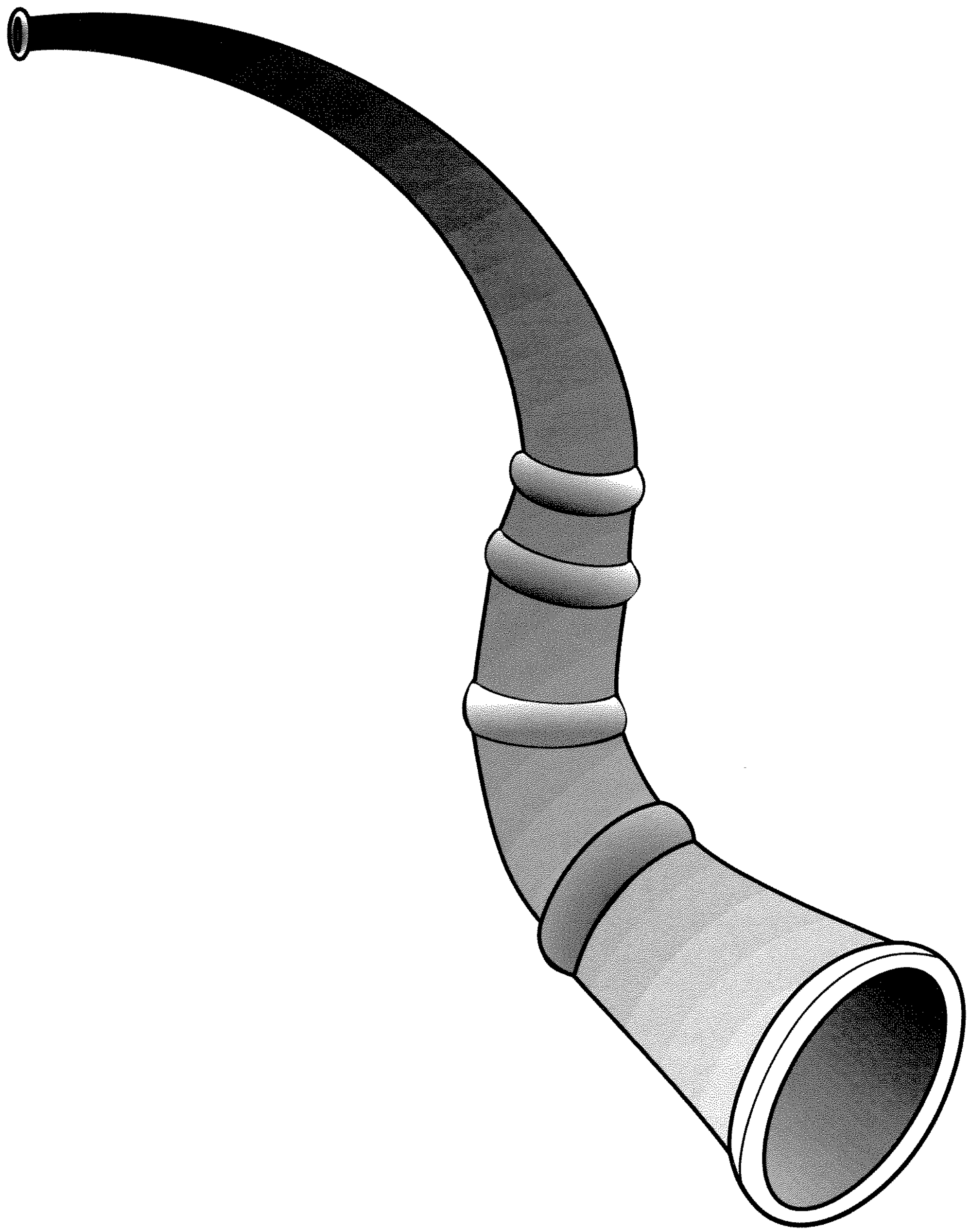

Chapter One

Physical Options

by Gail I. Gudmundsen, MA

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INTRODUCTION

The first goal of any hearing aid fitting should be to make speech audible but never distorted or uncomfortable. In the author's view, an additional goal should be to provide at least partial restoration of the "normal" range of loudness experience. The purpose of this chapter is to present options for choosing shell styles for custom hearing aids, and for choosing the best earmolds for behind-the-ear (BTE) fittings. Evaluation procedures, verification measurements, ordering techniques, circuitry, and signal processing options will be discussed in other chapters.

WHAT CRITERIA SHOULD BE USED TO CHOOSE STYLE?

The Individual's Preference

Any choice of hearing aid style should be made with the prospective user's preference as a primary concern. As a respected colleague of mine recently advised a young audiologist, "Give him what he wants." This was in response to the young audiologist's strong conviction that a certain style was the only appropriate option. In fact, given the user's degree of hearing loss, ear size, and the availability of dual receivers for increased power, the client's ITE style preference was not unreasonable. If a clinician is too heavy-handed and prevails in recommending against a person's preferred choice, there is a strong possibility that the aids will not be used much (or at all) beyond the trial period. Motivation is very important to users' success with hearing aids, and allowing them to participate in the decision regarding style will increase the chances that they will benefit from amplification.

Degree of Hearing Loss

In 1800, regardless of the degree of hearing loss, there were three ways to help someone hear better: 1) shout, 2) speak directly into the ear (which will be much louder than a shout at 3 feet), or 3) give the person an ear trumpet, horn, dome, speaking tube, or similar device. These devices were often quite ingenious, but had severely limited gain and relatively low fidelity.

In the 1940s, small vacuum tubes became available, but options for wearable amplification were still limited, this time to body-worn aids. In the 1960s, with the availability of transistors, the options included body aids, eyeglass aids and BTE aids. In the 1970s, style options increased as in-the-ear (ITE) hearing aids steadily gained the confidence of manufacturers, dispensers, and users.

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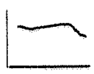
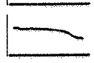
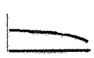
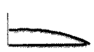
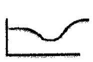
In the mid 1990s, completely-in-the-canal (CIC) hearing aids became an important addition to style options, making high fidelity amplification possible with all styles. We no longer have to follow old guidelines, such as considering only a BTE if the loss is severe; learning to lip-read if there is a precipitous loss above 2000 Hz; waiting a while if the loss is mild; or never aiding the poorer ear if the loss is asymmetrical.

Figure 1 gives options of shell style for different hearing loss configurations. There are many options available in most hearing loss categories. Assuming appropriate circuitry and venting, there are very few limitations regarding style for all degrees of hearing loss from mild through severe.

Figure 2 shows the choice of styles from a different perspective, the manufacturers' suggested fitting ranges for various types of hearing aids. It appears from this chart that there are few "no" answers to hearing aid type, regardless of the degree of hearing loss. Is this good news or a dispensing dilemma?

Experienced practitioners will appreciate the wide range of fitting possibilities. Some may even have had success with some of the fittings considered high risk or not recommended. Inexperienced clinicians might hesitate to try higher risk fittings, but good clinical judgment is often gained by trying fittings that seem borderline. Armed with realistic expectations and adequate understanding of earmold material, venting, canal length, circuitry, ear size and shape, loudness tolerance, and individual client capabilities, clinicians might occasionally try canal aids with a moderate-to-severe loss, ITEs with a severe-to-profound loss, or half-shells or CICs with a severe loss.

