

Chapter Six

Signal Testing Approaches

Clinical Procedures To Improve User Satisfaction with Hearing Aids

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INTRODUCTION

Professionals dispensing hearing aids have a responsibility to provide the best possible fitting. This chapter will outline several procedures we have used over the past several years, which are comprehensive and, we believe, have an excellent chance of resulting in user benefit and satisfaction.

The procedures presented in this chapter occur over a span of three prospective-user visits. The first visit includes pure-tone, speech and immittance audiometry, loudness judgments for pulsed tones, assessment of individuals' motivation toward amplification, counseling on fitting options, and obtaining the unaided portion of the Abbreviated Profile of Hearing Aid Benefit, or APHAB (1). The second visit includes coupler measures of the aids, measuring their real ear performance, and aided loudness judgments for speech. The final visit includes obtaining the "aided" and the resulting "benefit" scores for the APHAB and fine-tuning the electroacoustic characteristics of the aids in response to the user's assessment of benefit during the 4-week trial period.

The clinical procedures presented in this chapter have evolved over several years and will continue to evolve as new information and insights become available. That is, for any clinical procedure to be successful, it must be capable of change and not remain dormant.

FIRST VISIT: PRE-FITTING DATA

Comprehensive Audiometry and Assessment of Motivation

During the initial visit, a comprehensive case history is taken and pure-tone and speech audiometry are measured in the conventional manner. Immittance audiometry is pursued if the audiometric or speech results warrant ruling out conductive, mixed, or retrocochlear pathology. After these tests, candidacy and motivation toward amplification is discussed for the first time. During these discussions, the audiologist needs to accurately assess the motivation of the potential user. We believe that dispensing hearing aids to unmotivated people can do significantly more harm than good. If the experience is unsatisfactory, the user's feelings will be transferred to friends and family members who may also be considering amplification. Therefore, it would not be surprising that these potential users would no longer consider amplification because of their friends' or relative's negative

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experiences. Therefore, dispensing hearing aids to an unmotivated person is strongly discouraged, because it may lead to more than simply a return for credit. When counseling such people, audiologists should suggest that the present may not be the most appropriate time for them to consider amplification, and urge them to think about what was discussed and make an appointment at a later date when they feel more motivated.

Real Ear Measures of Loudness Discomfort

One of the most important facets of a successful hearing aid fitting is the assurance that the amplified signal does not exceed a level at which the user reports it as being too loud. As part of the initial evaluation, the intensity level is measured at the maximum comfort level (MCL) by placing the probe tube from a probe microphone in the ear canal approximately 4–6 mm from the eardrum to obtain the sound pressure level (SPL) near the eardrum (2–5). To assure that the end of the tube is that distance from the eardrum of an adult, it is marked 30 mm from its tip; the mark is placed at the intratragal notch of the outer ear and taped into position.

Directly measuring the SPL near the eardrum can be accomplished in two ways using at least one commercially available real ear analyzer, the Frye 6500 (Frye Electronics, Inc., Tigard, OR). Clinicians should refer to the manual of the real ear analyzer they use to determine how to do this. When using the Frye, one method is to eliminate the signal to the loudspeaker under the “Operation Parameter” menu. In this menu, pressing the left arrow button on the probe module until the intensity level shown on the video monitor is ‘off’ eliminates the signal to the loudspeaker. This action disables the loudspeaker and converts the device to a spectrum analyzer: the audiologist can then directly measure the SPL near the eardrum by reading the dB SPL appearing as RMS OUT on the monitor. An alternative method is to call up the “Calibrate Probe” menu and read the measured SPL under the ‘probe’ column on the monitor.

Using either method, a calibrated ER-3A insert earphone (Etymotic Research, Elk Grove Village, IL) is connected to the earphone output of an audiometer calibrated to ANSI-1989 specifications (6). In addition to the earphone performing within those specifications, its impedance must match that of the audiometer. The ER-3A is available in 10, 50, or 300 ohms to match the outputs of the numerous audiometer and earphone combinations currently available. For example, the 50-ohm model is appropriate if the audiometer uses TDH-49 or TDH-50 earphones, while the 10-ohm model is appropriate for use

with the TDH-39. Interestingly, a 50-ohm ER-3A can be used for audiometers designed to be used with the 10 ohm version; however, the measured output will be ~6 dB greater. Moreover, the clinician should never use a 10-ohm ER-3A with an audiometer designed for a 50-ohm earphone. This can result in excessive distortion and damage to the audiometer. When not sure which insert earphone is appropriate for the audiometer/earphone combination, the clinician should call the local equipment representative or the manufacturer.

At this point, the earphone is placed in the ear canal using an appropriately sized E-A-R™ foam tip (Cabot Safety Corporation, Indianapolis, IN). Another method of coupling the ER-3A to the ear canal is to use immittance tips connected to a special adapter (ER3-06) included with the earphones. In either case, the tip is inserted deeply enough that its lateral aspect is flush with the opening of the ear canal and pulsed (200 msec on/off) pure tones between 500–4000 Hz in octave and mid-octave intervals are presented to the listener. The user is asked to judge the loudness of the signal with choices between ‘very soft,’ ‘soft,’ ‘comfortable, but slightly soft,’ ‘comfortable,’ ‘comfortable, but slightly loud,’ ‘loud, but OK,’ and ‘uncomfortably loud’ (7).

Using an ascending procedure, the attenuator is increased or decreased in 5 dB steps to determine the threshold level where the user consistently reports that the pure-tone signals are ‘loud, but O.K.’ This level is read in dB SPL from the monitor of the analyzer and documented as the loudness discomfort level (LDL) in the client’s chart. As part of the hearing aid fitting at a later date, the audiologist, using a real ear analyzer, measures the output (in dB SPL) from the aid in response to a pure-tone sweep of 90 dB SPL to assess the relationship between the measured output and the measured LDLs. The audiologist would like the measured output values below the measured LDLs. This would indicate that even loud environmental sounds should not be uncomfortably loud to the wearer of the aid.

Counseling

As it is important for the potential user to obtain a realistic picture of amplification benefits, he or she must be counseled on the following points. First, the performance with the aids in quiet must be significantly better than the performance without them. The individual is reminded that the final judgment of significant benefit does not rely on the outcome of the numerous measures described in this chapter, but rather that decision is his or hers alone. Hopefully, the results of the well-thought-out

adjustments and strategies applied by the audiologist will correlate highly with the final judgment of the user. Second, the performance with the hearing aids in noise must be significantly better than performance without them in the same listening environment. Most people seek amplification because they experience difficulty in recognizing speech in noise. If this goal cannot be reached, why would the person even consider purchasing the instrument? Third, and most important, the person should not expect performance with hearing aids in noise to be as satisfactory as performance with them in quiet. To expand upon this point, we as clinicians explain that persons with unimpaired hearing do not recognize speech as well in a noisy restaurant as they do in a quiet living room. Therefore, there is no logical reason for the user of a hearing aid to expect those aids to perform as well in noise as they do in quiet. Fourth, soft speech should be soft, but audible; average speech should be comfortable; and loud speech should be loud, but not uncomfortable. Fifth, the earmold or hearing aid shell must be comfortable; the wearer's voice should not sound as if he or she is speaking at the bottom of a barrel; and there should be no feedback. Finally, we emphasize that if all of these criteria are not fulfilled, then the user must return the hearing aid for credit, readjustment, or replacement with another form of technology. We emphasize that we do not want these to be another set of hearing aids lying in a dresser drawer!

Next, when appropriate, we spend considerable time counseling the person on the advantages of binaural amplification. At our facilities, we strongly promote binaural fittings to eliminate the head shadow effect and to yield a more natural amplified sound. We counsel the individual to use the hearing aids equally as a monaural and binaural fit during the 30-day trial period. When that person sees whether or not the second hearing aid is beneficial, about 85 percent of the time they decide to keep it. The remaining 15 percent felt they performed equally well with one hearing aid in either ear and decided to return the other for credit. Under the strategy of an initial monaural fitting, we found that only 15 percent of our clients converted to binaural. For these reasons, when the audiometric results and case history profile are appropriate, we fit binaurally during the initial fitting.

Next, we demonstrate, via models and a hearing aid display case, the wide variety of hearing aid styles available at our facilities: behind-the-ear (BTE), in-the-ear (ITE), in-the-canal (ITC), completely-in-the-canal (CIC), contralateral routing signal (CROS); binaural contralateral

routing signal (BICROS); bone conduction, and so forth. In addition, we discuss and demonstrate various available technologies, such as the linear and nonlinear nonprogrammable, programmable with a single memory, and programmable with multiple memory instruments and their remote controls. The overall goal of this extensive counseling is three-fold. First, the audiologist needs to determine the most appropriate fitting in terms of style and technology. Second, we believe that a well-informed individual will be more satisfied than an uninformed or underinformed one. Third, the person needs to feel as involved in the selection of the appropriate hearing aids as is the audiologist. The final hearing aid selection is based upon the interaction of such issues as a) the magnitude and configuration of the hearing loss; b) user reaction to the remote control; c) listener lifestyle and its demands upon communication; d) importance of communication on the telephone and the sensitivity of the telecoil switch; e) user demands for the best signal processing to reduce the deleterious effects of background noise; and finally, f) cost. It is important to emphasize that the issue of cost must be the decision of the consumer and not of the audiologist.

