et al, however, it is now possible to obtain 130 dB of undistorted output at 300 Hz, as measured in a closed ear canal. Thus, 100 dB SPL of undistorted output at 300 Hz is theoretically available in an open canal fitting, making an open canal, low frequency emphasis hearing aid practical.

The new approach

Fig. 1 shows the insertion gain, measured on the KEMAR manikin, of what these authors have designated the K-BASS hearing aid. (The acronym K-BASS is pronounced as "K-base" and stands for Killion Bass Amplified unobStructed Sound.)

In order to obtain the open canal response of Fig. 1, this aid had to be designed to produce a coupler response with a peak gain of 50 to 55 dB at 350 Hz, as measured in a 2 cc coupler, falling at roughly 12 dB per octave between 350 and 1300 Hz, and then at roughly 36 dB per octave above 1300 Hz.

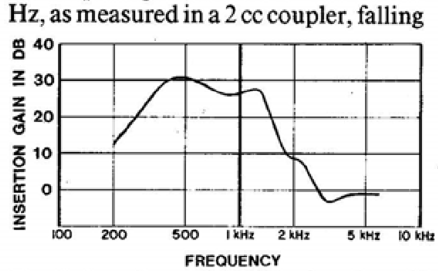

Fig. 1. Insertion gain of the hearing aid measured on the KEMAR manikin with the "free field" earmold of Fig. 3.

The first versions used either a body aid or a CROS configuration, with a CI-series receiver mounted in a BTE case and coupled as shown in Fig. 2. The use of a long, small-diameter tube inside the case to obtain greater low frequency emphasis dates back to the 60s. In this application, a 75 mm (3") length of 1 mm (.039") diameter tubing provided sufficient acoustic mass to move the first resonance down from 1000 Hz to about 500 Hz.

The 1.5LP earhook shown in Fig. 2 uses a two-section acoustic filter (designed by direct analogy to lumped-element electrical filters) to provide a rapid high frequency response cutoff above 1500 Hz. Such multisection acoustic filters date back to the patents of G.W. Stewart[2] in the 20s. The present filter, as measured in a 2 cc coupler, produces a gain at 2500 Hz nearly 60 dB below the gain at 350 Hz.

A disadvantage to the construction shown in Fig. 2 is the use of a 680 ohm damper in the ear tube. Experience has shown that some individuals encounter moisture problems with dampers

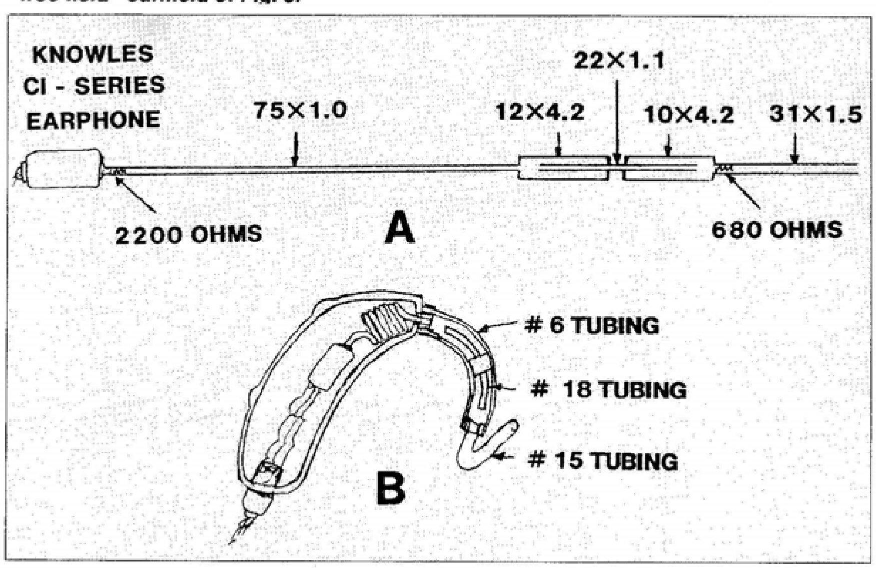

Fig. 2. Sound-channel diagram (A) and physical layout (B) of K-BASS earphone coupling with 1.5LP earhook.

Mead C. Killion, PhD, is president of Etymotic Research, Elk Grove Village, IL. Charles I. Berlin, PhD, and Linda Hood, PhD, are both with the Kresge Hearing Research Laboratory, LSU Medical Center, New Orleans, LA.

located in this tube. Although less problems might be expected in an open canal fitting, the damper was eliminated by use of the 1.5LP earmold construction shown in Fig. 3, where the important detail is the .86 mm (.034") bore for 12 of the last 15 mm of the sound channel. The last 3 mm is left larger in diameter to serve as a "wax trap" for easy cleaning. (The same sound channel can be obtained in a tube fitting by using 12 mm [.5"] of #20 PVC tubing inserted inside a prebent #15 ear tube.)