When choosing earmold and hearing aid style, the clinician should consider the slope of the hearing loss. With some styles, it may be impossible to provide

DEGREE	RANGE	BTE	ITE	ITE-LP	HS	ITC	MINI CANAL	C/C	COMMENT
1. Mild		•	•	•	•	•	•	•	All styles=OK, vent=impt, beware OE
2. Mild/Mod		•	•	•	•	•	•	•	All styles=OK, vent=impt, except c/c
3. Mod		•	•	•	•	•	HR	•	Fitting Flexibility if few or no pots available
4. Mod/SCV		•	•	•	•	HR	no	•	Feedback, Max gain = most import. consid.
5. Severe		•	•	•	HR	no	no	HR	Feedback, Max gain = most import. consid.
6. Severe/Profound		•	HR	no	no	no	no	no	Feedback, Max gain = most import. consid.
7. Profound		•	no	no	no	no	no	no	BTE's=aids of choice; there is a rare occasion when IDE's with Dual rec. could work.
DIFFICULT									
8. Cookie Bite		•	•	•	•	HR	no	•	Venting is very important
9. Precipitous		•	•	?	no	no	no	HR	Beware of O.E. and Pbk
10 Reserve Slope (Depending upon degree)		•	•	•	•	•	no	•	Venting is important, except c/c
11. Nl=No loss with Ski Slope		•	•	•	HR	no	no	•	OE & Pbk most important; Ventinng import.

HR = High risk, but possible, esp: with programmability
no = Don't attempt: High failure rate expected or totally impacted
NR = Not recommended for best results

Figure 1.
Options of shell style for different hearing loss configurations.

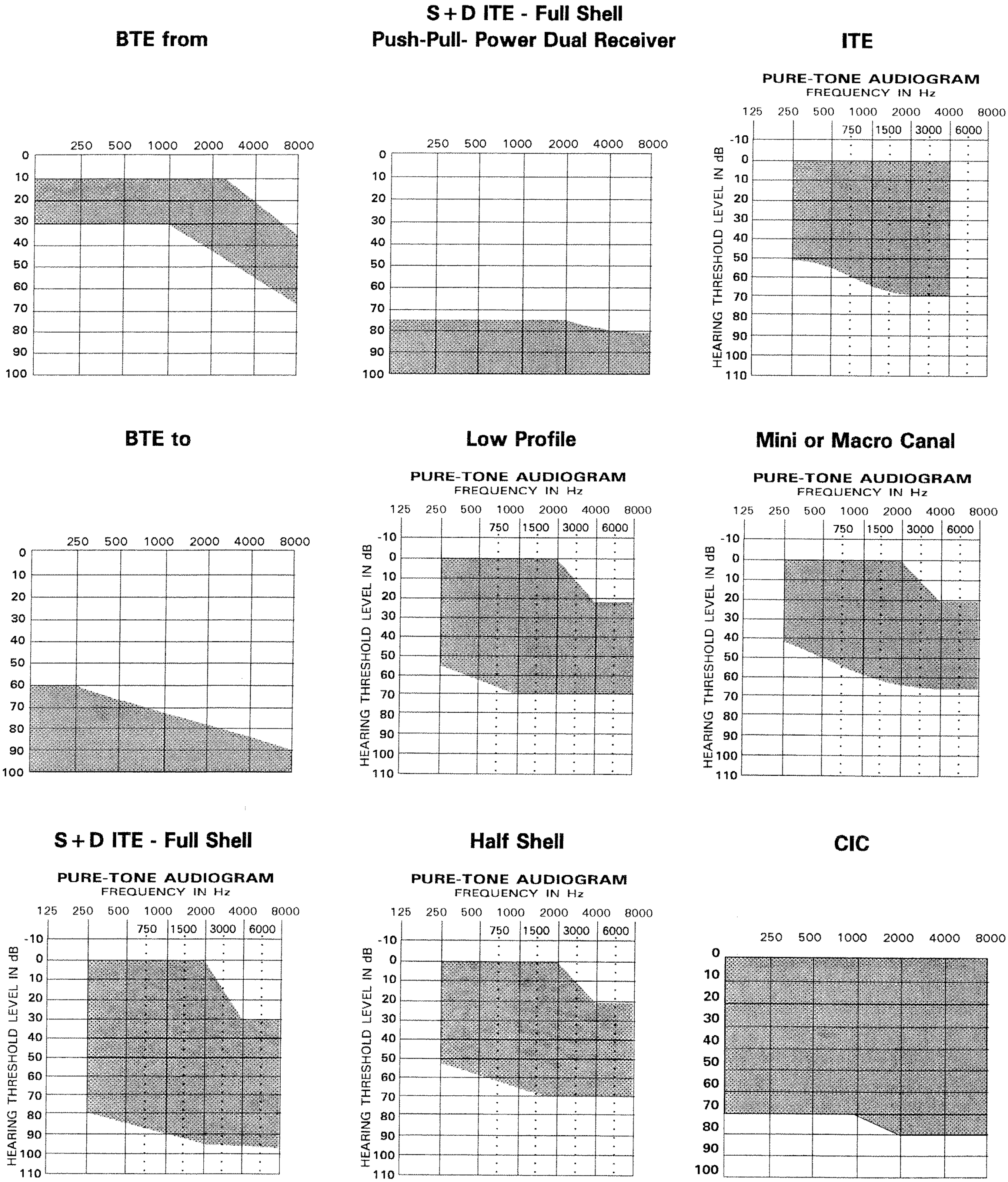


Figure 2.
Manufacturers' suggesting fitting range.

enough gain in the high frequencies if the slope is precipitous, or if the loss is profound above the mid-frequencies. In these cases, providing improved audibility for sounds in the frequency region where the thresholds are becoming rapidly poorer becomes particularly important (1). "Fitting the slope," and abandoning the unreachable region becomes critical. The second formant of speech is rarely above 2000 Hz and if the audiologist delivers clean mid-frequencies, the recognition of transitions from vowels to consonants will be enhanced, resulting in greatly improved speech intelligibility. With steeply sloping high frequency losses, programmable instruments and hearing aids with adjustable bands (or channels) are extremely useful in shaping the high frequency response while containing feedback. Where possible, the clinician should roll off the high frequencies (above the region of the slope he or she is trying to reach) to prevent feedback that the user cannot hear. Earmolds that are best suited for these configurations will be discussed in the section on earmold acoustics.

Size and Shape of the External Ear and Ear Canal

Except with the obvious physical characteristics of a malformed pinna and/or concha, or a surgically modified outer ear or ear canal, it is often difficult to predict whether a particular style of mold will give good results solely on the basis of physical and otoscopic inspection of the ear. Containment of feedback and retention are important for all individuals. Canal-type molds and canal aids are sometimes contraindicated depending on the severity of the loss and/or the shape of the pinna and concha. In some cases retention of the mold is better accomplished with a half-shell mold than a low-profile or full-concha style, depending on the shape of the concha.

In a surgically modified ear canal with a large volume of 5 to 10 cc, the output speech production level (SPL) can drop by 10 to 20 dB. Conversely, a stiff middle ear system from ossicular fixation, tympanosclerosis, or other condition, can increase the eardrum SPL (gain and output) by 10 to 20 dB (2). With deep-canal and CIC fittings, there is an increase in gain, output, and high frequency emphasis because of the deep placement of the ear-tip. If a particular style option is on the borderline of a fitting range, the dimensions of the ear canal, the intended placement of the ear-tip, and the impedance of the middle ear can help predict if it would be realistic to try that style. Adults and children with the same hearing loss will have different gain and output requirements because of the differences in ear canal volume.