Unaided Outcome Measure

It is imperative for a comprehensive fitting process to include some assessment of the user's impressions of benefit, such as the *Profile of Hearing Aid Performance* (8), the *Communication Profile of Hearing Impairment* (9), the *Hearing Performance Inventory* (10), the *Hearing Handicap Inventory* (11), or the *Hearing Measure Scale* (12).

At our facilities, we ask the individual to complete the unaided portion of the APHAB (1,7). This is a 24-item questionnaire on the user's assessment of his or her performance in a variety of listening situations without, and then with, his hearing aids. The difference between the aided and unaided scores is the "benefit score," which quantifies the benefit perceived by the user as provided by the hearing aids. The 24 questions are divided into 4 subscales of 6 questions each. The first includes the ability to understand speech in background noise (BN). A typical BN question is "When I am in a crowded grocery store, talking with the cashier, I can follow the conversation . . ." The second subscale is concerned with listening in reverberant environments (RV). An RV question is "It's hard for me to understand what is being said at lectures or church services . . ." The third subscale is concerned with listening in a situation that is relatively easy (EC). An EC question is "I

have to ask people to repeat themselves in one-on-one conversation in a quiet room” The final subscale is concerned with how aversive are loud environmental sounds (AV). An AV question is “the sound of screeching tires is uncomfortably loud”

For each question, the client is presented with the letters A through G, representing the percentage of time (1–99) the specific listening situation is felt to present a problem. Circling the letter “A” indicates that this is a problem 99 percent of the time (“always”), while “G” represents 1 percent of the time (“never”). Both the unaided and aided segments of the APHAB are available in interactive computer form.

Thus, the dependent variable for both segments is the percentage of time the user perceives a problem. When we use this questionnaire, we hope to see high problem scores for the unaided segment and significantly lower ones for the aided segment, resulting in a relatively high benefit score that shows the user perceives significant benefit. The responses to the unaided segment are placed in the client’s chart and retrieved after he or she has had the opportunity to wear the aids for 3–4 weeks. It is at that time that the aided section of the APHAB is administered and the benefit score calculated.

PRIOR TO SECOND VISIT: COUPLER MEASURES

ANSI-1987

When the hearing aids arrive, they are placed on an HA-1 coupler and their performance compared to the ANSI-1987 measures (13) supplied by the manufacturer. First, the performance of the hearing aids must adhere to their stated specifications, and harmonic distortion must be less than 10 percent (7).

Smoothness of the Frequency Response to Multiple Input Levels

We also evaluate the smoothness of the frequency-gain response to input levels of 50, 65, and 85 dB SPL. **Figure 1** illustrates the response of one digitally programmable hearing aid measured in an HA-1 coupler for 60 and 70 dB (upper curves), 80 dB (third curve), and 90 dB (lower curve). The 90 dB curve in the top graph reveals a very jagged frequency-gain response, while that of the bottom graph is as smooth as the response for the 60 dB input. To achieve this, the audiologist reduced the compression kneepoint (CK); that is, the hearing aid was

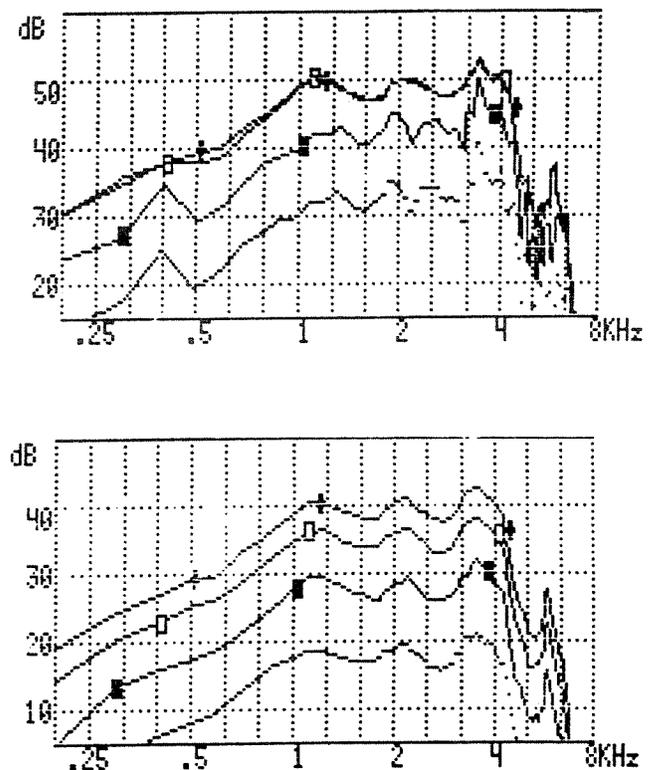


Figure 1.

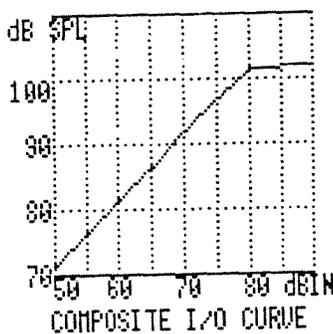
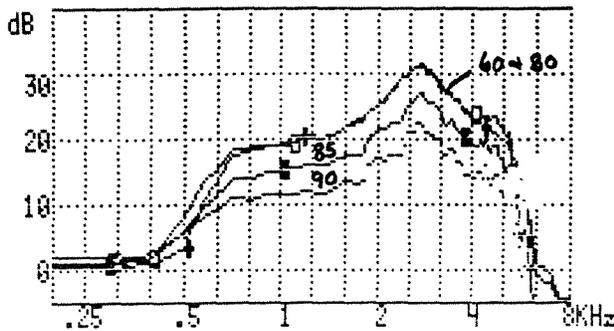
Family of frequency-gain response curves of a programmable hearing aid measured in a HA-1 coupler at 60–90 dB in 10 dB steps. Top: linear amplification. Bottom: nonlinear amplification with the compression kneepoint programmed at 46 dB.

reprogrammed to provide nonlinear processing to improve the headroom for higher input levels (14).

We believe it is important for audiologists to be sure that the morphology or “smoothness” of the frequency-gain response remains the same for an input level of 90 dB as it is at 60 dB. Revit reports that a jagged response at higher input levels indicates the presence of intermodulation distortion and may result in reduced recognition of speech (15). In noisy backgrounds, the talker as well as the listener typically increase vocal effort in order to increase the intelligibility of their message (i.e., Lombard effect). Also, the speech of the user is considerably louder than that of the person with whom the user is attempting to communicate. If the hearing aid has reduced headroom, resulting in increased intermodulation distortion at higher input levels (i.e., increased vocal effort while speaking in noisy backgrounds or increased overall level of the user’s voice), then the recognition and sound quality of speech may deteriorate considerably.

Input-Output Function

Another coupler measure that can provide valuable information is the input-output (I/O) performance of the hearing aid. **Figure 2** shows this performance for a non-linear hearing aid with the CK programmed to activate at an input level of 80 dB. The hearing aid was placed onto an HA-1 coupler and the I/O function of the analyzer activated. Under a speech composite signal, the lower graph in **Figure 2** clearly shows that the performance of the hearing aid is linear for input levels between 50 to 80 dB. That is, as the input intensity is increased over a range of 30 dB (50 to 80 dB), the output also increases by 30 dB (71.3 to 101.5 dB). However, between 80 to 90 dB (range of 10 dB), the output increases by only 1 dB (101.5 to 102.5 dB), a compression ratio (CR) of 10:1. That is, for a 10 dB increase to the input of the hearing aid there is only a 1 dB increase in its output. The family of frequency-gain responses in the top graph of **Figure 2** clearly shows the two upper curves nearly superimposed



INPUT SPL	OUTPUT SPL
50 dB	71.3 dB
55 dB	76.3 dB
60 dB	81.5 dB
65 dB	86.4 dB
70 dB	91.8 dB
75 dB	97.1 dB
80 dB	101.5 dB
85 dB	101.8 dB
90 dB	102.5 dB

Figure 2. Top: a family of frequency-gain response curves measured in a HA-1 coupler at 60–90 dB in 10 dB increments. Bottom: Input-output measures using a composite speech noise.

upon each other and therefore no change in gain for input levels of 60–80 dB. However, as the input signal is increased to 85 and 90 dB there is a decrease in gain.