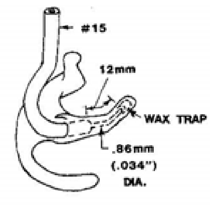

Fig. 3. Construction of 1.5LP earmold.

One problem with the CROS configuration is that it makes a binaural fitting impractical. One of the surprise benefits of a low frequency open canal fitting is that a substantially greater insertion gain can be obtained in the IROS configuration at low frequencies without feedback oscillation than can be obtained at high frequencies. In separate measurements, it was found that nearly 40 dB of insertion gain without feedback oscillation could be obtained at low frequencies with a sufficiently deep ear tube insertion, which is 20 dB greater than the maximum insertion gain that can be safely obtained in an IROS configuration with most individuals at 3 kHz.

The high power, low frequency emphasis Zenetron ZP-70P was modified to produce the desired response and afforded enough room inside the case for a 75 mm length of tubing. Most recent K-BASS hearing aids have been supplied in the IROS configuration.

In both the IROS and CROS configurations, greater gain can be obtained with a deeper ear tube insertion, as shown in Fig. 4. The "free field mold,"

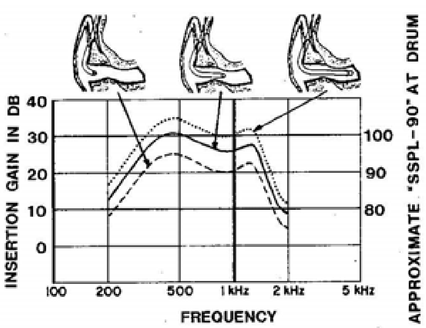

Fig. 4. Effect of insertion depth of ear tube (or earmold tip) on the maximum gain and output available from the new aid.

or what is now sometimes called a "Janssen mold," construction shown in Fig. 3 allows for a deeply inserted small-diameter sound channel. (The insertion gain response shown in Fig. 1 was obtained with the tip of the ear tube placed at midcanal, 13 mm from the eardrum postion microphone in the KEMAR manikin.)

Clinical results

As a result of a nationwide search for patients with sensorinueral hearing loss and residual high frequency hearing at frequencies above 8 kHz, Kresge Hearing Laboratory of the South came across a group of patients who had audiograms which showed "islands" of normal hearing in the 2 to 4 kHz range. Figs. 5-9 show the audiograms of the first five patients fit with the K-BASS hearing aid.

The first patient to use such an aid, J.C., was a 6-year-old boy who had a severe, low-frequency sensorineural loss with normal hearing thresholds at 3 to 6 kHz in the right ear and a severe sensorineural loss in the left ear. He was wearing an occluding earmold and a Zenetron ZP-15 aid in the right ear at the time of the initial evaluation. Reports showed poor word recognition ability, dependence on visual cues and poor progress in school. J.C. received the first version of the K-BASS aid in the body aid configuration. Fig. 5 shows an audiogram depicting his unaided and aided sound field performance for narrow band noise with the earphone fitted to the right ear. J.C. has now been using this hearing aid for over a year. The audiologists and school personnel working with him report a marked change in alertness and an improvement in vocabulary, speech monitoring and auditory discrimination.

Patient O.D., 64 years old, had never been successfully fitted with a hearing aid in 22 years. Virtually all the aids she tried had occluding molds or, in some way, disrupted her normal sound perception in the 2 to 4 kHz range. Her audiogram indicated a moderate low frequency sensorinueral loss and normal hearing sensitivity at 2 to 4 kHz in the right ear and a moderate to severe sensorinueral loss with a rising configuration (loss decreasing with frequency) in the left ear. Her sound field audiogram for warble tones in Fig. 6 shows her unaided thresholds and aided thresholds with a CROS configuration of the K-BASS aid. She reports that this is the most comfortable aid she has ever had and that it gives her excellent speech awareness. Although she still does not "understand everything that's said" to her, she does not feel that her ears are "closed in" or that the hearing aid blocks out her useable hearing.