There may be medical reasons for choosing a particular style of hearing aid. If there is chronic drainage from an ear, a BTE with a vented or open earmold is preferable to a more occluding ITE (if feedback can be avoided). Some individuals with chronic otologic conditions may have to alternate ears or decrease the use of a hearing aid in one ear during periods of infection or drainage. When an ear can not be occluded, and a large amount of gain is required, a contralateral routing signal (CROS) instrument may be a viable alternative so that a nonoccluding earmold can be used in the ear with the medical condition. Feedback should not be a problem, because the head shadow will provide an additional 10 to 20 dB of isolation. The user's ongoing medical management must be considered when the best style of earmold or shell is being chosen. For persons with Temporal Mandibular Disorder, certain styles and materials provide better comfort.

It should not be assumed that an ear is too small for a particular style. Components can now be placed in various arrays depending on the space available. If there is a question about the appropriateness of a particular style, the earmold lab or hearing aid manufacturer should help. The audiologist should choose the venting and the circuitry, but the lab should be allowed to build the shells and determine how the bores, vents, and components will fit. The fitter can then verify the acoustic and electronic appropriateness of the devices on the potential user.

Dexterity

People usually know what they can handle. If their manual dexterity precludes easy insertion and removal, or easy handling of batteries or controls, small hearing aids will not be the instruments of choice. There are occasional exceptions: screw-set volume controls or remote controls make certain styles possible and sometimes even preferable, but if the clinician feels that this is risky, it will save time and disappointment if potentially difficult management tasks are tried out while options are being discussed. Users will usually acknowledge their limitations and opt for a style better suited to their capabilities.

Occupation and Lifestyle

An individual's occupational environment or social situations may require the use of hearing aids with special telecommunications equipment, stethoscopes, music recording headsets, broadcasting equipment, or other assistive devices. If an individual is involved in physical activities or sports, a style should be chosen that is compatible with the level of activity. Wind noise, perspiration, and security-of-fit should be considered. Comfort and cosmetic concerns should also be addressed when the fitter and the user are making decisions about style.

Age and Previous Hearing Aid Experience

There are no presumptions about success, and no rules to follow regarding age or previous hearing aid experience: there are just too many individual differences. Young children, and adults with severely limited physical or mental capacity, will usually be assisted by others with the management of their hearing aids. For most other individuals, the factors just discussed—individual preference, manual dexterity, occupation, and lifestyle will direct the clinician to the right decision.

ITE hearing aid order forms ask for the client's age and previous hearing aid history. That is because there are corrections for gain and output for these factors figured into the formulae that determine which matrices dispensers receive when no circuitry recommendations are supplied. We assume that clinicians reading this book would not even consider sending only pure tone information when ordering hearing aids, or allow manufacturers to choose circuitry based on these criteria. The style that is most appropriate for the acoustic needs of the users and for the ease of management of parents or caregivers is the style that should be chosen.

In cases where previous users of conventional linear amplification are fitted with nonlinear wide dynamic range (WDR) compression hearing aids, individuals may comment that sounds are not loud enough. Several weeks of using better circuitry accompanied by good counseling regarding accommodation, users' expectations, and the intended outcome should produce a long-term favorable result. There are no studies that give compelling reasons to consider age or previous experience in choosing hearing aid style or circuitry. If a better style and improved circuitry are selected this time, the past is the past.

Cost

Any one of the factors above could become dominant when selecting the style of hearing aid. Additionally, a user's preference for a certain style may be dictated by financial considerations. MarkeTrak research indicates that cost is one of the top five reasons for non-purchase of hearing aids (3). Currently, CICs and many programmable instruments are considerably more expensive than other styles. Wearers of hearing aids are consumers. Their financial resources vary, and their perceptions of the value of hearing aids are unpredictable. Cost should be frankly discussed early in the selection process so that any compromise on style or circuitry can be handled at the outset. Alternative funding sources can be explored, if necessary. In addition to charitable organizations and governmental programs, the expansion of managed health-care benefits and other insurance supplements provide additional opportunities for obtaining hearing aids through funded benefits and discount plans.

EARMOLD DESIGN

Physical Fit

The three essential components of any successful earmold fit are comfort, seal, and a good acoustic result with the hearing aid, verified by real ear measurement. If comfort is not accomplished, the earmold should be modified or a new impression should be taken and a new mold ordered. If seal is not accomplished, feedback will occur, so the need will be to modify, build up, use temporary foam o-rings or have a new impression taken and a reorder issued. If comfort and seal are achieved but a good acoustic result is not accomplished, the mold or the circuitry should be modified, or reordered.

There is no substitute for taking a good impression. Even if a mold for a deep-canal fitting is not ordered, a long, full impression past the second bend should be taken; it will give the earmold lab more information from which to make a properly fitting mold at the length specified by the clinician.

Materials

There are basically two categories of earmold material—hard (acrylic) and soft (a variety of PVC, polyethylene and silicones). Usually, but not always, soft earmolds prevent feedback better than acrylic molds, and are typically chosen when the hearing loss is severe or profound. Both can be completely comfortable.

Most earmolds for BTE hearing aids are available in both hard and soft materials, but a few earmold styles are not available in some soft materials. Ear-tips on acrylic BTE earmolds and the canal portion of custom hearing aids can be ordered in flexible material for comfort or retention, but usually to prevent feedback. A few CIC manufacturers offer all-soft shells, and many users report greater comfort with this material.

Acrylic does not change over time. If feedback occurs after a long period of time, it is most likely that the shape of the individual's ear has changed and modification or replacement is necessary. Soft vinyl materials shrink, turn yellow, and become hard after variable amounts of time depending on the wearer's body chemistry. With adults, replacement of vinyl earmolds is suggested about once a year, but this varies widely among individuals. Soft earmolds are replaced for children whenever the fit and hearing aid response are compromised, which is usually first noticed when feedback begins to occur. Silicones are very stable and virtually indestructible, except for tearing, but require special skill on the part of the earmold lab to process properly, and are more difficult to modify in the clinician's office.

There is a controversy about fitting children with hard earmolds. It is rare that a child sustains an injury to the external ear from a broken earmold. Many educational audiologists routinely recommend soft earmolds for comfort, fit, and retention rather than safety considerations. Obviously, children with severe-to-profound hearing loss require soft earmolds to prevent feedback; however, many children successfully and safely use earmolds and ITE hearing aids that are made of hard materials. Very soft materials are not always good for children because the molds can actually fold back against the ear canal, preventing sound from exiting the bore.

Earmold Style

There are many earmold style options. Some of them are chosen purely for comfort or cosmetic reasons, but all styles were designed to achieve a specific acoustic benefit. This applies to both BTE earmolds and custom hearing aids.

Hearing aids are available from nearly 100 hearing aid manufacturers, but there are only about 15–20 earmold labs in the U.S. There are many similarities in the products offered by earmold labs, but each lab may use different designations for certain specialty molds. Clinicians should review the catalogs and the descriptions of the various molds in order to help determine the appropriate molds for the potential user.

Earmold Acoustics

This chapter is about physical options for hearing aid selection. A discussion of earmold acoustics and venting would require an entire chapter of its own. The basic principles have been superbly covered by Lybarger, Cox, and others, and are accessible in many audiology publications and textbooks (4).

It is important, however, for practitioners to understand the basic concepts of earmold acoustics and venting in order to know what to order, how to measure the effects of venting in the real ear, and how the earmold or shell can be modified to give a better response when they are faced with problems.