Figure 3 illustrates another example of using coupler measures to verify performance. In this case, we programmed a crossover frequency at 1,300 Hz. This divides the frequency response of the aid into two bands, or channels, with the low band below 1,300 Hz and the high band above it. Because the user had standard loudness growth in the low frequency region, we programmed the aid so that the low band performed as a linear device by setting its CR to provide 1:1 amplification. Thus, for every 1 dB increase to the microphone, there was a corresponding 1 dB increase at the output of the hearing aid. In the high band, the loudness growth test revealed a reduced dynamic range. To accommodate this range, we programmed a 2:1 CR in the high band; for every 1 dB increase to the microphone, there was a 0.5 dB increase at the output. The verification of this programming is clearly seen in **Figure 3**. For the frequencies below 1,300 Hz, the gain does not change as the input is increased from 60–90 dB. However, in the frequency region above 1,300 Hz, there is a steady decrease in gain as the input signal increases from 60–90 dB in 10 dB steps. Thus, the coupler measures have verified that the hearing aid is performing in the manner in which it was programmed.

In **Figure 2**, the I/O evaluation was performed using a speech composite signal. In the case of a multi-band aid, it is helpful to measure I/O performance using pure tones. For the adjustments to the hearing aid described in **Figure 3**, it would be useful to determine the I/O performance using one pure tone below 1,300 Hz and one above it. For the hearing aid described in **Figure 2**,

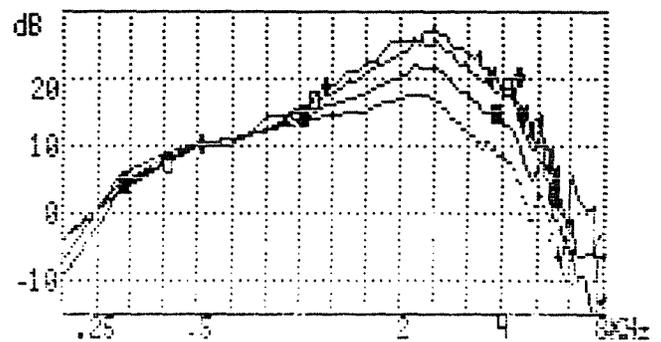


Figure 3. A family of frequency-gain response curves measured in a HA-1 coupler at 60–90 dB in 10 dB steps for a programmable hearing aid. The crossover frequency was programmed at 1,300 Hz. The low band was programmed with a 1:1 CR and the high band with a 2:1 CR.

we would measure the I/O performance at 500 Hz and 3,000 Hz and would like to see a 1:1 I/O function at 500 Hz. That is, for a 40 dB range (50–90 dB) input there should be a 40 dB change in output. For the 3,000 Hz signal with a 40 dB range input, there should only be a 20 dB change in the output because of the 2:1 CR programmed into the high band.

SECOND VISIT: REAL EAR MEASURES

Real ear measures are probably the most reliable assessment of amplification benefit. Research has found that the 95 percent confidence interval for real ear measures is approximately 3 dB (16,17). By comparison, the 95 percent confidence interval for functional gain measures (i.e., unaided sound-field, pure-tone, or spondee thresholds minus aided sound-field, pure-tone, or spondee thresholds) is approximately 15 dB (18). That is, if the audiologist modifies a hearing aid (i.e., changes vent size or tubing diameter; changes the damper in the earhook, rotates a potentiometer, or reprograms), there would have to be an approximate 3 dB difference between the gain measured during and after the first real ear measure in order for the difference to be considered significant. However, because of the greater variability inherent in functional gain measures, the difference between the second and first measure would have to be greater than 15 dB for the results to be significant. One can readily see that real ear measures are considerably more reliable. Audiologists should use them consistently to determine the real ear performance of hearing aids.

Typically, at least three measures are required. First, there is the measurement of the response of the ear canal without the hearing aid in place, the real ear unaided response (REUR), an accurate and reliable measure of the resonance of the ear canal. Next, the hearing aid shell or earmold coupled to a BTE is placed in the ear canal and the volume control is typically adjusted to the listener's most comfortable level (MCL). To accomplish this, we suggest presenting 65 dB of speech composite noise from the real ear analyzer and asking the client to adjust the volume control so the amplified signal is comfortable. When this has been accomplished, the speech weighted composite noise is presented once again. The resulting measure is the real ear aided response (REAR) of the hearing aid and represents the absolute measure of the device's performance. The relative difference between the REAR and REUR (REAR–REUR) measures is the

real ear insertion response (REIR), or the real ear gain provided by the hearing aid. The REIR is compared with the prescribed gain to determine whether the frequency-gain response is appropriate for the hearing loss.

Real Ear Unaided Response (REUR)

The person is seated in a chair facing a loudspeaker placed at ear level at a distance of 12–18 in (30.5–45.7 cm). The tube from the probe microphone is marked 30 mm from the tip; the mark placed at the intratragal notch and taped in place. The person is asked to focus on an orange dot placed on the loudspeaker. A short burst of a speech weighted composite noise is presented at a level of 65 dB SPL and stored as the unaided response (thicker line in the bottom graph of **Figure 4**). This measure represents the ear canal resonance. In the unimpaired adult ear, the REUR should have a peak amplitude of around 13 dB at 2,800 Hz (17). If the REUR is greater than normal, a dip (decrease in gain) will appear in the measured REIR. If the REUR is shallower than normal, then there will be a hump (increase in gain) in the measured REIR. If the audiologist measures the individual REUR, he or she can use this information when ordering the matrix for the ITE, ITC, or CIC fittings (19–21). If a correction is made in the matrix, there is a greater possibility that the measured REIR will be smoother. In addition, if the audiologist is fitting a programmable hearing aid, some systems allow adjustment of parameters (resonant peak control, crossover frequency, gain in different frequency bands) to eliminate any dips or humps in the REIR.

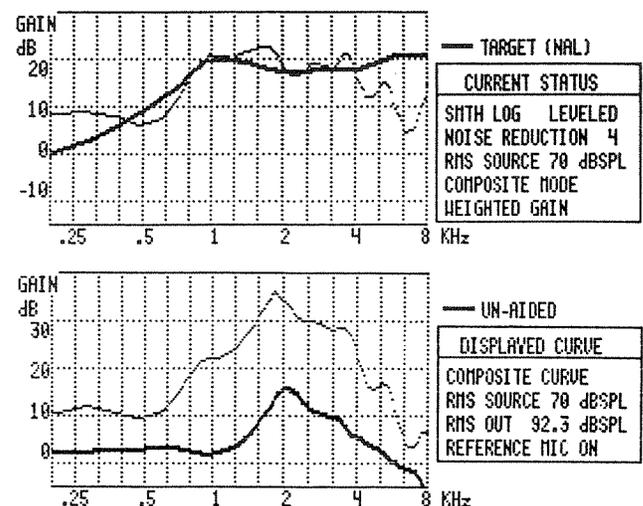


Figure 4.

Top: measured REIR to prescribed NAL-R. Bottom: measures of the REUR and REAR.

HEARING AID WORKSHEET FOR ITE/ITC

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=====
[2] [3] [4] [5] * [6] [7] [8] * [9] [10] [11]
  Hz HL SENSATION AI AI * REAL-EAR GAIN *AIDED THRESHOLD
  NAL LIB VAL * NAL LIB VAL * NAL LIB VAL
=====
250 15 42 30 0.07 * -6 0 2 * 21 15 13
500 35 28 28 0.13 * 10 9 7 * 25 26 28
1000 35 24 24 0.18 * 19 12 13 * 16 23 22
1500 55 * 23 18 22 * 32 37 33
2000 65 -7 0 0.00 * 26 21 29 * 39 44 36
3000 70 * 26 23 25 * 44 47 46
4000 70 -15 0 0.00 * 26 23 15 * 44 47 55
=====
MODIFIED UNAIDED AI= 0.38
=====
[12] [13] [14] * [15] [16] [17] * [18] [19] [20]
AIDED SENSATION * AI CONTRIBUTION* AIDED AI
  NAL LIB VAL * NAL LIB VAL * NAL LIB VAL
=====
36 42 44 * 30 30 30 * 0.07 0.07 0.07
37 36 35 * 30 30 30 * 0.14 0.14 0.14
43 36 37 * 30 30 30 * 0.22 0.22 0.22
19 15 22 * 19 15 22 * 0.21 0.16 0.24
12 9 1 * 12 9 1 * 0.09 0.07 0.01
=====
MODIFIED AIDED AI= 0.74 0.67 0.69
IMPROVED S/N= 11 9 9
=====
[21] [22] [23] * [24] [25] * [26] [27] [28] *
2cc COUPLER * RESONANCE * CORRECTED 2cc *
  NAL LIB VAL * REUR CORR* NAL LIB VAL * Hz
=====
3 9 11 * 2 -1 * 2 8 10 * 250
19 18 16 * 3 -1 * 18 17 15 * 500
28 21 22 * 2 -2 * 26 19 20 * 1000
32 27 31 * 10 4 * 36 31 35 * 1500
35 30 38 * 13 0 * 35 30 38 * 2000
38 35 36 * 10 -5 * 33 30 31 * 3000
33 30 22 * 6 -4 * 29 26 18 * 4000
=====
[29] [30] [31] [32] [33] NAME _____ DATE _____
INSRT RE HA-1 RE HA-1 DESIR
LDL SSPL SPL DIFF SSPL FREQ OUTPUT _____ EAR _____
=====
95 250 GAIN _____ CIRCUIT _____
100 108 109 -1 108 500
95 101 99 2 101 1000 SLOPE _____ OPTIONS _____
90 100 95 5 100 1500
100 114 110 4 114 2000 COMMENTS _____
110 119 124 -5 119 3000 _____
110 117 117 0 117 4000 _____
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Figure 5. Worksheet to calculate the required 2 cc full-on gain necessary to match a prescribed target.

