Validation of Hearing Instruments, Part I: Patient Questionnaires

By Julie K. Purdy, PhD

As Part One of the series, this article looks at using questionnaires as hearing instrument validation tools. Specifically, the Abbreviated Profile of Hearing Aid Benefit (APHAB), the Hearing Activity Questionnaire and the Shortened Hearing Aid Performance Inventory (SHAPI) are examined relative to how they can be used to assess benefit, pinpoint patient needs and improve customer satisfaction.

During the 1990s, many methods have been advocated and more than a dozen can now be used to validate the performance and benefit of hearing instruments. This article is the first in a series of articles that will examine the different techniques that can be employed for verification. The series will evaluate output-based verification, speech-based assessment, sound field measurement, manufacturer-directed fitting, fitting rules, SPL-O-Grams, linear and non-linear prescriptive fitting formulas, as well as the patient self-assessment questionnaires discussed in this article.

A large number of self-assessment questionnaires exist from which to choose, including: the Hearing Handicap Inventory for the Elderly (HHIE),the Client Oriented Scale of Improvement (COSI), the Abbreviated Profile of Hearing Aid Benefit (APHAB), the Hearing Measurement Scale (HMS), the Social Hearing Handicap Index (SHHI), the Hearing Aid Performance Inventory (HAPI), the Shortened Hearing Aid Performance Inventory (SHAPI), the Hearing Handicap Scale (HHS), the Hearing Performance Inventory (HPI), the Denver Scale of Communication Function (DSCF), the Hearing Activity Questionnaire, the Profile Questionnaire for Rating Communicative Performance and the Communication Profile for Hearing Impaired Individuals (CPHI). (For reference sources to these scales, see the article by Jess Dancer, EdD, in this issue of *HR*.)

Of these many self-evaluation measures, three will be discussed in this article: the APHAB, the SHAPI and the Hearing Aid Questionnaire. While all of the above-mentioned scales offer viable alternatives to self assessment, the three featured in this article were selected because they each have normative data, are reasonably short (ranging from 14-38 items) and each assess *aided* performance.

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The APHAB

Initially, the PHAB (Profile of Hearing Aid Benefit) was developed at the Univ. of Memphis to assess the experiences of patients wearing hearing instruments. It was then expanded to include unaided experiences and contains 66 items with seven sub-scales. As its name suggests, the Abbreviated Profile of Hearing Aid Benefit developed by Cox and Alexander[1], is a streamlined version of the PHAB. The APHAB has been incorporated into the IHAFF (Independent Hearing Aid Fitting Protocol), a prescriptive fitting approach for non-linear instruments.

The APHAB component of the IHAFF is a self-assessment inventory designed to assess patient communication in everyday situations. The inventory has been developed to provide a standardized test quantifying the disability associated with hearing loss. The test provides for outcome measure capability as it compares unaided-to-aided performance via 24 items with six statements in each of its four sub-scales:

- *Ease of Communication (EC)*: Assesses difficulty in communicating in optimal conditions such as quiet environments;
- *Reverberation (RV)*: Assesses communication problems in reverberant rooms such as classrooms or auditoriums;
- *Background Noise (BN)*: Assesses communication difficulties in rooms with high background noise levels such as restaurants or cocktail parties;

• *Aversiveness (AV)*: Assesses the unpleasantness of certain environmental sounds such as construction noise or traffic.

Each of the 24 test items consist of a statement, such as "When I am in a crowded grocery store, talking with the cashier, I can follow the conversation," and "The sounds of running water, such as a toilet or shower are uncomfortably loud" and "I have to ask people to repeat themselves in one-on-one conversation in a quiet room." The patient is asked to choose a response from the APHAB Response Scale:

- Always (99%)
- Almost Always (87%)
- Generally (75%)
- Half the time (50%)
- Occasionally (25%)
- Seldom (12%)
- Never (1%)

As with any test, the instructions are important. The patient is informed that, if they have not been in the situation described, they should think of a similar situation, if possible. Patients should read each item carefully: a response of "Always" may indicate many problems, and at other times, indicate few problems (i.e., the test is designed in this manner to ensure that the patient is paying close attention to their responses.) Because of this design, when the test is completed, most of the response alternatives should be used. The test is commercially available on disk so the patient can take the test either on paper or on a computer.

An example of the computer-based method from Starkey Labs' Professional Fitting System (PFS) is shown in Fig. 1 on page 22. The "Without Hearing Aid" portion of the test should be administered before or at the initial fitting, while the "With Hearing Aid" portion should be administered at the two-week follow-up[2] or after 2-5 weeks using the hearing instrument to ensure adequate experience with the devices.[3] Patients are allowed to view their responses to the "Without Hearing Aid" section when completing the "With Hearing Aid" section, and can change earlier responses if they no longer agree with them. If fewer than four questions on a sub-scale are answered, accuracy of that sub-scale score is reduced, so it is important to stress to the patient to complete as many of the questions as possible.

Normative data was obtained from 55 subjects determined to be successful hearing instrument users.[1] All were experienced users of at least one year and wore their hearing instruments at least four hours per day. Most were elderly with mild-to-moderate sloping or flat bilateral hearing losses, and most wore ITEs (about half were bilaterally aided). This data was used to generate equal-percentile profiles for unaided, aided and benefit scores on each sub-scale (Fig. 2, see page 22). To obtain a benefit score, the aided score is subtracted from the unaided score. If the benefit score is positive, then performance with the hearing instrument is perceived by the patient as better than performance without the hearing instrument. If the benefit score is negative, then performance with the hearing instrument is poorer than performance without the instrument. If a difference of ≥22% is obtained for the EC, RV or BN score, significant benefit is indicated. If all three improve by ≥10%, then there is a 96% probability that a true difference/benefit has occurred. If all three improve by ≥5%, then there is an 89% probability that a true differ-

ence/benefit has occurred. An example of the summary information is provided in Fig. 2.

Even more important than the documentation of benefit, in the author's opinion, is the ability to use the APHAB to focus on the patient's specific areas of communication difficulty. In this way, the APHAB helps to develop realistic expectations and to explain why a particular hearing instrument was selected to cope with the communication area of difficulty.