A BTE earmold is more than a plastic plug that holds the hearing aid in the ear. It is an integral part of a sound transmission system that begins at the receiver of the hearing aid and includes the earhook, the tubing, and the sound channel from the end of the tubing to the tip of the earmold. The diameter and length of the tubing, the distance from the end of the tube to the end of the earmold, the size of the bore, the length of the canal portion, and the vent size and angle all affect the response of the hearing aid. **Figure 3** shows the effects of different earmold constructions with the same BTE hearing aid at the same settings (5). It is important to remember that the earmold controls the response of the hearing aid. With ITE hearing aids, the mold plays a lesser, but still important role in the response of the aid.

Occlusion Effect

Classic complaints for the occlusion effect are, "my voice is hollow," "there is echo in my voice," "I sound as if I'm talking in a barrel, or a tunnel," or "I have a sensation of a plugged or stuffy feeling like a head cold." The low frequency amplification of the vibration from the user's own voice creates this unnatural sound.

We can all experience the occlusion effect by closing off our ears and saying "ee." As confirmed by probe measurements, our voices can generate 90–110 dB SPL in the occluded ear canal, 20–30 dB above the normal level in an open ear. This can be loud and distracting if we are trying to carry on a conversation, and can make it

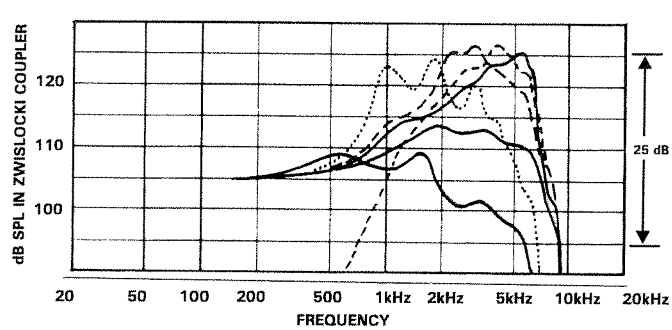


Figure 3.
Frequency response tailoring using various earmold constructions with a single amplifier-receiver combination. (Reprinted with permission from Killion, 1980.)

difficult for us to monitor our own voice, or to understand much of anything while chewing.

The occlusion effect may be present and troublesome with a wide range of hearing losses, but is most noticeable when hearing is near normal in the lows. The occlusion effect is due to sound transmission into the ear canal from vibration of the cartilaginous portion of the ear-canal wall induced by flesh- or bone-conducted vibration. The source of the vibration is the roughly 140 dB SPL created during vocalization of closed vowels, such as /i/ and /u/ (ee and oo) in the back of the mouth (6).

Shallow placement of the earmold results in the most occlusion effect below 500 Hz. **Figure 4** shows the amount of ear canal SPL produced by one individual vocalizing /i/ (ee) in a closed (occluded) earmold, an open ear (unoccluded), and with various amounts of venting.

The traditional fix for the occlusion effect has been to vent the earmold (with the results seen in **Figure 4**). With smaller and smaller custom hearing aids, vent size is often limited, and the occlusion effect can not be reduced as effectively with canal aids as with full-shell styles. CICs provide an obvious exception, but *any* deeply sealed ear-tip can reduce, or in some cases eliminate, the occlusion effect. Techniques for measuring and monitoring the occlusion effect with real-ear probe microphone equipment are described by Mueller, Hawkins, and Northern (7), and Revit (8); these methods provide clinicians with good tools for attacking the problem.

Open-Canal Fittings

The traditional approach to fitting high frequency hearing loss was to provide high frequency emphasis BTE hearing aids with closed earmolds. This was an electronic approach that could be achieved with the right combination of circuitry, but users objected to poor sound quality because of the occlusion effect, or in worst cases, insertion loss from occluding earmolds. Monaural fittings with this approach were usually unsuccessful.

Individuals with unimpaired hearing in the low and mid-frequencies still often complain of the occlusion effect even with vented or partially occluding earmolds. High-pass hearing aid circuitry is now available for in-the-ear instruments; however, depending on the user's low frequency hearing, venting may still produce the most natural sound. Open-canal fittings are an acoustic approach, used to reduce low frequency amplification and make sound more natural when fitting high frequency hearing loss. Canal hearing aids and mini-canal aids are not the instruments of choice with this type of hearing loss because of the limited amount of venting possible, unless a deeply sealed fitting is accomplished.

An open earmold should not be used with a high frequency emphasis hearing aid. Earmolds, such as acoustic modifier molds (typically hollowed out to produce a large diameter, 5 mm-long vent channel with a positive venting valve) or non-occluding molds with high frequency emphasis hearing aids may unfavorably alter both the mid- and high frequency response. Staab et al. (9) concluded that the bandwidth of the BTE hearing aid should be as *wide* as possible when using these types of earmolds.

The insertion depth of an open tube will have a modest effect on the frequency response, but a large effect on feedback. Some 15 dB change in useful gain before feedback can sometimes be obtained by adjusting the depth of the tube in the ear canal. A good place to start for maximum gain before feedback is a surprisingly shallow 8 to 10 mm depth (10).

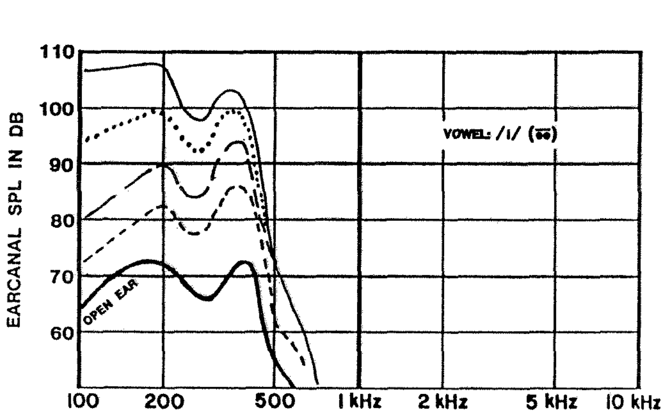


Figure 4.
The amount of ear canal SPL produced by one person vocalizing /i/(ee) in an closed earmold, an open ear, and with various amounts of venting.

Deep Canal Fittings

Deep-canal fittings can be accomplished with any hearing aid or earmold. We have been fitting deeply sealed earmolds on clients for decades, most often for severe and profound hearing losses, to prevent feedback. Deep-canal fitting refers to the placement of the *ear-tip* of the hearing aid, not the depth of the ITC or CIC faceplate in the ear. The most important consideration is where the ear-tip seals. A deeply-sealed ear-tip can produce 5 to 8 dB additional high frequency emphasis (11).

Recent studies on the occlusion effect (6) remind us of what Zwislocki found in the 1950s: there is a reduction of the occlusion effect when the earmold is sealed at the bony portion of the ear canal. There are other acoustic benefits of deeply sealed ear-tips that will be discussed in the next section on the advantages of CICs.

Tubing

New earmolds are sent with the tubing glued into the mold at a specific distance from the tip of the earmold. When replacing the earmold tubing, the frequency response of the aid will be changed if larger tubing than the original is used, or if the tubing is pulled to the end of the earmold. Tubing that is too large for the bore will be squeezed down and choke off the highs. A loss of 5 to 10 dB has been reported in typical children's earmolds (12). For best acoustic results with BTE earmolds, it is important to understand the mathematical relationship between bore size, and tubing length and diameter. A brief explanation is given in the next section.