Figure 5 shows a printout from a computer program that allows the audiologist to enter the audiogram (Column 2) and individual REUR (Column 24) to calculate a corrected 2 cc full-on coupler response (Columns 26–28) necessary to achieve one of three possible prescribed REIRs (20,21). The data in columns 26–28 can be used by the audiologist to help select an appropriate 2 cc coupler response provided by the manufacturer in its matrix selection manual. The authors provide several examples where the coupler response selected using the correction for the individual REUR (Columns 24,26–28) arrived closer to matching the prescribed REIR than if a matrix were selected that did not correct for the individual REUR (Columns 21–23). As an aside, most real ear analyzers incorporate programs that accomplish the same goal as reported in **Figure 5**.

Real Ear Aided Response (REAR)

Next, the hearing aid or earmold is placed in the ear canal and great care is taken to be sure that the probe tube has not moved from the original position. First, as described earlier, the user is asked to rotate the gain control of the hearing aid to his/her MCL as he or she listens to speech-weighted noise presented at 65 dB SPL. When this is accomplished, the user is once again asked to focus on the dot of the loudspeaker as the absolute measure (in gain or output) of the performance of the hearing aid is measured (REAR) and stored (lighter line in the bottom graph of **Figure 4**). Most real ear analyzers automatically calculate the difference between the REAR and REUR to display the REIR (lighter line in the top graph of **Figure 4**). Usually, the audiologist enters the audiometric thresholds and the software calculates and displays a prescribed REIR to which the measured REIR is compared (darker line in the top graph of **Figure 4**). For the results illustrated in **Figure 2**, most audiologists would agree that the measured REIR very closely matches the prescribed NAL-R REIR. Unfortunately, at this point most audiologists would end their validation and assume a successful fit because the measured REIR matches the prescribed REIR. As this chapter will explain, there are several additional measures that need to be taken to validate the appropriateness of the hearing aids to the user. We are convinced that if these procedures are pursued, there will be a greater assurance that the final fitting will be judged successful by the user.

Real Ear Insertion Response (REIR)

The most reliable and efficient method for determining the performance of a hearing aid is to determine whether the measured REIR matches a prescribed REIR. At the second visit, the client's audiometric data are entered into a real ear analyzer (**Figure 6**, top) to generate a target REIR (**Figure 6**, bottom and the darker line in the top graphs of **Figures 4** and **7**). The most popular prescriptive target appears to be the NAL-R (22); however, this target is most appropriate for persons with mild to moderately-severe hearing loss. If the hearing loss is greater, an alternative and more appropriate target is advised, such as the POGO (23), the Libby 2/3 (24), the Berger (25), or the revised NAL for severe hearing loss (26). In addition, any selected target is often modified at our facilities for two additional reasons. First, if the client has a conductive or mixed hearing loss, the targeted gain is increased by 20–25 percent of the air-bone gap to a maximum of 8 dB (27). Second, when the hearing aid fit-

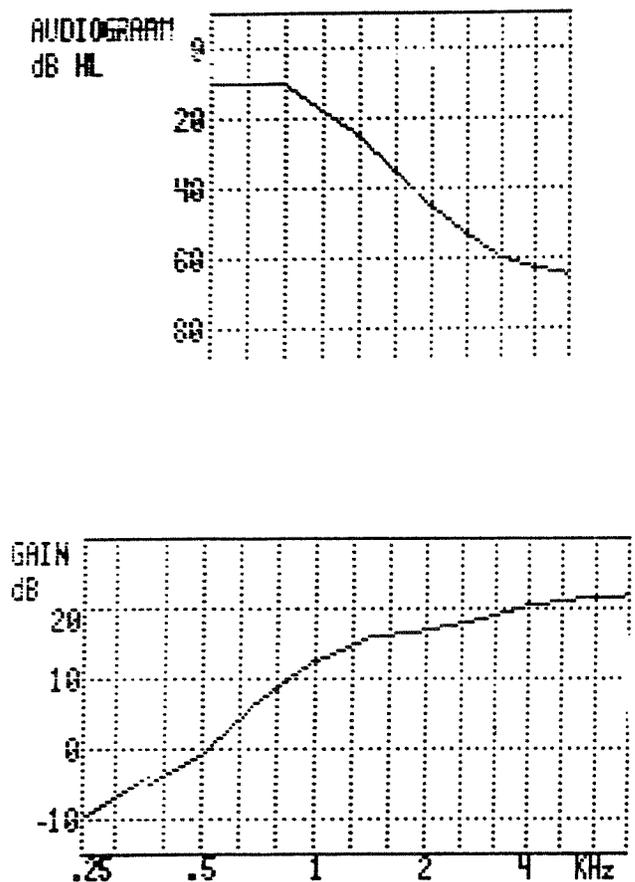


Figure 6.

Top: Audiogram entered into a real ear analyzer to calculate prescribed real ear gain. Bottom: prescribed real ear gain for that audiogram.

ting is binaural, we decrease the targeted gain for each ear by approximately 3 dB to compensate for binaural loudness summation: prescriptive formulas are based upon a monaural fitting. Clients often report binaural aided performance as too loud when the electroacoustic characteristics of the hearing aids were adjusted monaurally to match the prescribed REIR.

REIR Target for Linear Amplification

If the hearing aids contain linear amplification (i.e., constant gain for varying input levels until the saturation level of the instrument is reached), we determine whether the measured REIR matches the prescribed REIR by presenting an input signal level of 65 or 70 dB SPL (i.e., $REIR_{65-70}$). **Figures 4** and **7** illustrate the measured $REIR_{70}$ (thin curve) in relation to the prescribed NAL-R REIR. In these figures the measured $REIR_{70}$ compares well to the prescribed REIR. However, we are more concerned about whether the shapes of the two match and not overly concerned if the measured $REIR_{65-70}$ does not hit the prescribed REIR at each and every frequency, because the user has the ability to adjust the overall gain. If this goal is accomplished, we are reasonably assured that adequate amplification has been provided to allow average conversational speech in a quiet environment to be audible and comfortably loud.

REIR Targets for Nonlinear Amplification

Currently, prescriptive targets for nonlinear hearing aids (i.e., the gain of which increases or decreases in re-

sponse to the intensity of the signal) do not exist. Significant efforts are currently underway to provide such standards for validating the performance of hearing aids using nonlinear processing (7,28). In the interim, we believe that audiologists can use the same prescriptive targets developed for linear technology.

To accomplish this, we suggest evaluating the performance of nonlinear hearing aids using three input levels. **Figures 8** and **9** illustrate this point. First, with an input of 50 dB, we would like the measured REIR ($REIR_{50}$) to exceed the prescribed REIR by 7–8 dB (upper thin curves in **Figures 8** and **9**, the prescribed NAL-R is represented by the thicker lines in those figures). This goal would only be valid if the amplifier had a CK of from 40 to 45 dB (i.e., ReSound or K-Amp™) and a CR of 2:1. That is, the NAL-R target was developed assuming an input level of 65–70 dB. Now, with an input of 50 dB (15 dB less than 65 dB) and with an amplifier hav-

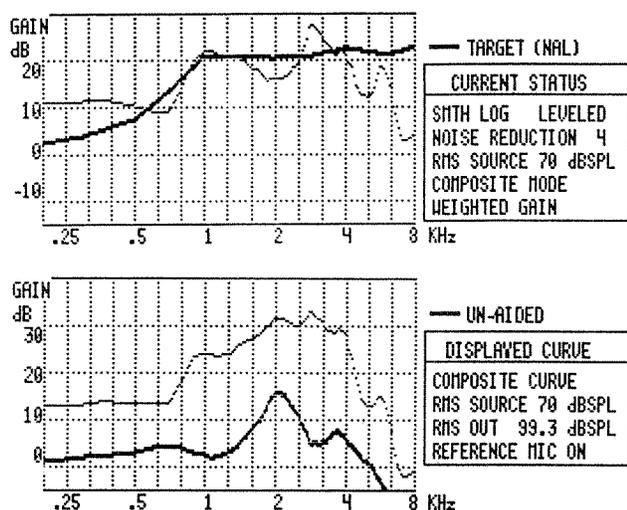


Figure 7. Top: measured REIR to prescribed NAL-R. Bottom: measures of the REUR and REAR.

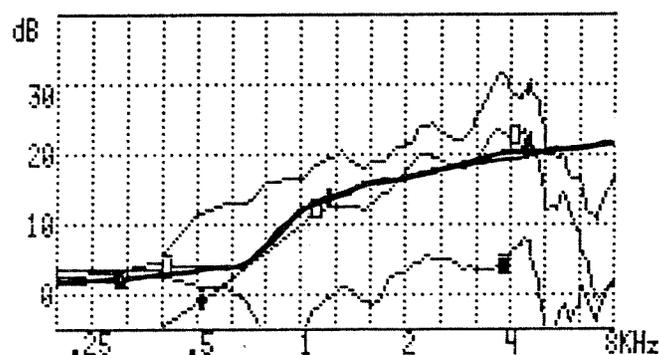


Figure 8. Measured REIR to prescribed NAL-R (bold curve) for 50 dB (upper curve), 65 dB (middle curve) and 85 dB (lower curve).