K.E. is a 12 year old with a moderate to severe low frequency sensorineural hearing loss in both ears; normal hearing sensitivity from 3 to 6 kHz in her right ear and from 4 to 9 kHz in her left ear. Her mother has a similar type of hearing loss. A K-BASS aid was fitted to her right ear in a CROS configuration. Unaided and aided responses to narrow

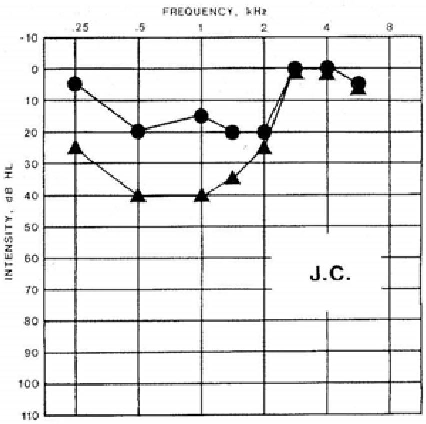

Fig. 5. Sound field audiogram for patient J.C.—(▲) unaided and (●) aided.

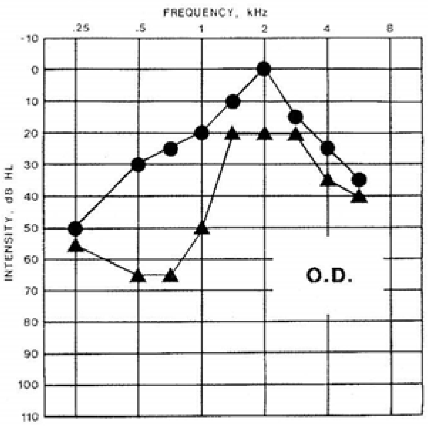

Fig. 6. Sound field audiogram for patient O.D.—(▲) unaided and (●) aided.

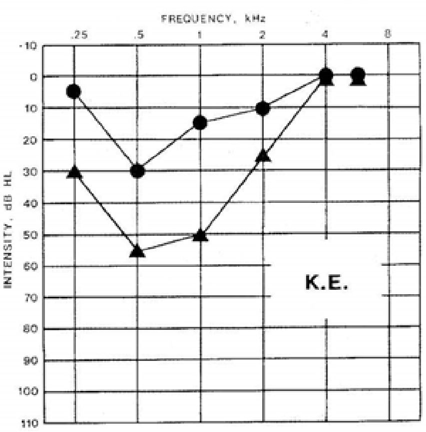

Fig. 7. Sound field audiogram for patient K.E.— (▲) unaided and (●) aided.

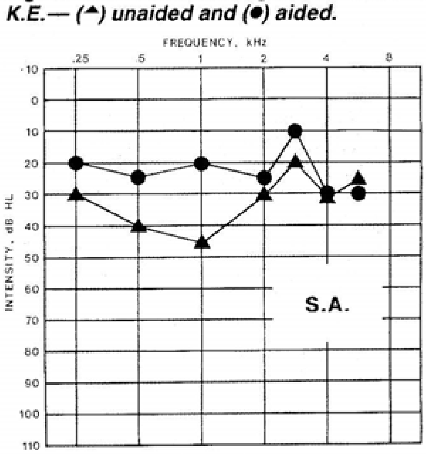

Fig. 8. Sound field audiogram for patient S.A.—(▲)unaided and (●) aided.

band noise stimuli presented in a sound field are shown in Fig. 7. These results indicate significant improvement in detection levels for low frequency stimuli with no change in detection levels at 4 and 6 kHz. Her aided thresholds are within normal limits for frequencies from 250 to 6000 Hz except at 500 Hz.

Patient S.A., age 6, has residual high frequency hearing with a normal hearing threshold at 12 kHz in the left ear and an island of normal hearing at 3 to 4 kHz in the right ear. She first tried a translator hearing aid in the left ear which was not satisfactory. She is now wearing a K-BASS aid with a CROS configuration to her right ear with only limited success. Her unaided and aided sound field test results for narrow band noise are shown in Fig. 8.

Patient I.C. is an administrator who is quite dependent upon her hearing in meetings. She has attempted to use amplification in the past with no success, stating that she "could not tolerate the sound after a few hours." Her audiogram shows a moderate low frequency sensorineural loss in the right ear with an island of normal hearing at 6 kHz and moderate to severe sensorineural loss in the left ear with a rising configuration. Thresholds for frequencies above 8 kHz did not show residual high frequency hearing in either ear. An open canal IROS fitting of a K-BASS aid for her right ear produced the improved sound field audiogram for warble tones shown in Fig. 9. Though she has used the aid for only a short time, she states that "this is the first time that a hearing aid may actually help" her. While detection levels are quite good, her word recognition ability remains poor with the aid. Auditory training with the aid as a possible modification using a compression rather than peak clipping output are being considered to help improve her benefit.(Although the limited bandwidth provided by the 1.5LP earhook filters out high frequency distortion products, so that peak clipping is much less objectionable here than it would be in a wideband hearing aid, there is still noticeable interference between the direct and amplified sound for close-by talkers with the aid in its present form at full gain.)