The size and thickness of tubing must be specified when ordering BTE earmolds. As the degree of hearing loss increases, more powerful hearing aids are needed. Naturally, increased gain and output will create more vibration in the earmold tubing. While standard earmold tubing is #13, thick-wall and super-heavy wall #13 tubing have the same internal diameter as the standard #13, but the outside diameter is thicker, and is reported to be better for molds that are used with high-gain instruments.

Dual-diameter tubing is sometimes used to shape frequency response. Stepped-bore tubing in ITEs can increase high frequency response by a few dB (4). Smaller diameter tubing such as #16 is used in BTE earmolds when a reverse-horn effect is desired. The most easily recognized example of dual-diameter tubing is the Libby Horn (13). **Figure 5** shows the effects of dual-diameter tubing in earmolds (4). Some combinations of tubing can roll off the highs, some enhance the high frequency response. If specific effects are desired, it is best to verify the result with probe measurements.

Bore Size And Horn Action

In a BTE earmold, the boost in high frequency emphasis due to horn action and quarter-wave resonance action starts at about the frequency where the distance between the change in the tubing diameter and the outlet

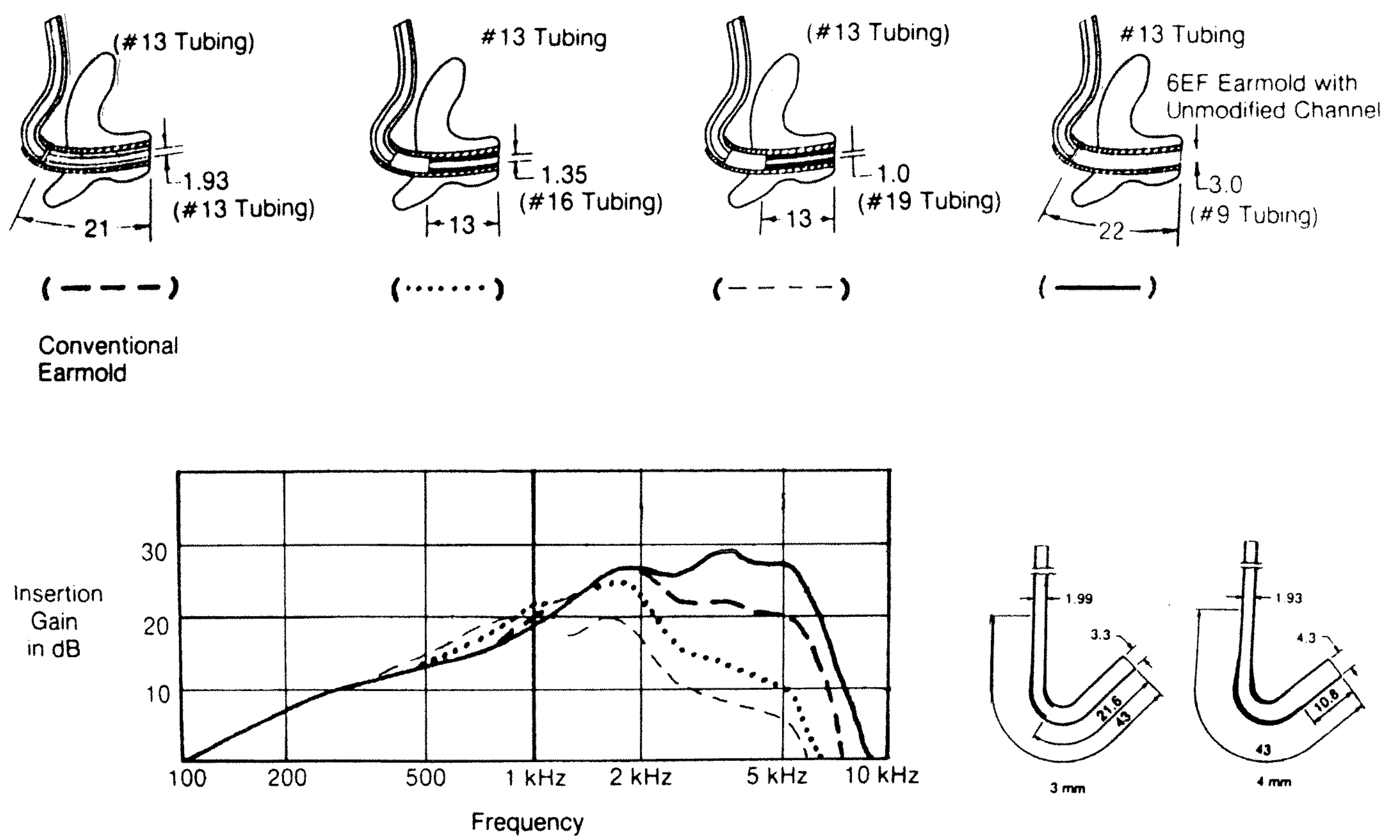


Figure 5.
Effects of dual-diameter tubing in earmolds.

of the ear-tip is a quarter wavelength. F(kHz)=86/length (mm). For example, trying to increase the high frequency response by pulling the tubing back from the tip by 10 mm will produce only about 1 dB improvement at 4000 Hz, because the starting or cutoff frequency will be nearly 9 kHz (86/10=8.6 kHz). It would have been better to use a Libby Horn whose large diameter bore begins 22 mm back from the tip (86/22=3.9 kHz), giving a 5–10 dB improvement at 4 kHz, compared to a conventional earmold.

The diameter on children's earmolds should always be checked. If the bore is too small, there will be a significant reduction in the high frequency response. For the best high frequency response, a 3-mm Libby Horn or continuous flow adapter (CFA) earmold should be used. CFA earmolds are produced with a fixed bore size. The tubing is changed by replacing the entire elbow-tube assembly. The tubing can not be pinched because it is affixed to the adapter. Thus, the high frequency response of the hearing aid is maintained or in many cases, enhanced. **Figure 6** shows the difference in frequency response with standard #13 tubing and 3-mm and 4-mm Libby Horns (14). There is little difference between the 3-mm and 4-mm Libby Horns except above 6000 Hz. All three earmolds were used with damped earhooks.

Real ear probe measurements should be used to check earmold and vent-resonance performance. All the horn and vent theory in the world will not predict a constricted tube in a vent channel or an unusual combination of ear and vent impedance.

Venting

A common misunderstanding about venting is that it is used to reduce low frequency amplification—often to reduce the occlusion effect or to solve the complaint that background noises are too annoying. The logic is that the larger the vent, the more the lows are reduced. This is inaccurate. Venting of earmolds and hearing aids has two major effects: to *reduce* low frequency amplification produced by the hearing aid, and to *let in* low frequency sound without amplification. What is sometimes ignored is the effect of the vent on the sound coming *into* the ear through the vent. With the low frequency rolloff in the typical hearing aid response, the low frequency gain of the hearing aid may be substantially less than zero. Under these conditions, the low frequency sound *coming in through the vent* will be higher than the low frequency sound delivered to the ear canal by the hearing aid. If the hearing aid is turned off, low frequency sounds will still reach the eardrum through a vented earmold, so a vented earmold can in some situations, provide an increase in low frequency gain compared to an occluding earmold (14).

At higher frequencies, the output of the hearing aid dominates. At all frequencies, the sound that is heard is a complex combination of the sound coming in through the vent and the sound delivered by the hearing aid. **Figure 7** nicely illustrates this complex phenomenon (14). Above 700 Hz, the output of the hearing aid dominates. Below 300 Hz, the sound coming in through the vent dominates. At about 400 Hz, the real-ear response depends on the relative phase. If the two paths are in phase, the signals add. If they are out of phase, a "notch" is seen in the response curve. Most hearing aids fall between 90 and 180° (out of phase).