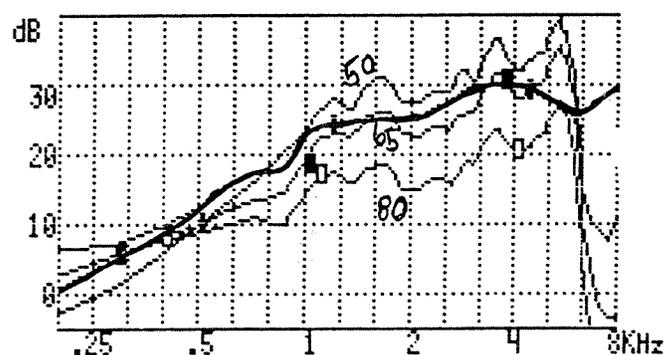


Figure 9. Measured REIR to prescribed NAL-R (bold curve) for 50 dB (upper curve), 65 dB (middle curve) and 85 dB (lower curve).

ing a CR of 2:1 (i.e., for every 1 dB input there will be a 0.5 dB increase in gain), we would expect to observe a 7.5 dB increase relative to the prescribed gain for NAL-R. If the amplifier has a higher CK or a less aggressive CR (i.e., less than 2:1), then the difference between the measured REIR₅₀ and REIR₆₅ dB would be less than 7–8 dB. Second, we would like to see the measured REIR₆₅ match the prescribed REIR (middle thin line in **Figures 8** and **9**). Finally, we would like to see the measured REIR₈₅, fall below the prescribed REIR by approximately 10 dB (lower thin line in **Figures 8** and **9**). That is, with a 20 dB increase in input (65 to 85 dB) and with a hearing aid having a 2:1 CR, we would expect a 10 dB decrease in gain. Again, the magnitude by which the measured REIR₈₅ falls below the prescribed REIR is dependent upon the CK and the CR of the hearing aid. **Figures 8** and **9** illustrate results of two cases where these three goals have been reasonably attained.

Before going on to the next section, it would be helpful to consider the important role of how the hearing aids are coupled to the ear. The top graph of **Figure 10** illustrates the real ear measures for a BTE fitting for two earmold configurations. The lower thin line represents the use of an earmold where #13 tubing extended to its tip. The upper thin line represents a 4-mm horn ear-mold configuration. The replacement of the tubing with the

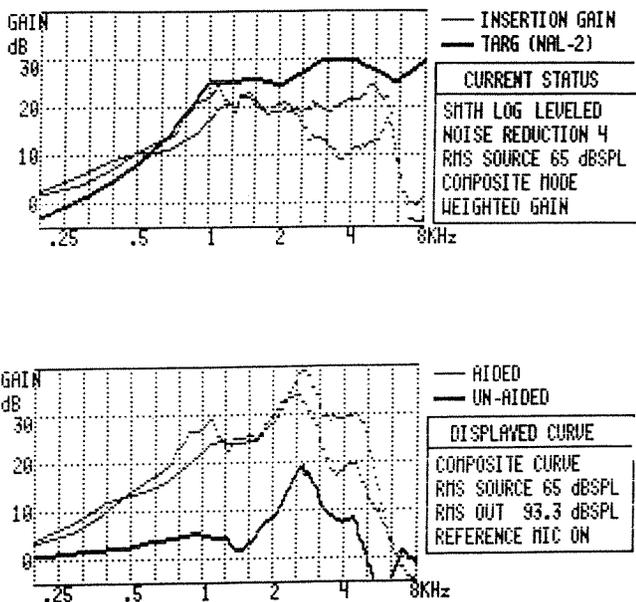


Figure 10. REIR measures. Top: 4 mm horn. Bottom: #13 tubing to the tip of the earmold.

horn design increased the measured REIR (i.e., closer to the prescribed REIR) by approximately 10 dB in the frequency region above 2,000 Hz. We cannot overemphasize the importance of paying very close attention to how the hearing aid is coupled to the ear!

Due to the effect shown in **Figure 10**, and because of the importance of amplification of the frequency region above 2,000 Hz to improve speech recognition, there are only two occasions when we do not order a 3-mm or 4-mm horn for our clients. One is for those with rising configurations, where high frequency amplification in the frequency region above 2,000 Hz is not required. In fact, in these cases we often order a reverse horn earmold design. The other situation is for persons who have a profound hearing loss in the frequency region above 2,000 Hz, where amplification could not possibly improve the recognition of speech, but could result in feedback. Feedback forces the user to reduce the volume, thereby losing amplification in the frequency region below 2,000 Hz where the greatest amount is required.

Another example of the importance of paying close attention to how the hearing aid is coupled to the ear is illustrated in **Figure 11**. In this case, an individual with a BTE scheduled an appointment because he felt the hearing aids were not providing the amplification they had in the past. After checking the ear canals for cerumen, one of the authors placed the hearing aid on the HA-1 coupler and observed the lower frequency-gain response illustrated. Comparing this result to the previous measures showed the response to be lower than the original. Inspection revealed a clogged damper in the earhook. The damper was removed and replaced. The upper curve in **Figure 11** reveals the improved low and high frequency response. The client appreciated the improved sound quality provided by the new damper.

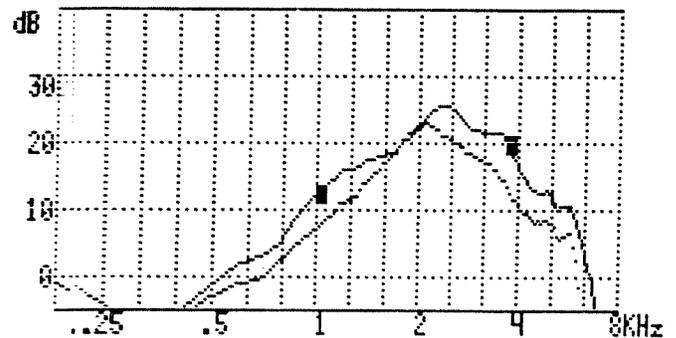


Figure 11. REIR measures. Top: unclogged damper. Bottom: clogged damper.

Smoothness of REAR Measures for Multiple Input Levels

Earlier, we emphasized the need for the hearing aid coupler measures to be as smooth for inputs of 85–90 dB as for inputs of 50–60 dB. The same goals also need to be achieved for the aid performance when worn by the user. To measure this, we closely observe the smoothness of the REAR at 50, 65, and 85 dB to be sure that the morphology of the $REAR_{85}$ curve is as smooth as the $REAR_{50}$ curve (7). If it is more jagged, then the hearing aid may be generating an excessive amount of intermodulation distortion (15). **Figures 12** (REAR measured as gain) and **13** (REAR measured in output) reveal the $REAR_{50}$ (lower curve), $REAR_{65}$ (middle curve), and $REAR_{85}$ (upper curve). The smoothness of the frequency response for $REAR_{85}$ is similar to the smoothness for $REAR_{50}$. Again, it appears that our goals have been achieved.

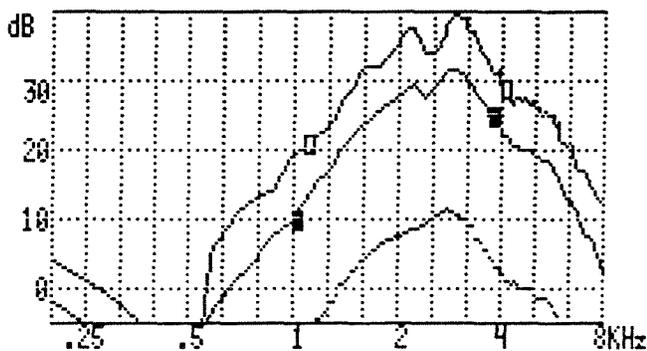


Figure 12. REAR (in gain) measures for input levels of 50 dB (lower curve), 65 dB (middle curve), 85 dB (upper curve).

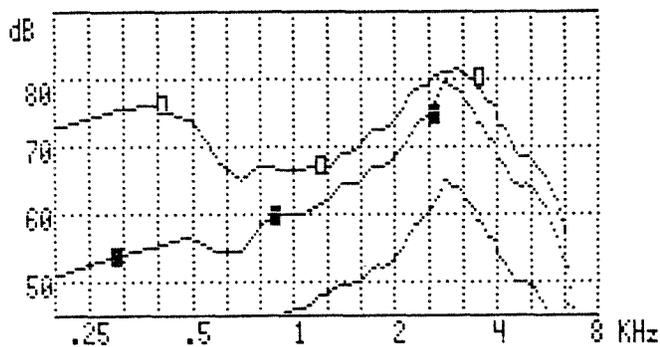


Figure 13. REAR (in output) measures for input levels of 50 dB (lower curve), 65 dB (middle curve), 85 dB (upper curve).