For example, patient W.B. is a retired 66-year-old male patient who has never used amplification. His unaided APHAB scores are displayed in the table below, as well as in Fig 3 (see page 22):

Subscale	EC	RV	BN	AV
Raw score	89	56	43	37
Percentile	80th	20th	5th	80th

In the unaided or aided scores, a higher number indicates a greater percentage of problems. *Lower percentile rankings indicate fewer problems.* From these scores, we can see that W.B. has extreme difficulty with communication in quiet (EC), with the least amount of problems in noise (BN). Aversive sounds are also a problem (AV). Following amplification, W.B. demonstrated the following scores (also see Fig. 4 on page 22):

Subscale	EC	RV	BN	AV
Benefit score	54%	19%	-7%	15%
Percentile	65-80th	20th	5th	65th

For benefit rankings, the higher the percentage, the greater the benefit. Negative benefit scores, such as the BN condition, indicate that the patient feels they are functioning more poorly with the hearing instruments than without. This allows for a counseling opportunity or a fine-tuning of the patient's compression/-output controls on their hearing instrument(s).

Cox suggests that, when the EC, RV and BN are all above the 35th percentile and AV falls below the 65th percentile, the scores are associated with good adjustment to the patient's hearing instruments. The reverse of these conditions may be associated with poor adjustment to the prescribed amplification. In the case of W.B., reverberation (RV) and background noise (BN) fall below 35%; his hearing instruments may require modification to achieve satisfactory adjustment. W.B. does demonstrate increased benefit with reverberation and aversive sounds, but feels he is functioning more poorly in noise. Such a result would probably be followed by adding/adjusting compression for the patient.

Another way of using the APHAB is to compare two different hearing instruments (e.g., new vs. old instruments). A comparison of the BN subscale, for example, could be used, with a difference between benefit scores of at least 22% indicating a true difference between the two instruments.

In summary, the APHAB is an effective way to gather information regarding the likelihood of patient satisfaction, as well as a patient's own interpretation of the successfulness of the fitting. At a time when outcome measures are becoming increasingly demanded by third-party payers, the APHAB is an important and viable option for demonstrating benefit.

Hearing Activity Questionnaire

The Hearing Activity Questionnaire is comprised of 14 different listening situations and is described by Dillon et al.[4] The listening situations are as follows:

1 You are in a conversation with a member of your family or a good friend at home in quiet.

2 You are at the dinner table with your family.

3 You are in a conversation in the kitchen while preparing a meal or doing the dishes.

4 You are watching TV or listening to the radio.

5 You are talking on the telephone.

6 You are shopping and talk to a shop assistant now and then.

7 You are having a conversation while riding the bus/train or in a car.

8 You are having a conversation at a crowded barbecue.

9 You are having a conversation while walking on the street.

10 You are listening to a speaker at a lecture, in church, in the theater or the like.

11 You are having a conversation with someone at a large noisy gathering.

12 You are talking with a clerk in a large office (bank, post office or the like) with usual office noise (e.g., typing, printing, talking, etc.).

13 You are having a conversation at a restaurant, a cafe or a canteen.

14 You are listening to music.

For each of the listening situations, the patient is asked to answer Part a, b and c, as described below:

a How often they experience the situation described (choices are "every day"; "several times/week"; "1-2 times/week"; "not very often"; "never");

b Whether they use their hearing instrument (or other device, such as a loop system for questions 5-10) in that specific situation (choices are "always"; "often"; "sometimes"; "seldom"; "never");

c How helpful they find the hearing instrument in that specific situations (choices are "very helpful"; "helpful"; "very little help"; "no help"; "hinders").

Patients are instructed to skip questions b and c if they answer "Never" to question a, and to skip question c if they answer "Never" to question b.

The answers are weighted from 4-0 points (i.e., with answers of "every day/always/very helpful" being scored as 4 points while answers of "never/hinders" being scored as 0 points). Three different indices can be generated from these 14 questions:

1 *Social Activity Index*: The total amount of points obtained for question "a" divided by 56 points (i.e., 4 possible points x 14 questions);

2 *Use of Hearing Aid Index*: Total number of points for question "b" divided by (4 x y), where y is the number of situations that the subject experienced;

3 *Benefit Obtained with Hearing Aid Index*: The total number of points for question "c" divided by (4 x z), where z is the number of situations in which the subject used the hearing instrument.

Perhaps the key to the Hearing Activity Index is that it identifies areas where current hearing instrument users find their instruments unsatisfactory. These areas can then be addressed through additional counseling, technology, adjustment or replacement of the current hearing instrument.

For example, if it is found that W.B. had hearing difficulty "every day" when listening to the TV and that he "always" wore his hearing instruments and that he found the hearing instruments to be "very little help," the hearing care professional can then prioritize that item for hearing instrument adjustment and/or add an assistive device (e.g., infrared TV amplification system) to resolve what would otherwise be a constant irritation to the patient.

The SHAPI

Walden, Demorest and Hepler[5] described the 64-item Hearing Aid Performance Inventory (HAPI) in 1984. The HAPI was designed to

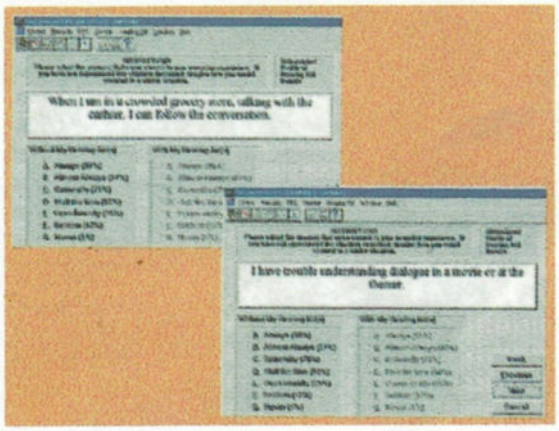

Fig. 1. *Computer-based version of the APHAB (Figs. 1-4 from PFS software).*

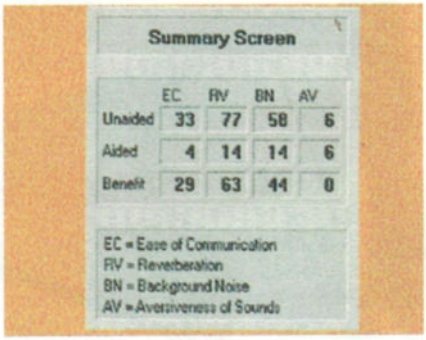

Fig. 2. *Raw data summary screen.*

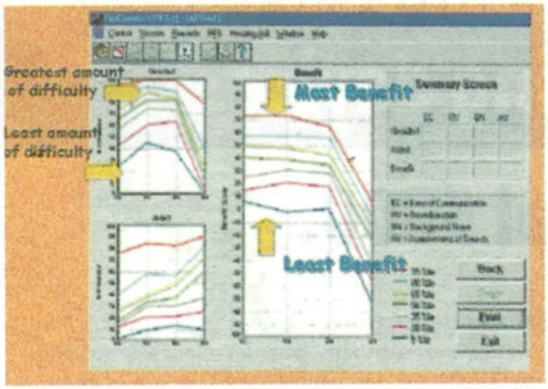

Fig. 3. *Unaided data (small box on upper left), aided data (small box on lower left) and benefit data (large box on right) scores for patient W.B. For the unaided graph, the upper lines denote the greatest amount of difficulty; for the benefit graph, the upper line (e.g., red) denotes the greatest amount of benefit (highest percentile).*