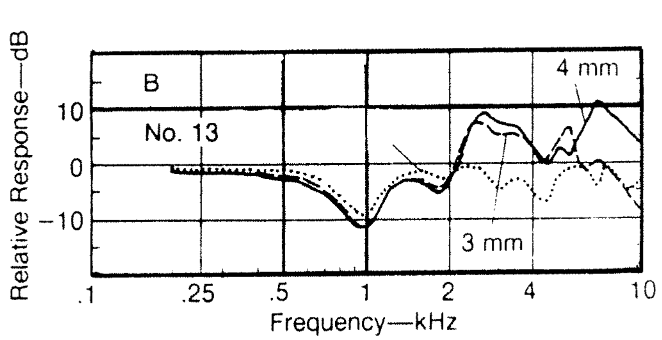


Figure 6.
Difference in frequency response with standard #13 tubing and 3-mm and 4-mm Libby Horns.

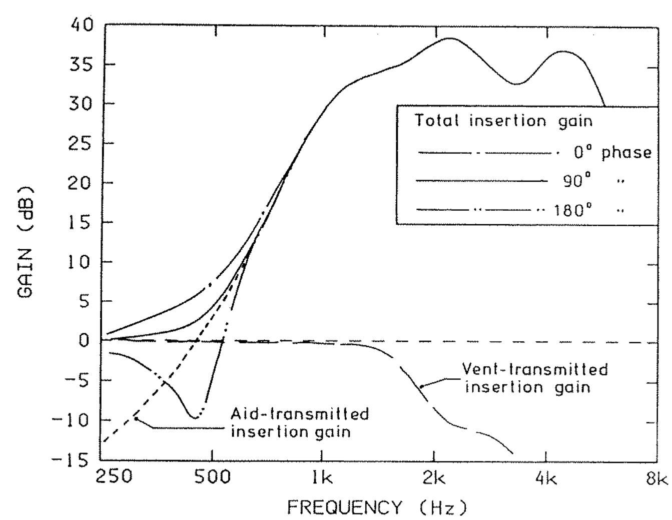


Figure 7.
Complex combination of sound coming in through the vent and sound delivered by hearing aid.

There are some venting challenges with hearing aids, such as the K-AMP, whose acoustic output is in phase with its input. (The designers argue that this provides the most natural reproduction of incoming sound.) When adjusted for a flat response and 0 dB gain for loud sounds, a real ear peak of 10-12 dB at 500 Hz, for example, can occasionally produce what amounts to a reverse-slope response for loud sounds. At the vent resonance frequency, the two sources of sound into the ear canal add to produce a peak. More commonly, the slit leak around the earmold damps the vent resonance, and less of a peak is seen. When the problem occurs, the solution is to introduce damping into the vent channel with a positive venting valve (PVV) insert with a BTE earmold, or a Knowles damper with an ITE mold.

Other types of hearing aids may produce a notch in their response near the frequency of the vent resonance. In this case, the acoustic output of the hearing aid is out of phase with the input and subtracts from the open-vent sound coming in. A dip of that sort is usually not a problem, but a different vent insert or potentiometer adjustment can often eliminate it.

Venting effects will vary with all hearing aids, including programmable ones, and should be verified with real ear measurements. When users state that they hear better in noise with their hearing aids turned off, this may be caused by an abnormal vent resonance that can only be tracked down with probe measurements.

Vent inserts

BTE earmolds can be ordered with select-a-vent (SAV) and PVV. These inserts have holes of different diameters, resulting in different amounts of low frequency reduction. PVVs are preferable because they give slightly better damping of the resonance peak for a given low frequency reduction. Despite the fact that there are five sizes of SAV and PVV (six, including the solid plug). Only the two largest sizes of insert give any appreciable low frequency reduction unless the vent channel is very large and short—with a diameter of 3 mm and less than 5 mm in length—as in an acoustic modifier earmold (15).

ITE aids are often supplied with short lengths of tubing that insert into the vent channel. The vent diameters vary among manufacturers and by hearing aid style. Smaller custom aids may have smaller vent inserts. When plugging a vent of any kind, it is best to verify the change by real ear measurement; the larger the vent opening, the more the response curve may be dominated by vent resonance.

Damping and Earhooks

Ears and brains prefer a flat (smooth) insertion response. The addition of dampers in the earmold tubing or in the earhook flattens the peaks in the hearing aid response. The first peak in a BTE response usually occurs around 1000 Hz. Damping the tubing or the earhook can significantly smooth the peak (4). This can be done by the clinician and then verified with real ear measurements. **Figure 8** shows the response-smoothing effects of dampers for different locations in the earhook and tubing of BTE earmolds. (A) shows no damping and (E) shows the smoothest response at the tip of the tubing as it enters the earmold, but it is the least practical placement, due to moisture problems and difficulty of retubing.

Many BTEs are now available with damped earhooks. ITEs can be ordered with damped coupling assemblies, dampers in the receiver tube, or internally damped receivers. Response-modifying earhooks developed by Etymotic Research can be used to modify frequency response (10). Low-pass, high-pass, 2 kHz notch-filter and cookie-bite earhooks were designed to cooperate with specific earmold configurations and tubing to achieve predicted target gain for unusual losses. The response-shaping features of recent programmable instruments have made it easier to fit more difficult losses. Since the response peaks still occur, some programmable instruments also have damped BTE earhooks and filters in ITE receiver tubing.

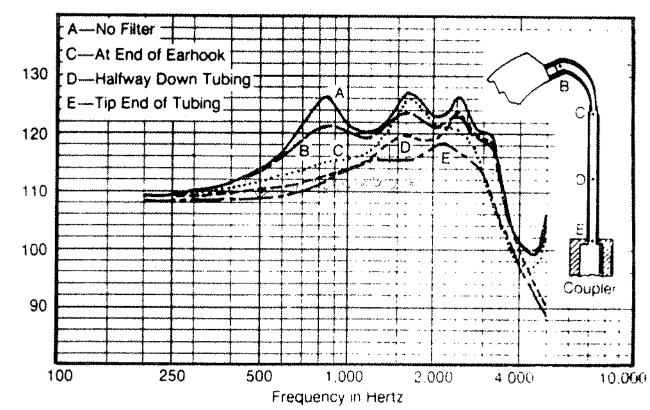


Figure 8.
Response-smoothing effects of dampers for in the earhook and tubing of BTE earmolds. A = no damping; E = smoothest response at tip of tubing.

ACOUSTIC ADVANTAGES OF DIFFERENT STYLES

One of the most important bonuses of recent advances in hearing aid technology is that performance no longer has to be sacrificed for size. Bandwidth and response smoothness of microphones and receivers have actually improved with their decreasing size, as has nearly every other property: resistance to shock damage, magnetic shielding, and microphone insensitivity to vibration. Degree and slope of hearing loss are still important factors in style selection, but given the wide range of fitting possibilities now available, the acoustic advantages of certain styles should also be considered.

Advantages of Behind-the-Ear Aids

BTEs are the instruments of choice when feedback is a major concern. **Table 1** shows a comparison of approximate maximum gain before feedback for BTE hearing aids with different amounts of venting (personal communication with M.C. Killion, 1997). For a given effectiveness in earmold seal, the available gain is simply proportional to the distance from the vent opening to the microphone opening.