Real Ear Saturation Response with a 90 dB Input ($RESR_{90}$)

With the hearing aid still in place and the volume control at the same position, we use a 90 dB pure-tone sweep (200–8,000 Hz) to measure the SPL near the eardrum to see whether the measured $RESR_{90}$ is below the LDL measured at the initial evaluation. If it is, we know that intense environmental sounds should not be perceived as uncomfortably loud (2). **Figure 14** illustrates the achievement of this relationship to the measured LDL (dots) at 500–4,000 Hz for one client. At each test frequency, the measured $RESR_{90}$ (thin line) is below the measured LDL.

Loudness Judgments for Speech

In the real world, the listener is often exposed to varying levels of speech with a much broader bandwidth than frequency-specific stimuli. Therefore, it is important to include in the protocol a method to assess loudness judgments for a speech-like signal (7). To do this in a clinically efficient manner, we present the speech composite noise from the real ear analyzer at 50, 65, and 85 dB SPL to an aided listener and ask him or her to judge the loudness of the speech-weighted noise using the same loudness scaling categories described earlier. If the hearing aids are adjusted properly, he or she should rate 50 dB input as either ‘very soft,’ ‘soft,’ or ‘comfortable, but slightly soft.’ For an input level of 65 dB SPL, the wearer should rate the loudness as ‘comfortable, but slightly soft,’ ‘comfortable,’ or ‘comfortable, but slightly loud.’ For the input level of 85 dB SPL, the wearer should never report a rating of ‘uncomfortably loud.’ If he or she does, the audiologist must consider reducing the output and/or CK or providing a more aggressive CR.

Assuming that the goals have been achieved, we counsel clients on the use and care of the hearing aids, making sure they can remove and insert the batteries as

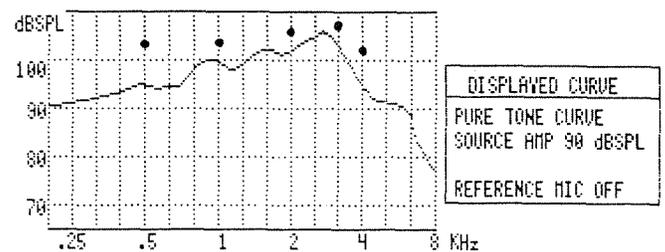


Figure 14. $RESR_{90}$ measure. Dots are the LDLs measured in dB SPL near the eardrum at the initial visit.

well as the aids themselves. We once again review the anticipated benefits in a variety of listening situations and inform them that we will call in 2 to 3 days to determine how they are doing. Clients are scheduled to return in 3–4 weeks to assess their overall satisfaction with the fitting.

THIRD VISIT: OUTCOME MEASURES

Hearing Aid Assessment

At this visit, 3–4 four weeks after the hearing aids are dispensed, we explore the user's overall satisfaction with the hearing aids: how well has he or she performed listening to speech in a variety of situations, how good is the sound quality, how easy is communication on the telephone, removing and inserting earmolds, aids, or batteries, and how long do the batteries last? We also examine issues related to the comfort of the hearing aids and those related to the presence or absence of the occlusion effect. It is during this interview that decisions are made about readjusting the electroacoustic or transmission line characteristics of the instruments. For example, if the person was fitted with binaural, multiple-memory, programmable aids, the authors use the following strategies to help him or her make judgments to achieve a better sound quality or improved recognition of speech in quiet and noise.

Strategy to Adjust Electroacoustic Characteristics for Listening in Quiet

Usually, when fitting a two-memory hearing aid, the initial electroacoustic characteristics for the first memory are programmed to be most beneficial for listening under relatively quiet listening conditions (i.e., watching television, one-on-one conversation around the dinner table, chat in the family room). Typically, programmable parameters are adjusted so that an input of 65 dB will match NAL-R, while the measured REIR₅₀ will appear above, and REIR₈₀ below, the NAL-R target.

After the individual has used the aids for 3–4 weeks, he or she may feel the amplified signal is too loud, too soft, too bassy, or too tinny. To help the user make decisions while we reprogram the instruments, we seat the client facing two Radio Shack 3.5 in (8.9 cm) Minimus loudspeakers at 1 m. The speakers are mounted at ear level, side-by-side on the wall of the sound suite and receive signal from a high quality cassette recorder and 2-channel amplifier. The person listens to female connected discourse presented at 58 dBA from the left

loudspeaker and multi-talker babble presented at 51 dBA from the right, to create a +7 dB signal-to-noise ratio (S/N), the average S/N ratio in a quiet living room (29). Other signal and noise combinations are also available. While he or she listens to these two signals, we inform the listener that we will be programming changes into the hearing aids. As we do so, we ask the client to inform us if the change improved the sound quality (30), and speech intelligibility (31) of the female connected discourse. The form on **Figure 15** provides criteria for sound quality ratings (unnatural versus natural, crinkling versus smooth, tinny versus full) and speech intelligibility ratings (0–100 percent or very bad to very good). This is not a measure of speech recognition scores at some constant presentation level; rather, the user is being asked to judge whether he or she understands 10, 30, 70, or 100 percent of what the female voice is saying. The goal of this strategy is to find the adjustment of the parameters that provide the best sound quality (natural, smooth, and full) and speech intelligibility (as close to 100 percent as possible) to the client. For most people, this procedure takes 10–15 min.

Strategy to Adjust Electroacoustic Characteristics for Listening in Noise

Usually, when fitting a two-memory hearing aid, the second memory is programmed to be most beneficial for listening under relatively noisy listening conditions (i.e., conversing in a crowded restaurant or cocktail party, listening in a house of worship). **Figure 16** illustrates the typical initial REIR responses for a two-memory programmable hearing aid. The lower curve is the initial REIR for the second memory and shows significantly less low frequency gain and slightly greater high frequency gain than does the first. The rationale for this fitting strategy is to reduce the amplification of the predominantly low frequency ambient noise and provide slightly greater high frequency gain so it will be easier for the listener to hear the high frequency consonant sounds over the background noise.

Surprisingly, a number of clients have reported an inability to detect any significant difference in the benefit or sound quality between the two memories under this strategy. On the other hand, an impressive number of clients have reported significant benefit from these settings in Memory 2 when listening in noise. Such contradictions and the general unpredictable nature of client reports constantly remind the authors of the need to take the time to customize the electroacoustic characteristics

	VERY	RATHER	MIDWAY	RATHER	VERY	
	0 1	2 3	4 5	6 7	8 9 10	
UNNATURAL						NATURAL
CRINKLING						SMOOTH
TINNY						FULL
	0 1	2 3	4 5	6 7	8 9 10	

SPEECH INTELLIGIBILITY RATINGS

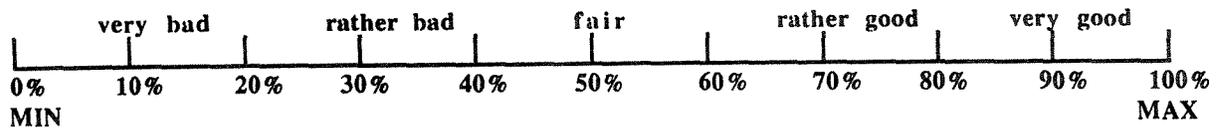


Figure 15. Form used to help users provide reliable assessment of sound quality and the intelligibility of speech.

of the hearing aids to each user so that he or she realizes the greatest benefit.

After the individual has used the aids for 3–4 weeks, it may be necessary to reprogram the second memory if the user feels that the amplified signal is not different from that of the first memory or that the second memory provides little benefit in noise. The same procedure described above is followed when adjustments are made to improve listening in noise, with the difference being that the level of the female connected discourse is increased to 68 dBA and that of the background noise to 67 dBA (i.e., +1 dB S/N ratio). Cox and Alexander reported that in the typical party environment, the S/N ratio was +1 dB (29). That is, as the noise level increases so

does the level of the signal, but the ratio declines from +7 dB in quiet to +1 dB in noise.

Aided APHAB and Benefit Scores

Also at this visit, we ask the client to complete the aided portion of the APHAB. We enter the unaided and aided scores into the software package of the APHAB to calculate the benefit scores for the four subscales. **Figures 17 and 18** illustrate the report for an experienced user fitted with a programmable hearing aid after wearing linear ITE hearing aids with Class A amplifiers for over 10 years. **Figure 17** shows that the unaided problem scores of his linear hearing aids for the four subscales ranged from 4.7 percent (AV) to 93.0 percent (BN). That is, the user reported that when he listened in noisy environments (BN), he had problems understanding speech nearly 93 percent of the time. The next row shows the aided scores, where BN problems occurred 78.5 percent of the time for a benefit score of 14.5 percent, a score slightly below the 20th percentile (see the graph to the far right). This means that approximately 80 percent of successful users of linear amplification report greater benefit when listening in noise (1). **Figure 17** shows benefit scores of 27, 26.8, 14.5, and –83.3 percent for the EC, RV, BN, and AV subscales when he wore his linear ITE hearing aids.