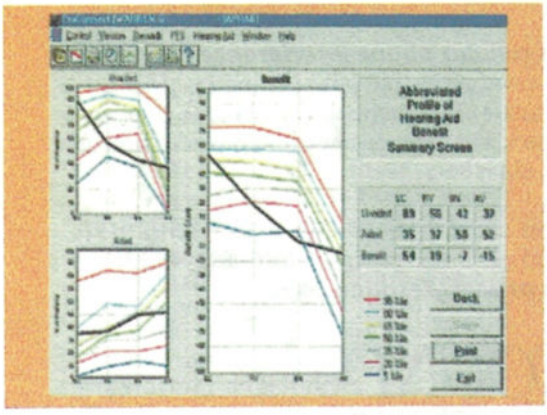

Fig. 4. *Benefit scores for W.B., using the same information as above.*

assess hearing aid benefit in a variety of different situations. Four variables that affect hearing aid benefit are assessed: 1) speech in quiet; 2) speech in noise; 3) speech with reduced information in the signal, and 4) non-speech stimuli. Patients are asked, post-fitting, to rate the amount of help provided by the hearing instrument in a variety of listening situations.

In 1992, Schum[6] developed a condensed version of the HAPI, the Shortened Hearing Aid Performance Inventory (SHAPI), comprised of 38 items providing information for three situations: 1) speech in quiet; 2) speech in noise, and 3) listening situations with reduced visual cues. Examples of items from the SHAPI include:

- You are sitting alone at home watching the news on TV.
- You are involved in an intimate conversation with your partner.
- You are at home engaging in some activity and the telephone rings in another room.
- You are driving your car and listening to a news broadcast on the radio. You are alone and the windows are closed.
- You are in the kitchen in conversation with your partner during the preparation of an evening meal.

Like the HAPI, patients are asked to rank benefit for a given situation by choosing from a 5-point numbering scale (note that, unlike the other scales, high scores on the SHAPI reflect little benefit):

Ranking	Score
Very helpful	1
Helpful	2
Very little help	3
No help	4
Hinders	5

Jerram and Purdy[7] provided group data of hearing aid benefit for the three different listening situations so that an individual patient's scores can be compared to the group data to assess benefit. Once again, normative data is critical to compare an individual's score to group data, but looking at individual items can be very helpful in making alterations to a patient's current amplification strategy.

For example, if W.B.were to complete the SHAPI, he would have considerable difficulty with the speech in quiet, but not with speech in noise. If speech-in-quiet scores were examined, it would be found that he had difficulty with such items as hearing the phone ring in another room or when someone speaks softly. As one possible strategy, W.B.'s current hearing instruments could be readjusted to provide more amplification for low frequency gain. While this could be accomplished in a variety of ways, one method would be addition of a circuit with dynamic range compression or lowering the kneepoint of his WDRC instrument.

Summary

A large number of self-assessment questionnaires exist from which to choose. Each offers the ability to have patients provide structured input into how they perceive themselves (and/or their hearing instruments) to function. The three measures discussed in this article allow the hearing care professional to assess aided performance, but the author encourages the reader to investigate the other methods in order to choose the one that is right for the needs of their particular practice setting.

The dispensing professional, in particular, can use this information to address individual areas of concern through counseling or modification of the hearing instruments. A questionnaire offers an important means of verification and insight into a patient's needs. It not only solicits the patient's input, but also assures them that we, as hearing care professionals, are listening to them and attending to their specific hearing goals as we modify their hearing instruments. ◆

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Validation of Hearing Instruments, Part 2: Linear Fitting Prescriptions

By Julie K. Purdy, PhD

This is the second in a series of articles about validation methods that can be used to assess hearing instrument fittings. The use of real ear measurements are discussed as well as how they can be applied in linear fitting formulas.

Throughout the history of hearing instrument fitting and verification, a variety of methods have been employed which hearing instrument practitioners have used as guidelines for success:

In the 1920s, "Normalization of Hearing" was attempted with a hearing instrument response selected that "mirrored" the audiogram with a constant subtracted. (The constant was the same at each frequency.) The objective was seldom achieved and seemed to result in overamplification.

In the 30's, "The Most Comfortable Contour" was employed that bisected the threshold of detection and the threshold of discomfort. A contour was established by finding MCL at 1 kHz, then matching the other frequencies. The prescribed amplification was the mirror image of that curve and often resulted in amplification of about one-half the hearing loss.

In 1946, the "Optimal Frequency Response" was described, specifying the use of a simple general rule rather than interpretation of the audiogram. This "Optimal Frequency Response" would satisfy the needs of most hearing-impaired listeners. Also, in 1946, Carhart recommended a comparison approach to hearing instrument fitting with three hearing instruments compared via aided Speech Recognition Thresholds (SRT), and word discrimination in quiet and in noise.

In the 1960s, a "Comfortable Level or MCL" approach was described with the goal to make sounds that were comfortable for the typical hearing-impaired person comfortable for the hearing instrument user. Gain was equal to the Most Comfortable Listening Level in dB SPL minus 65 dB SPL (normal conversational level). Comfort levels were to be assessed directly.

In the 1980s, prescriptive approaches via real ear measurements were introduced. A variety of formulas gained widespread use to include three fitting methods discussed in this article: The National Acoustic Laboratories (NAL) procedure, the Prescription of Gain and Output (POGO) and the Berger procedures. Each of these prescribe specific gain requirements regardless of the input levels. In addition, the gain requirements are obtained with a single input level.