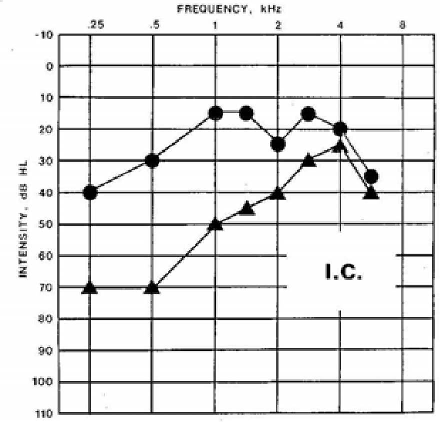

Fig. 9. Sound field audiogram for patient I.C.—(▲) unaided and (●) aided.

Unaided and aided detection levels for the Ling Five-Sound Test also were obtained for four of the five patients. Detection thresholds for (ah), (oo), (ee), (s) and (sh) are shown in Table 1 with and without the K-BASS hearing aid.

Stimulus	Patients S.A.	J.C.	I.C.	K.E.	Mean	Mean difference
ah	30/15	10/0	20/0	25/5	21/5	16
oo	50/30	20/10	35/15	40/20	36/19	17
ee	30/25	10/10	20/20	20/10	20/16	4
s	20/25	0/−5	25/5	0/0	11/6	5
sh	20/10	−5/−5	10/−5	0/0	6/0	6

Table 1. Comparison of unaided and aided detection thresholds, in dB HL, for the Ling Five-Sound Test in sound field for four of the patients described in the text. Unaided detection thresholds are left of the slash (/) and aided detection thresholds to the right.

The mean differences between unaided and aided conditions for detection of the vowel sounds (ah, oo and ee) were 16, 17 and 4 dB, respectively, while the mean differences for the higher frequency consonant sounds (s, sh) were 5 and 6 dB, respectively. The smaller unaided versus aided difference for (ee) is probably related to the higher frequency second formant energy in this vowel. These comparisons support the narrow band noise and warble tone findings reported for each patient and confirm a greater increase in detectability of low rather than high frequency information with the K-BASS aid.

These clinical reports indicate that the new aid is not a panacea for those with low frequency hearing loss, but may provide useful benefit in many cases. In this context, the recent research of VanTasell and Turner[3] is noteworthy. They tested a subject whose low frequency loss appeared due to a complete "absence of functioning sensorinueral units in the apical region of the cochlea," finding that he was nonetheless able to make use of sufficiently intense low frequency speech cues in understanding speech. The function of the new aid is to make such cues intense enough to be audible. □

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The authors wish to acknowledge Bill Murphy, who constructed the first low pass earphone coupling, and Don Wilson, who made the IROS version of the K-BASS possible through his development of a way to include 75 mm of tubing inside an existing ZP-70P hearing aid case. At some future date, it is hoped that an input AGC circuit could be included to avoid the distortion of the peak clipping output circuit of the ZP-70P aid.

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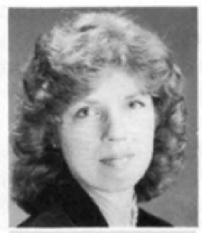
Charles I. Berlin, PhD, is director of the Kresge Hearing Research Laboratory of the South, LSU Medical School, Dept. of Otorhinolaryngology, New Orleans, LA. He also is a professor there and in the Dept. of Communicative Disorders at LSU Medical Center. His degrees include a BS from NYU, an MS from the U of Wisconsin and his PhD from the U of Pittsburgh in hearing science. He has done post-doctoral work at Johns Hopkins Medical Institution. He has been the recipient of a research career development award from the National Institute of Health Sciences.

Berlin



Hood

Linda J. Hood, PhD, is a post-doctoral fellow at the Kresge Hearing Research Lab of the South, LSU Medical School, New Orleans, LA. She received her BS degree in speech and hearing from Bowling Green State U, her masters degree in audiology from Kent State U and her PhD in audiology from the U of Maryland. She was a recipient this year of a research award from the ASHA Foundation.

Mead C. Killion, PhD, is president of Etymotic Research, Inc., Elk Grove Village, IL. His degrees include an AB in mathematics from Wabash College, an MS in mathematics from IIT and his PhD in audiology from Northwestern U.

Killion

He currently serves as adjunct professor of audiology at Northwestern U.