Degree of hearing loss can direct the audiologist to suggest a BTE, but it is not always the deciding factor. Until recently, there was greater fitting flexibility with BTEs because of multiple controls, but this is much less of a problem now, with the availability of computer-programmable and multiple-potentiometer ITE instruments. The best directional microphones are still available only in BTEs, but more effective directional microphones should be available in ITE products in the next few years.

BTEs are a good choice with precipitous high frequency hearing loss when there is good hearing in low and mid-frequencies, or when venting ITE or canal-aid shells does not sufficiently reduce the occlusion effect. BTEs may be chosen whenever

- feedback is a significant concern
- the user reports his/her best acoustic performance (e.g., reduced occlusion effect and most natural-sounding
- the best response can be verified on real ear measurements
- ease of management of the instruments is best achieved with a BTE aid.

Advantages of In-The-Ear Aids

One major acoustic advantage of ITEs over BTEs is microphone location. In ITEs, the microphone location takes advantage of pinna focusing effects, resulting in an enhancement of high frequency sounds from 2000–5000 Hz of approximately 2 to 3 dB. The first peak in a BTE response is usually at 1000 Hz. ITEs have a shorter distance to transmit sound from the receiver to the ear canal, which results in the first major peak between 2000 and 3000 Hz that more closely resembles the natural resonance of the ear at approximately 2700 Hz (16).

Advantages of Completely-In-the-Canal Aids

CICs have advantages over ITEs that have the same 2 cc coupler specifications because of the deeper microphone location and the deep placement of the ear-tip that typically occurs. The smaller volume left in front of the ear-tip causes an increased SPL at the eardrum. This can result in increased output of 4 dB in the low frequencies and 8 to 10 dB at 4000 Hz. Gain is increased even more: the increased output implies increased gain, and the deep microphone location adds a high-frequency boost. The gain increase of a CIC over an ITE is about 5 dB at low frequencies, and 13 dB at 4000 Hz.

Table 1.
Comparison of approximate gain.

	Leak Distance to Microphone	Estimated Before <1 mm	Maximum Feedback 3 mm	Gain in dB vs. Vent Size Accoustic Modifier	Open Canal
Body	300	80+	60	50	40
BTE	30	60+	50	40	30
ITE	10	50+	40	30	20
Canal	3	40+	30	20	10

The equivalent volume of the ear behind a typical BTE or ITE is not 2 cc, but closer to 0.7 for ITEs. It is only about 0.25 cc for deeply sealed CICs. Because of this reduced volume of air, the CIC aid will typically have 9 dB greater undistorted output at the eardrum than in a 2-cc coupler at low frequencies, and 20 dB greater output at the eardrum at higher frequencies (11).

The total of all effects gives the real-ear response of a CIC aid some 15 dB high frequency boost relative to a full-shell ITE with the same 2 cc coupler measurements. **Table 2** gives the estimates of conversion from the 2 cc coupler to real-ear insertion gain, and from SSPL90 in the coupler to SSPL at the eardrum (11,17,18).

Feedback is often reduced with CICs because of the deep seal, and because there is little or no venting. A recent study indicated that the occlusion effect can be reduced approximately 10 to 15 dB from 250–1000 Hz with a deeply sealed CIC compared to a medium-length ITE canal. There is less wind noise with a deeper microphone location, and telephones and stethoscopes are reportedly easier to use with CICs. Pinna and concha cues for localization are preserved in their entirety up to about 15 kHz with the microphone located inside the ear canal entrance (19).

DIRECTIONAL HEARING AIDS

Although directional microphones have been available in BTEs since the 1970s their use declined until recently. More than 80 percent of all hearing aids dispensed in the U.S. are custom in-the-ear hearing aids, and, until recently, there has not been a way to achieve enough separation between microphones in ITEs to obtain adequate signal-to-noise ratio.

At the present time, first-order directional microphones that are available in conventional BTEs and in some programmable BTEs can improve signal-to-noise ratio by 3.5 dB in typical situations, and from 10 to 15 dB in unusual circumstances. The improvement comes from reducing interference from the rear.

Studies that have been done in a variety of anechoic and reverberant conditions show general user preference for directional hearing aids in less reverberant environments, and when using binaural hearing aids. With the more frequent use of binaural hearing aids, and a number of research groups working on improved directional microphone applications for hearing aids, it is reasonable to expect substantial advances in this technology resulting in significant improvements in the ability of listeners with hearing impairment to hear in noise.

CROS, BICROS, TRANSCRANIAL CROS, AND CROS-PLUS

A detailed description of contralateral routing of signals (CROS) amplification will not be discussed in this chapter, but the decision to choose CROS or a CROS-type variation as a style option deserves brief mention.

Contralateral Routing of Signal(s)

CROS amplification was first introduced in the 1960s (19,20). CROS hearing aids are currently an option when a client has one unimpaired, or nearly unimpaired, ear and one unaidable ear. The use of a CROS aid eliminates the head shadow and allows the user to hear from the poorer side, even though there is no amplification into that ear. One of the original uses of CROS aids was to separate the microphone from the receiver so that a

Table 2.

Table Real-ear corrections for gain and output

Frequency in Hz	250	500	1000	2000	3000	4000	6000	8000
A GAIN in dB	7.5	7	9	7	10.5	18.3	23	23
B OUTPUT in dB (RECD)	7.5	7.5	10.5	14	18	21	24.5	26.5

Reprinted from the *Journal of the Acoustical Society of America* with permission of M.C. Killion (18).

large amount of high frequency gain with a nonoccluding earmold or tube-fitting could be used without feedback in cases of precipitous high frequency hearing loss. If using high-gain binaural amplification is not successful with a very severe loss, a Power-CROS is an option. The microphone is housed at one ear while the receiver is in the instrument on the other.

A wireless CROS hearing aid contains a microphone housed in a BTE case worn at the unaidable ear; sound is received at the good ear in either an ITE shell or another BTE case. Open-mold or tube fittings are common depending on the hearing in the better ear. A wired CROS can be built into either ITE or BTE styles. The major advantages of CROS are improved localization ability, better balance of sound, and ability to hear from the poorer side. The major disadvantage of this fitting is marginal, if any, improvement in noise, except when the signal is on the side of the poorer ear.

Binaural Contralateral Routing of Signal(s)

BICROS amplification is considered when there is hearing loss in both ears but one ear is unaidable. Like CROS aids, there is a microphone at the poorer ear that communicates via a cord or by wireless RF transmission, and there is an additional hearing aid in the better ear. Style options are the same as those for CROS hearing aids.

Transcranial CROS

Transcranial CROS (21,22) is used when there is one unimpaired, or nearly unimpaired, ear and no residual hearing in the other (a dead ear). A monaural power aid, either ITE, BTE, or CIC is worn in the dead ear. When the gain is high enough for stimuli to produce crossover to the opposite cochlea, users report improvement in localization ability.

Sullivan (21) reported aided (from the dead-ear side) thresholds consistent with the assumption that the Transcranial CROS operated with a 50 dB interaural attenuation. Gudmundsen and Killion[1] measured two unilateral subjects with an ER-3 and with three different Knowles receivers: The EF-9909 (commonly used in BTE aids), ED-1932 (commonly used in ITE and canal aids), and the EJ-3021 (a dual-receiver vibration-canceling arrangement). In these experiments, the lowest interaural attenuation was approximately 60 dB (see **Figure 9**).

This means that an ITE hearing aid with 60 dB of gain placed in the dead ear will produce the same gain near 2000 Hz as a 0 dB gain hearing aid placed in the good ear. When the sound is coming from the dead side, the good ear will effectively hear 20 dB better because the head shadow is eliminated. A large number of hearing aid users utilizing this arrangement in combination with CROS-PLUS (see below) reported substantial benefit despite the limited frequency region over which the interaural attenuation is low enough to make this work (23).