During the 1990s, a variety of methods have been advocated to include self-assessment questionnaires, output based verification, speech-based assessment, sound field measurement, manufacturer-directed fitting, fitting rules and SPL-O-Grams. In addition, linear fitting formulas have continued to be used as well as new, non-linear prescriptive formulas.

Currently, we do not have difficulty with our options in terms of validation. The dilemma, rather, is in selecting the appropriate form of validation from a large array of validation methods. In addition to having a variety of ways to validate fittings, we must feel comfortable that if the outcome meets the expectations, then our definition of a successful fitting has been achieved. Obviously, we must have an initial expectation in order to make a circuit selection. We hope this expectation can be transferred to the manufacturer and, when the resulting instrument is verified on our patient, will lead to patient satisfaction. We need to ensure that our expectations are appropriate for our patients. But what should we use as our initial expectations?

This article is the second in a series about validation methods which can be used to assess our hearing instrument

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fittings. During this series, we will evaluate self-assessment questionnaires (see Jan. '99 *HR*), output-based verification, speech-based assessment, sound field measurement, manufacturer-directed fitting, fitting rules and SPL-O-Grams. In addition to the linear fitting formulas discussed in this article, we will also examine the newer non-linear prescriptive methods in a future issue of *HR*.

Real Ear Terminology

Real ear measurements have an advantage over other verification procedures because they are fast, efficient and accurate. They can be obtained on uncooperative patients such as infants, children and mentally retarded adults. They are equivalent to functional gain measurements obtained in sound field but do not require a sound booth. A final advantage is that they are able to assess the individual effects of the hearing instrument in the patient's ear. By placing a probe in the patient's ear canal and generating a composite sound, we can measure the energy that reaches the eardrum of the patient at select frequencies. Real ear measurements are comprised of the following components:

▶ *Real Ear Unaided Response (REUR)*: The REUR is the naturally occurring open ear gain, the result of the collection and transfer of sound by the external ear. This naturally occurring open ear gain is due primarily to the external canal resonance, head and pinna effects. In adult ears, it results in a 15-20 dB advantage at 2700 Hz and 10-12 dB advantage at 4000-5000 Hz. An example of a REUR is shown in Fig. 1.

▶ *Real Ear Occluded Response (REOR)*: Often called insertion loss, the REOR reflects the change in the REUR that occurs when the ear is occluded with a hearing instrument or earmold. The degree of REOR will differ depending on the style of amplification but can be as great as 20 dB. In most commercially available real-ear test equipment, the REOR is not tested directly.

▶ *Real Ear Aided Response (REAR)*: The REAR is the response of a hearing instrument after it has been inserted into the ear and turned on. It is displayed on the dB SPL scale and shows the actual distribution of sound energy in the proximity of the eardrum. An example of REAR is shown in Fig. 2.

▶ *Real Ear Insertion Response (REIR)*: The REIR is the mathematical difference between the REAR and the REUR. The gain provided by the open ear is subtracted from the gain provided from the hearing instrument. It is referred to in terms of "dB Gain" and is approximately equal to "Functional Gain." It is, typically, the REIR that is compared to a target generated by a prescriptive formula. An example of a REIR and prescriptive target is provided in Fig. 3.

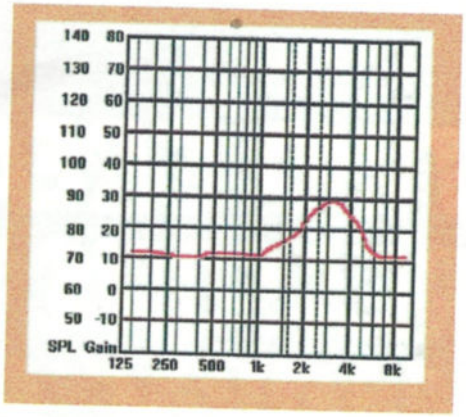

Fig. 1. *Real Ear Unaided Response (REUR).*

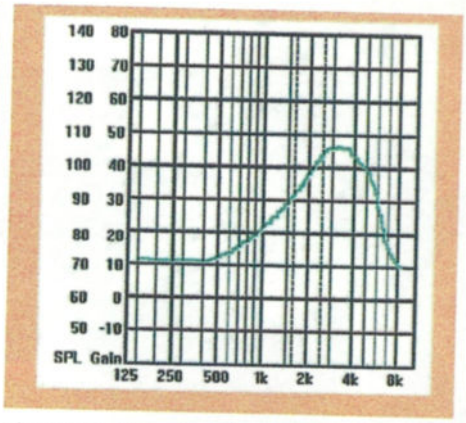

Fig. 2. *Real Ear Aided Response (REAR).*

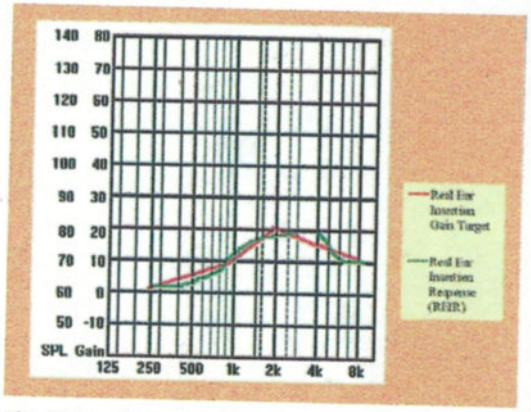

Fig. 3. *Real Ear Insertion Response (REIR) and REIR target.*

Mitigating Factors in the Use of Linear Fitting Formulas

While a variety of linear fitting formulas are available, for brevity, this article will examine three formulas: NAL, POGO and Berger:

▶ *NAL*: Byrne and Tonnison introduced this pure-tone-based procedure in 1976. The goal of the formula was to amplify the long-term spectrum of speech so that it was comfortably and equally loud across all frequencies. The initial procedure prescribed gain close to 1/2 of the hearing loss, but the procedure was modified in 1986 so that it now reflects, roughly, a 1/3 gain procedure. The formula used in this procedure is provided in Table 1. The formula is essentially linear, but it does have a correction if the sum of the thresholds of 500, 1000 and 2000 Hz exceeds 180:

0.116 (x-180)
(x = combined total of HL at 500, 1000 and 2000 Hz)

This formula also provides a modification if the hearing loss exceeds 90 dB at 2000 Hz. The formula does not specify a conductive or binaural correction.