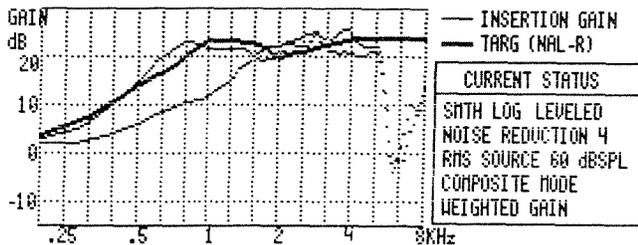


Figure 16. REIRs for a two-memory hearing aid. The upper REIR was programmed for listening in quiet and the lower for listening in noise.

RRDS Practical Hearing Aid Selection and Fitting

ABBREVIATED PROFILE OF HEARING AID BENEFIT (APHAB)

03/20/95

NAME: FILE NAME:
 FORM: A
 SCORING: PERCENTAGE
 Original Hearing Aid - Binaural Linear Class A ITE

Hearing Aid Experience: 4. Over 10 years
 Daily Hearing Aid Use : 4. 8 to 16 hours per day
 Age : 3. 50 to 64

Subscales	EC	RV	BN	AV
# of Items	6	6	6	6
UNAIDED	72.7	89.0	93.0	4.7
AIDED	45.7	62.2	78.5	87.0
BENEFIT	27.0	26.8	14.5	-82.3

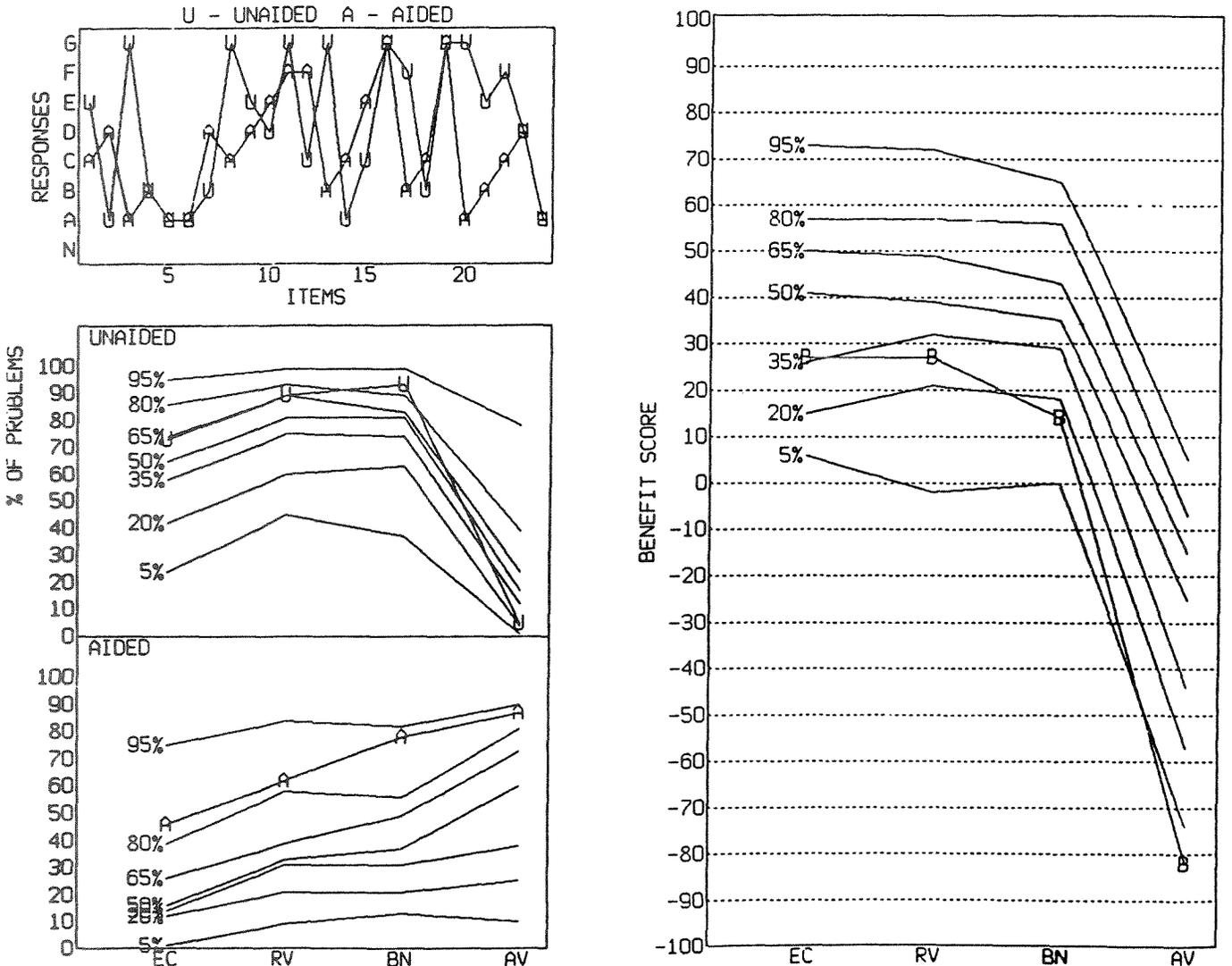


Figure 17
 APHAB for a client fitted with linear hearing aids.

ABBREVIATED PROFILE OF HEARING AID BENEFIT (APHAB)
03/20/95

NAME:
FORM: A
SCORING: PERCENTAGE
Phonak Audio Zoom - Right Ear

FILE NAME:

Hearing Aid Experience: 4. Over 10 years
Daily Hearing Aid Use : 4. 8 to 16 hours per day
Age : 3. 50 to 64

Subscales	EC	RV	BN	AV
# of Items	6	6	6	6
UNAIDED	72.7	89.0	93.0	4.7
AIDED	16.3	35.3	56.2	18.8
BENEFIT	56.3	53.7	36.8	-14.2

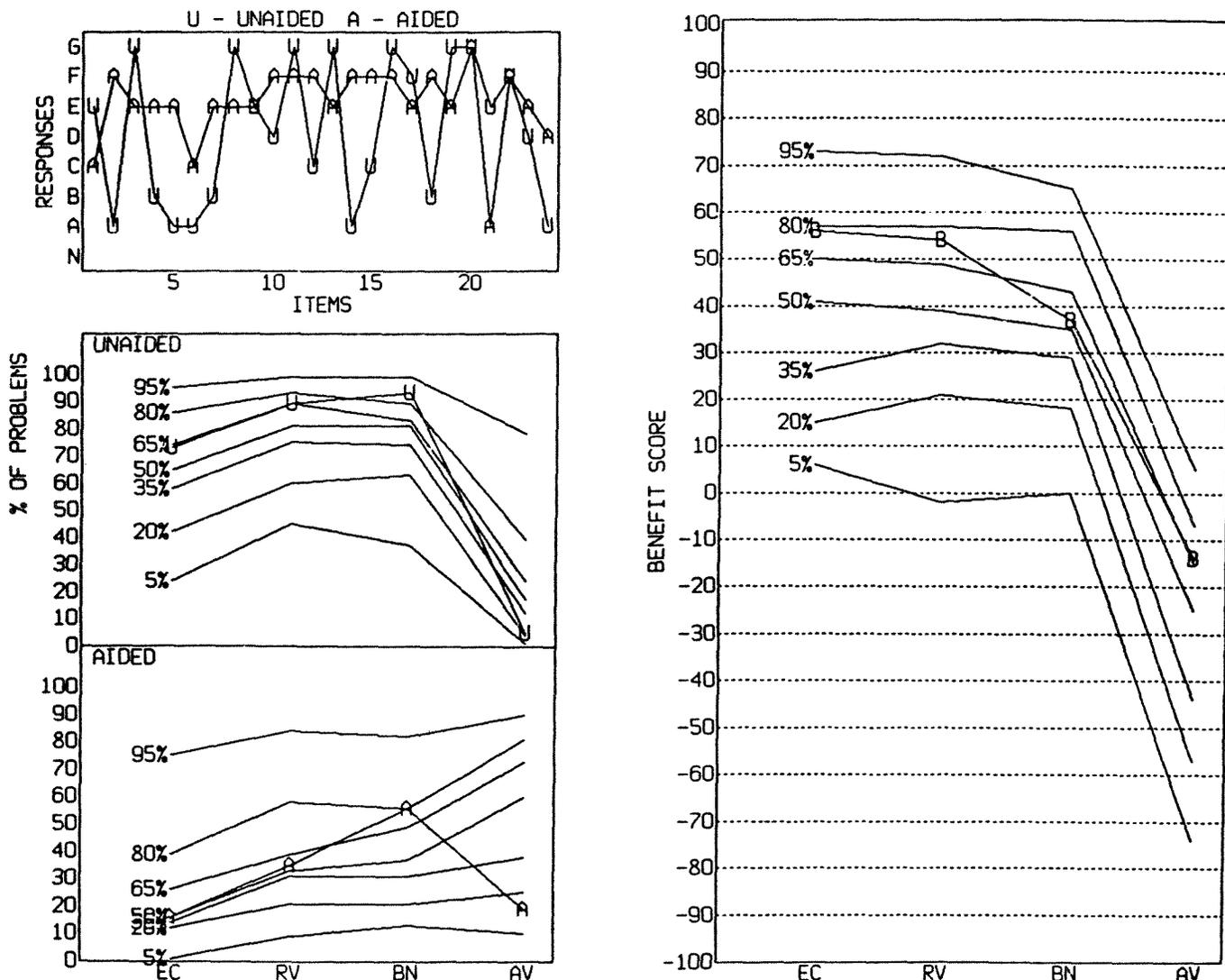


Figure 18.
APHAB for a client fitted with a programmable hearing aid.