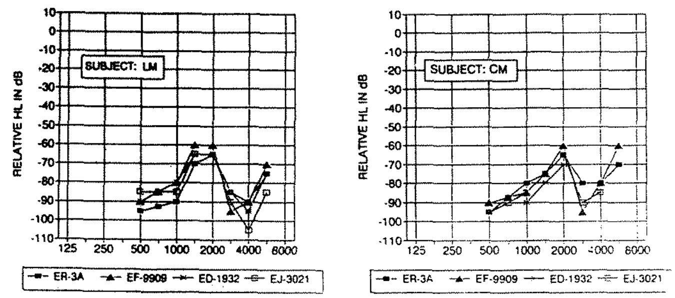


Figure 9.
Interaural attenuation of three earphones in ITE shells and of ER3-A insert earphone with foam eartip.

CROS-PLUS

CROS-PLUS (21,22) combines transcranial CROS and either classic-CROS or BICROS: the transcranial CROS portion adds the dimensions of distance and direction while the CROS or BICROS portion provides clarity (23). CROS-PLUS has two microphones, both on the unaidable side—one for the unaidable ear (the transcranial component) and one to pick up sound that will be transmitted to the good ear (the CROS advantage). BICROS-PLUS is modified to use three microphones, two at the unaidable ear, and one in the better ear. Style options are limited. Wireless fittings are usually not successful, and although it is still possible to have eyeglasses wired with this arrangement, a modified BTE is the preferred recommendation.

OTHER STYLES

Body aids are still available and serve a purpose when nothing else will reach a loss without feedback, or manual dexterity and the ability to manage anything smaller is severely limited. Some individuals have used body aids for years and are unwilling or unable to adapt to a BTE style. The most separation between the microphone and receiver is achieved with this style, but microphone location—wherever the individual puts the aid on

[1]GI Gudmundsen and MC Killion, Interaural Attenuation of Three Earphones in ITE Shells Compared to ER3A Eartip. Unpublished data, 1991.

or in the clothing—will determine the amount of clothing noise, body baffle, and interference that is present.

Eyeglass hearing aids account for only a small percentage of hearing aids dispensed today. They are most often used for CROS-type fittings. There is unlikely to be a resurgence of interest in eyeglass hearing aid technology, unless significant improvement in directionality/localization can be achieved with this style.

MONAURAL OR BINAURAL

For clinicians who fit a large number of hearing aids annually, the decision about monaural versus binaural is an easy one. They have seen the positive benefits clients receive when there is input to the brain from both ears: better localization, better speech understanding in noise, greater ease of listening (less strain), and better balance of sound.

The author strongly believes that it is better to give a skeptical individual two hearing aids at the start, and have one returned, than to start with one and see how it goes before deciding on a second aid. One of the primary reasons people fail with amplification is because they were only fitted monaurally. Libby (personal communication, 1995) reported that 80 percent of his failures were monaural fittings. Indeed, it is hard to motivate someone to try two hearing aids after one was not successful. Another reason for failure with monaural fittings could be inappropriate circuitry, which will be addressed in later chapters.

Counseling is a key ingredient in the fitting process when someone is hesitant about trying binaural hearing aids. Often these individuals report negative experiences from friends or relatives, and it is crucial that the many advantages of hearing binaurally are pointed out to the prospective user. A demonstration of binaural hearing should be part of the initial work-up at the time hearing aid candidacy is being determined. An opportune time to introduce the concept is prior to word recognition testing when the most comfortable (hearing) levels (MCLs) have been established: the clinician briefly speaks into one ear at MCL and then the other at MCL. The candidate is then asked to identify the source of the clinician's voice "right, left or both."

When the condition 'both' is identified, most listeners realize the benefit of binaural hearing aids. When directing the signal to both ears, the audiologist should reduce the level 5 dB to correct for binaural summation. The entire procedure takes less than 5 minutes and can save a great deal of time and effort later when the monaural/binaural choice is explained.

Results of an early study on late-onset auditory deprivation revealed that word recognition scores of subjects fitted binaurally remained stable over time, but subjects fitted monaurally (despite their symmetrical sensorineural hearing loss) showed a significant decrease in word recognition in the unaided ear (24).

Gelfand (25) reported that a significant auditory deprivation effect can develop within about 2 years (but as quickly as 7 months) of monaural hearing aid use. The good news is that word recognition of the previously unaided ear can return to its original level within about 2 years (but as quickly as 10 months) after binaural amplification is introduced. Auditory deprivation from monaural hearing aid use has been reported in children as well as adults. Various investigators have found that recovery from the auditory deprivation effect can result from the introduction of binaural amplification, but it does not reverse in every case, nor does it always result in *complete* resolution of word recognition ability. Since there does not seem to be a strong correlation with age or degree of hearing loss, the best way to avoid the problem is for the user to be fit binaurally in the first place.

The mixed results of previous monaural versus binaural studies may have been due to unrealistic test conditions or limited circuitry options available at the time of these studies. In her doctoral dissertation, Naidoo found that there was a statistically significant difference in binaural preference between subjects fitted with low distortion instruments and those fitted with standard linear hearing aids. Her data suggest that some people are happier with only one aid in noise when the circuitry distorts badly. With low distortion aids, however (and especially with wide dynamic range compression instruments), her subjects preferred binaural aids (26). With better options of signal processing and programmability, practitioners will likely increase their recommendations of binaural amplification.

ASYMMETRICAL HEARING LOSS

The decision to fit the poorer ear in an asymmetrical loss is often difficult for the inexperienced clinician. That is because there are no rules for determining "unaidable." The ability to judge midline on a binaural task, (see previous section) and the subjective rating of clarity are important in deciding whether to try amplification in an ear with disproportionately poor word recognition or a difficult-to-fit pure tone configuration. Most often the addition of an instrument in the poorer ear will provide better localization ability, better overall clarity, and better performance in noise with binaural amplification than with a CROS-type instrument. It is a rare case in which providing amplification to an ear will make the situation worse. One exception is hyperacusis in which a person's tinnitus is exacerbated by noise. Exclusion from hearing aid candidacy due to central auditory disorders is not well documented.

A recent study of auditory deprivation in subjects with asymmetrical hearing loss indicated that the poorer ears of these subjects were analogous to the unaided ears of subjects with symmetrical sensorineural loss who were monaurally aided: fitting the poorer ear of subjects with asymmetrical loss may prevent or reverse auditory deprivation (27).

PROS AND CONS OF SELECTION CHOICE

This book is about hearing aid selection options, not final decisions. Good advice and decision-making strategies are contained in this book, but clinicians could still make the wrong decision. If they prepare their clients (and often their clients'families) by explaining their decisions and allowing the potential user to participate at whatever level is deemed appropriate, a relationship of trust will be established that will not be undermined if the instruments chosen are not perfect at the hearing aid fitting.

User motivation is highly important. The audiologist should give reasons for any decisions that are made and it should be explained that if option one is not successful, the fitting plan will be modified and explanations of how this will be accomplished should be given. The user's ability to assimilate technical information should not be underestimated. Potential users should be given consumer brochures as well as technical articles. Either they or someone they know might benefit from the information.

The individual's preference should be accommodated whenever possible, but he/she should be made aware of the clinician's boundaries for compromise. The clinician should be willing to try tough things, but also be willing to admit that a questionable fitting did not work. This is part of the learning process.

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