▶ *POGO*: McCandless and Lyregaard described a gain/output procedure in 1983 with the following in mind: 1) The procedure must be simple; 2) It must be practical, and 3) It must be based upon the hearing instrument user gain information. The formula is provided in Table 2. This formulas does recommend that additional gain be added for conductive losses, but the amount of additional gain is not specified. This formula, similar to NAL, is essentially linear but does have a correction for losses of greater than 65 dB. For binaural fittings, 3 dB should be subtracted from the prescribed gain. Output specifications are also made using the formula:

(Averaged UCL values of 500, 1000 and 2000 Hz) - 4dB.

▶ *BERGER*: This fitting procedure was first described in 1977 by Berger, Hagberg and Rane and has been revised several times with the current

Frequency (Hz)	Formulas	Hearing Instrument Style BTE/ITE
250	X + .31 HL250	-17
500	X + .31 HL500	-8
1000	X + .31 HL1000	+1
2000	X + .31 HL2000	-1
3000	X + .31 HL3000	-2
4000	X + .31 HL4000	-2
6000	X + .31 HL6000	-2
X = .05 (HL500 + HL1000 + HL2000)		

Table 1. *NAL procedure REIG formulas for BTEs and ITEs at use volume control.*

Frequency (Hz)	Formulas
250	1/2 HL -10 dB
500	1/2 HL -5 dB
1000	1/2 HL
2000	1/2 HL
3000	1/2 HL
4000	1/2 HL

Table 2. *POGO procedure REIG formulas for use volume gain.*

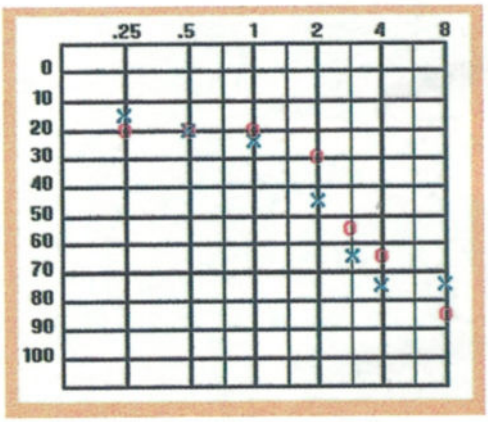

Fig. 4. *Audiogram for patient J.B.*

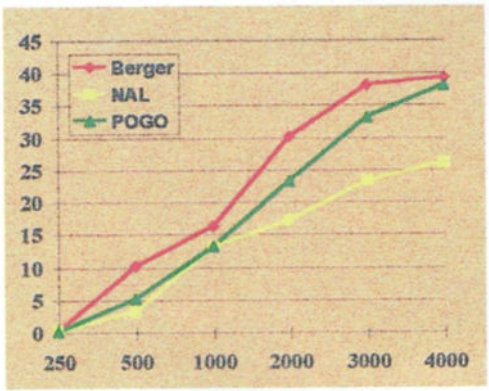

Fig. 5. *Example 1 of a comparison of three prescriptive formulas.*

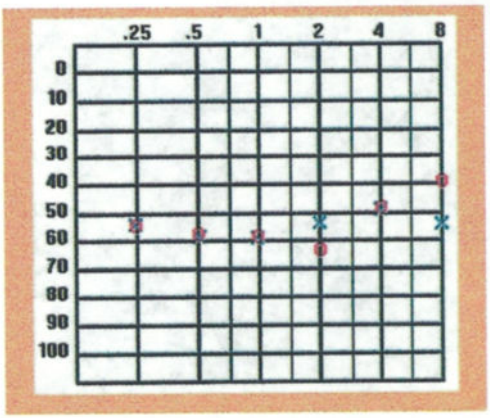

Fig. 6. *Audiogram for patient C.S.*

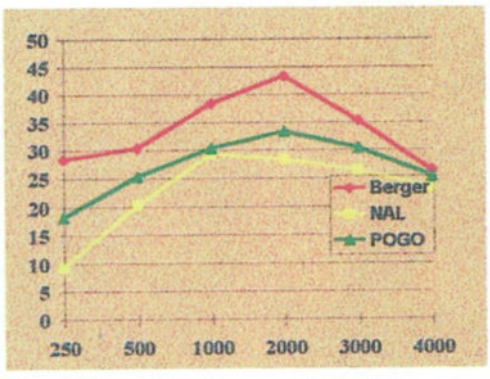

Fig. 7. *Example 2 of a comparison of three prescriptive fittings.*

procedure described in 1988. It is based upon the following: 1) The intensity of speech is between 55-75 dB SPL; 2) Desired gain is slightly greater than 1/2 of hearing loss; 3) Amplification of low frequency noise is detrimental to speech; 4) Less gain is needed at 500 Hz and below than is needed in the higher frequencies; 5) Information above 4000 Hz is not helpful; 6) The frequency response of the instrument should be smooth and not have prominent resonant peaks. The specific formula is shown in Table 3. This method does specify and air-bone gap correction for conductive loss: The gap is divided by 5 with up to an 8 dB correction. In addition, it specifies a 3 dB reduction in gain for binaural fitting.

So, what method to use? Sullivan, Levitt, Hwang and Hennessey probably said it best when they wrote: "A result of important consequence to clinical implementation of these methods is the significant interaction between prescriptive method and subject. This interaction suggests that different methods may be needed for subjects with different hearing loss characteristics." In other words, no single formula will meet the needs of all patients and, indeed, different formulas will provide patients with very different amplification experiences.

Fig. 4 depicts the audiogram for a patient J.B. who is a 42-year-old engineer who has previously worn canal hearing instruments and is now being fit binaurally with another set of instruments. Fig. 5 shows the prescriptive formulas for this patient's left ear for the three prescriptive formulas described in this article. As shown, prescriptive gain can vary from 17 dB SPL for NAL at 2000 Hz compared to 30 dB SPL gain with Berger, or 23 dB SPL for NAL at 3000 Hz compared to 38 dB SPL for Berger.

Another example of the large differences in prescribed gain with various formulas is provided for patient C.S. The audiogram is provided in Fig. 6 for this patient who is a 45-year-old female real estate agent who has had a moderate sensorineural hearing loss since childhood. She likes the sound of her old hearing instruments, which are six years old and were fit to match a NAL target. The prescriptive targets for her new aid for the right ear are provided in Fig. 7. As shown, prescribed gain varies from 29 dB SPL at 1000 Hz for NAL to 38 dB for Berger and 28 dB SPL for NAL at 2000 Hz to 43 dB SPL for Berger.