RRDS Practical Hearing Aid Selection and Fitting

ABBREVIATED PROFILE OF HEARING AID BENEFIT (APHAB)

03/21/95

NAME:
FORM: A
SCORING: PERCENTAGE

FILE NAME:

Hearing Aid Experience:
Daily Hearing Aid Use :
Age :

Subscales	EC	RV	BN	AV
# of Items	6	6	6	6
UNAIDED	12.3	18.5	54.0	2.8
AIDED	4.7	10.2	12.0	2.8
BENEFIT	7.7	8.3	42.0	0.0

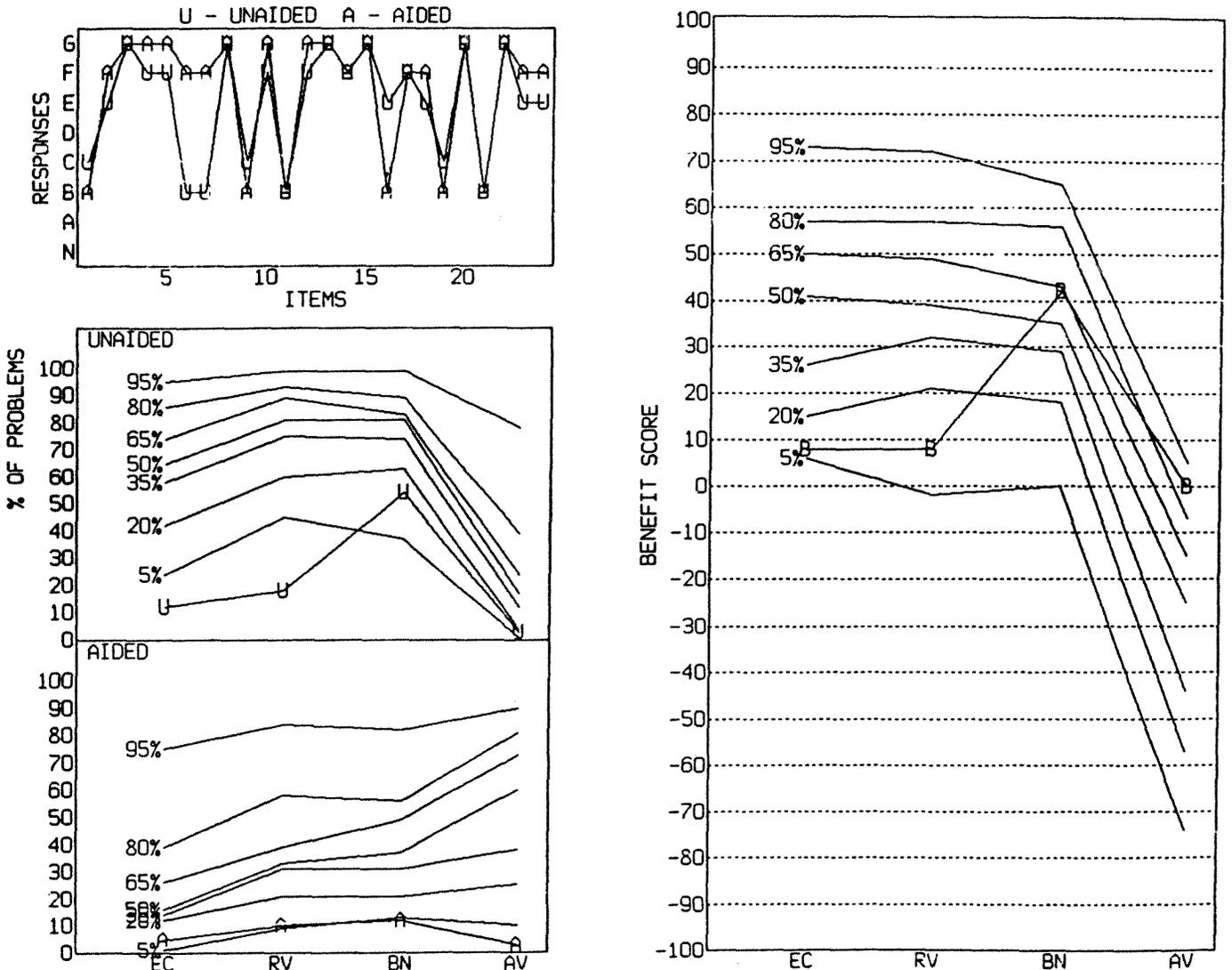


Figure 19. APHAB for a client showing a ceiling effect for the unaided condition.

Hearing Aid Questionnaire

Speech Quality	#1	#2	#3	All	None
Which Memory made speech more:					
Distinct					
Pleasant					
Natural					
Comfortably Loud					
Uncomfortably Loud					
Performance was better with a close friend in a one-on-one situation					
Performance was better with a stranger in a one-on-one situation					
Performance was better listening to TV with no one else talking					
Performance was better listening to TV with one or more people talking in the background					
Performance was better on the telephone					
Performance was better listening at a meeting with one speaker					
Performance was better listening at a meeting with several speakers					
Performance was better listening at a family gathering					
Performance was better listening to the radio in the car					
Performance was better listening to a passenger in the car					
Performance was better listening in an "elegant" restaurant					
Performance was better listening in a family restaurant					
Performance was better listening in a house of worship					
Performance was better listening in a movie theater					
Performance was better listening to recorded music					
My own voice was more natural					
Overall, my performance was best					

Figure 20. Questionnaire designed to determine user preference for three memories of a programmable multiple-memory hearing aid.

Figure 18 shows the scores for the same subject after he was fitted with a three-memory, programmable hearing aid with dual microphones reported to improve the S/N ratio by an average of 7.7 to 8.5 dB (32). The benefit scores improved to 56.3, 53.7, 36.8, and -14.2 percent for the respective subscales, putting him in the 50th to nearly the 80th percentile. Thus, his programmable hearing aid resulted in benefit scores for the EC, RV, and BN subscales that were 29.3, 26.9, and 22.3 percent better than those of his previous aids, and the programmable hearing aids were 68.1 percent less aversive to loud sounds. The reader can see how the APHAB might be a useful tool to measure the benefit (or lack thereof) between two fittings.

The APHAB results from another client (**Figure 19**) demonstrate the need to interpret these results with caution. Looking only at the benefit row and the percentile rank graph to the right, one might conclude that the user did not perceive benefit with his hearing aids. That is, the benefit scores for EC and RV were less than 10 percent, and his performance was below the 20th percentile. However, the unaided score indicates that the individual reported little or no problems for the EC and RV conditions: because of these low unaided scores, the individual presented a "ceiling effect" where benefit could not be accurately demonstrated. This situation is analogous to a person who demonstrates an unaided word recognition score of 100 percent. Then with the hearing aids in place: the aided score is also 100 percent. Because no differences are present between the two scores, one could falsely conclude that hearing aid use does not demonstrate benefit. However, this person reports significant benefit with his new aids and that their use has had a significant positive impact on his life! The point is that the audiologist must be capable of integrating both objective and subjective information from the client before being able to draw an accurate picture of benefits.

Overall, we hope to see benefit scores for the BN and RV subscales that are better than the average data reported by Cox and Alexander for successful users of linear amplification (1). We hope to see an AV benefit score that is as low as possible, indicating that aided sounds were not uncomfortably loud, and we hope to see as high a score as possible in each of the other subscales.

Finally, **Figure 20** presents a questionnaire developed by the authors to help determine whether the three memories of a multiple memory hearing aid were accom-

plishing their intended goals. Similar questionnaires have been developed for two- and four-memory programmable hearing aids. In this case, Memory 1 was programmed for maximum benefit in quiet, while Memories 2 and 3 were programmed for improved recognition in increasingly noisier listening situations. The first column asks the user various questions relative to sound quality, loudness, and listening situations of varying S/N ratios, including the telephone, music, and own voice. Finally, the person is asked for his or her overall assessment. For each question, the person can select any of the memories, ALL, or NONE, which he or she felt provided the best performance.

CONCLUSIONS

The authors have used the procedures described here extensively for over 6 months. We are convinced that they have resulted in greater user satisfaction, because our practice, through client referrals, has continued to grow at a time when many practices in our geographical area have declined. In addition, the number of hearing aids returned for credit, which has always been below 15 percent, has decreased even further. Above and beyond those factors, staff members have developed a greater sense of pride in the level of service they are providing when dispensing hearing aids.

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