No story can describe the problem this creates better than a situation which occurred when I had just joined Starkey Labs and was asked to participate in a fitting forum at a conference. One woman accused me by saying that she had ordered one of our CIC hearing instruments and the result had provided too much high frequency gain. I asked her if she had sent the hearing instrument back for modification. She said that she had simply switched to another formula and the response matched the target so she sent the patient on his way. Obviously, the frequency response of the hearing instrument had not changed; rather, the practitioner switched her expectation.

Frequency (Hz)	BTE	ITE
500	HL500 +10 / 2	HL500 +10 / 2
1000	HL1000 +10 / 1.6	HL1000 +10 / 1.6
2000	HL2000 +12 / 1.5	HL2000 +10 / 1.5
3000	HL3000 +13 / 1.7	HL3000 +10 / 1.7
4000	HL4000 +10 / 1.9	HL4000 +10 / 1.9
6000	HL6000 +10 / 2	HL6000 +10 / 2

Table 3. *Berger procedure formulas for full-on 2-CM3 gain.*

Whether or not the patient was satisficed remained to be seen! The above underscores the basic tenet that the target is not the stopping point, but rather the starting point.

Summary

Linear fitting formulas are one method of verifying hearing instruments fit on our patients. By placing a probe in the patient's ear and making several measurements, we can obtain fast, efficient, accurate, patient-specific measurements on both cooperative and uncooperative patients. Although these varied fitting methods were introduced more than 20 years ago, they remain viable validation procedures and should be considered in our efforts to successfully verify hearing instrument fittings. ◆

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Validation of Hearing Instruments, Part 3: Non-Linear Fitting Prescriptions

By Julie K. Purdy, Ph.D

Editor's Note: This is the third in a series of articles on methods for validating hearing instruments. Part 1 (Jan. '99 HR, pgs. 16-22) dealt with patient questionnaires and Part 2 (Feb. '99 HR, pgs. 42-48) dealt with linear fitting prescription formulas. For copies of these issues, please contact HR.

A variety of validation methods has been employed by hearing care professionals as guidelines for achieving success during the past few decades. In the 1980s, prescriptive approaches via real ear measurements were introduced. A number of formulas gained widespread use to include the three linear formulas discussed in the previous article[1] in this series: The National Acoustic Laboratories (NAL)[2] formula, the Prescription of Gain and Output (POGO)[3] and the Berger[4] procedures. Each of these formulas have in common the specification of gain requirements regardless of the intensity of the input signal level. Typically, the gain requirements are verified via a single input level—usually at or around the level of conversational speech (65-75 dB SPL).

During the 1990s, several non-linear prescriptive methods have been advocated for validation of hearing instruments. These methods include, but are by no means limited to, the Independent Hearing Aid Fitting Forum (IHAFF)[5] protocol, Desired Sensation Level (DSL [i/o])[6], and the FIG6[7] program. These formulas have in common the specification of gain relative to the input signal level and allow for configuration of more sophisticated (i.e., programmable) hearing instrument circuitry. This article is designed to briefly discuss the salient features of these three popular non-linear real ear prescriptive formulas.

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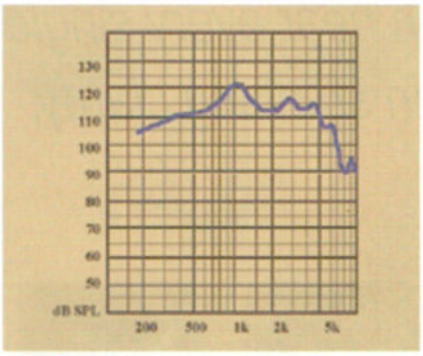

Fig. 1. *Example of Real Ear Saturation Response (RESR).*

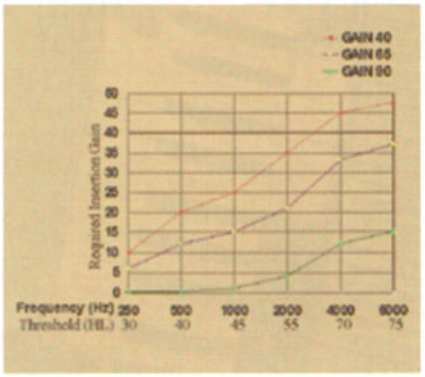

Fig. 2. *FIG6 target insertion example.*

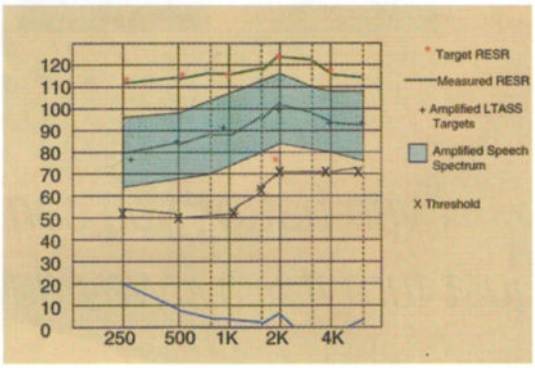

Fig. 3. *DSL [i/o] verification procedure.*

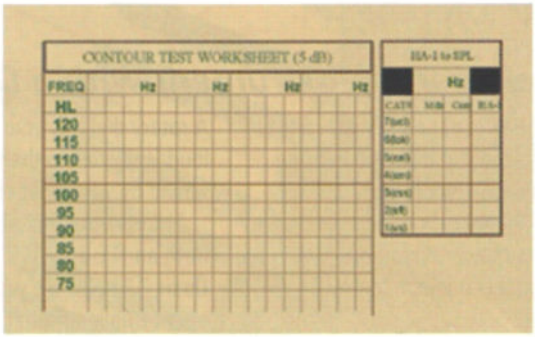

Fig. 4. *Sample VIOLA worksheet.*

Real Ear Measurement Terminology

By placing a probe in the patient's ear canal and generating a composite sound, it is possible to measure the energy that reaches the eardrum of the patient at select frequencies. The resulting real ear measurement has an advantage over other verification procedures because it is fast, efficient and accurate. The measurement process is comprised of several components: the Real Ear Unaided Response (REUR), the Real Ear Occluded Response (REOR), The Real Ear Aided Response (REAR) and the Real Ear Insertion Response (REIR). (*For a complete discussion of these terms, please see Part 2 of this article series.*[1]) In addition to these four important real ear measurements, this article will make use of two additional measurements, *Real Ear Saturation Response* (RESR) and *Real Ear to*

Coupler Difference (RECD), which can assist the dispensing professional in fitting non-linear instruments.

▶ *RESR:* The Real Ear Saturation Response is the actual measured SPL in the ear with an input level sufficient to put the instrument into saturation (typically 90 dB SPL). An example of a RESR is shown in Fig. 1.

▶ *RECD:* The Real Ear to Coupler Difference is the difference, in decibels, between the output of the hearing instrument measured in the ear versus that measured in the coupler using the same hearing instrument settings and input levels. The RECD can be made in a variety of ways, but one of the simplest methods for obtaining it is by generating the REAR from the patient with the volume control set at approximately half-on gain and at a 60-70 dB SPL input signal level. The hearing instrument is removed from the patient's ear and run in a coupler at the same volume control setting using the same intensity and type of signal. The values obtained in the coupler are subtracted from the REAR, rendering a RECD. (*For a complete discussion of how the RECD relates to the other two "decibel systems" used in the hearing care field (i.e., how the "dB HL of the audiometer" relates to the "dB SPL in the 2cc coupler" and to the "dB SPL of the eardrum"), the reader is referred to Larry Revit's article in the Nov. '97* Hearing Review, *pgs. 35-38.)*

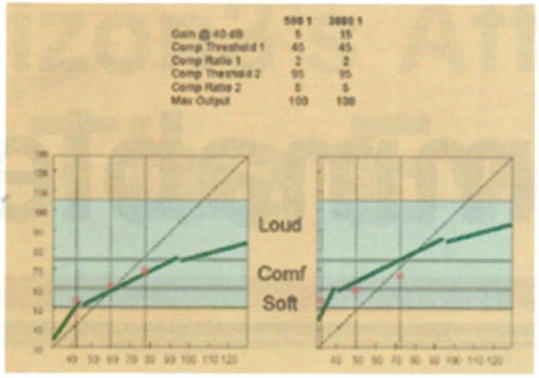

Fig. 5. *IHAFF VIOLA target example.*

Non-Linear Prescriptive Formulas

While a variety of non-linear fitting formulas are available, for brevity, this article will examine only three: FIG6, the IHAFF protocol and DSL [i/o].

▶ *FIG6:* The FIG6 program gains its name from an article by Killion and Fikret-Pasa[7] in which three types of sensorineural hearing losses were described. In that article, Figure 6 plotted the amount of gain required to achieve normal loudness perception based on the degree of hearing loss. The FIG6 fitting program is designed to calculate both insertion gain and coupler gain on a frequency-by-frequency basis relative to threshold data for

So, What Prescriptive Method Do We Use?

At the end of the description on linear fitting formulas in Part 2 in this series (Feb. '99) which dealt with the NAL, POGO and Berger fitting formulas, the rhetorical question was asked, "So what method do we use?" To answer the question, I quoted Sullivan, Levitt, Hwang and Hennessey[12] who wrote: "*A result of important consequence to clinical implementation of these methods is the significant interaction between prescriptive method and subject. This interaction suggests that different methods may be needed for subjects with different hearing loss characteristics.*"

In other words, no single fitting formula will meet the needs of all patients. Indeed, different formulas will potentially provide patients with very different amplification experiences. To illustrate this point, the audiometric data are provided in Fig. 6 for Warren, a retired 66-year-old man who has never worn hearing instruments, and for Lewis (Fig. 7), a 44-year-old chemist who suffers from Meniere's disease. Fig. 8 shows the gain and output recommendations for both of these patient's right ears for the three prescriptive formulas described in this article at 500 Hz and, in Fig. 9, for 3000 Hz.

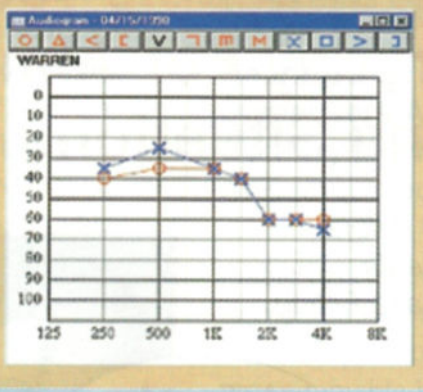

Fig. 6. *Audiogram for patient Warren.*

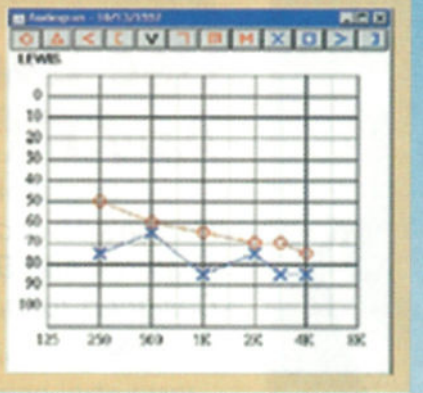

Fig. 7. *Audiogram for patient Lewis.*

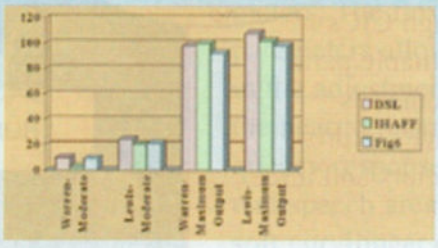

Fig. 8. *Comparison of gain and output measures for three prescriptive formulas at 500 Hz.*

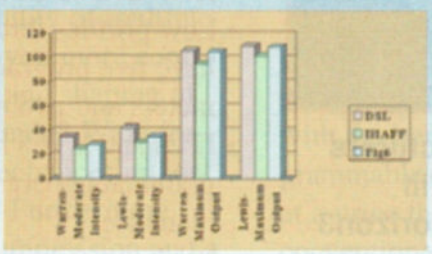

Fig. 9. *Comparison of gain and output measures for three prescriptive formulas at 3000 Hz.*

While true comparisons are difficult due to the varying prescribed input levels and procedures recommended for each formula, these comparisons are included to provide a rough estimate of the differences that can be present. ◆

two of the three types of sensorineural hearing loss types described by the authors. Type I hearing loss is characterized by hearing loss of up to about 40 dB with complete recruitment of loudness by 80 dB HL, and Type II hearing loss is characterized by hearing loss of up to about 60 dB with almost complete recruitment (i.e., very little gain required above 90 dB HL). Using FIG6 to fit Type III hearing losses (i.e., those greater than 70 dB HL) is not recommended by the authors.

Calculations via threshold for FIG6 are based upon average loudness growth data from many sources.[8,9,10,11] Upon entering the threshold data, the FIG6 program calculates the target insertion gain for each frequency for the three input levels, as well as compression ratios for a low and high frequency band for soft-to-moderate (40-65 dB SPL) and moderate-to-intense (65-95 dB SPL) levels. In addition, the program makes the appropriate corrections based upon Coupler Response for Flat Insertion Gain (CORFIG) values. These values are designed to correct for the variations in coupler responses that are derived from the style of amplification worn by the patient. The resulting values can be used to order or program/manipulate the gain, output, compression ratio and kneepoint controls for up to two bands of compression. When verifying data, there is a graph that provides target insertion gain for three hearing instrument input levels. Fig. 2 provides an example of a target insertion gain for the audiometric data provided at the bottom of the figure.

The FIG6 program is available on disk and has been incorporated into a variety of manufacturer's fitting procedures to simplify the process between audiometric assessment and circuit selection. (*For a more detailed discussion on the use of FIG6, see the article by Gitles and Niquette in the Nov/Dec '95 issue (pgs. 28-29) of* The Hearing Review.)

► *DSL [i/o]*: This program is a computer-assisted fitting procedure which specifies the input/output function of a hearing instrument. Individual threshold and *Loudness Discomfort Levels* (LDLs) may be entered or standard discomfort thresholds can be used. If the individual LDLs are entered, the standard values will be used to calculate the RESR, but the individual values will be displayed to allow for corrections to be made during the hearing instrument fitting, if such corrections are needed.

Additionally, individual corrections for the REUR or RECD can be entered to allow for a more customized fitting. Audiometric information is converted to SPL information and placed on a *minimum audible pressure* (MAP) graph. By bisecting the dynamic range, a target level or desired sensation level for the *long-term average conversational speech spectrum* (LTASS) is created. Ultimately, speech should remain audible, but should not exceed the RESR targets generated based on the audiometric information. An example of such a map with threshold information in SPL and RESR/amplified LTASS target information is shown in Fig. 3.

While such displays may look somewhat daunting, the reality is that, by entering audiometric information, the computer-based program provides full-on gain, output and compression information which can be employed to "build" a hearing instrument. Target coupler or insertion gain information can then be generated to verify the performance of the hearing instrument.

Like FIG6, this program has been incorporated into a number of manufacturer's fitting protocols to allow for simple conversion from testing to fitting. (*For more information on DSL [i/o], see the article by Sinclair, Seewald and Cole in the June '96 issue (pgs. 46-47) of* The Hearing Review.)

► *IHAFF Protocol*: The IHAFF protocol was developed by a group of hearing researchers in an effort to provide a comprehensive set of protocols which could be used in the selecting and fitting of hearing instruments while utilizing more sophisticated compression technology. The design and fitting portion of IHAFF is called VIOLA (Visual Input-Output Locator Algorithm). This component is designed to ensure that soft, moderate and loud sounds are audible but do not reach the LDLs of the listeners. Furthermore, it was developed so that loudness experienced by the listener is comparable to loudness experienced by normal-hearing listeners based on normative data comparing judgements of loudness of warble tones to speech spectra. The program uses threshold information as well as loudness measurements of soft, comfortable and loud ranges. The actual hearing instrument fitting matches three targets on a computer-generated input/output function.

VIOLA requires that specific procedures be followed which dictate the type of stimulus, manner of presentation and instructions provided to the patient. Pulse warble-tones are presented in an ascending fashion using 2-5 dB increments until patients reach level #7 of the descriptors, also provided by IHAFF (see Table 1). The test results are then repeated three more times for each frequency. Median SPL values for each of the descriptors are calculated, with a worksheet (a portion of which is provided in Fig. 4) provided to facilitate the calculation process. Testing a minimum of two frequencies is recommended—a low frequency (500 Hz) and peak amplification frequency such as 2000 or 3000 Hz.

When using the IHAFF protocol,

Table 1. Loudness Rating Scale for IHAFF

"You will hear sounds that increase and decrease in volume. You must make a judgement about how loud the sounds are. Pretend you are listening to a radio at the volume. How loud would it be? After each sound, tell me which of these categories best describes the loudness. Keep in mind that an uncomfortably loud sound is louder than you would ever choose on your radio no matter what mood."

7	Uncomfortably loud.
6	Loud, but o.k.
5	Comfortable, but slightly loud.
4	Comfortable.
3	Comfortable, but slightly soft.
2	Soft.
1	Very soft.

it is best to follow the manual, because much of it firmly establishes the importance for standardizing the manner of presentation and how the hearing care provider's instructions and the chosen stimuli used can shape the loudness growth function. Once loudness growth data has been obtained, this data is used to generate three target points for the soft, comfortable and loud sounds. The kneepoints and compression ratios for two frequency bands can be manipulated to achieve a best fit of the three data points.

Fig. 5 provides an example of the three targets for the low frequency band (left) and high frequency band (right). While the data points do not "hit" exactly on target, by using a compression ratio of 2:1 and a 45 dB kneepoint, such a circuit will come quite close to providing sufficient gain for this particular client.

The IHAFF is available on disk and has been incorporated by several manufacturers into their fitting protocols. Some of these systems (e.g., Starkey PFS) provide numeric displays of the four presentation frequencies, graphs of loudness growth measurements, and these can be used to select a circuit with the necessary compression, gain and output characteristics dictated by VIOLA. Verification at a variety of levels can also be performed for the patient.

Summary

Non-linear fitting formulas are one method of verifying hearing instruments fittings on patients. These formulas also allow hearing care professionals to specify gain and compression characteristics during the hearing instrument selection process. The selections can then be validated via a fast, accurate, patient-specific process on both cooperative and non-cooperative patients. All of the procedures detailed above should be considered as viable methods for validating hearing instrument fittings and serving as the starting point for successful hearing instrument fittings when using compression hearing instruments. ◆

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Validation of Hearing Instruments, Part 4: Output Measurements

By Julie K. Purdy, PhD

Hearing care professionals have a host of methods at their disposal when validating hearing instrument fittings. This article is the fourth in a series designed to investigate validation options. Previously discussed methods include *patient questionnaires* (Jan. '99 HR), *linear prescriptive formulas* (Feb. '99 HR) and *non-linear prescriptive formulas* (March '99 HR).

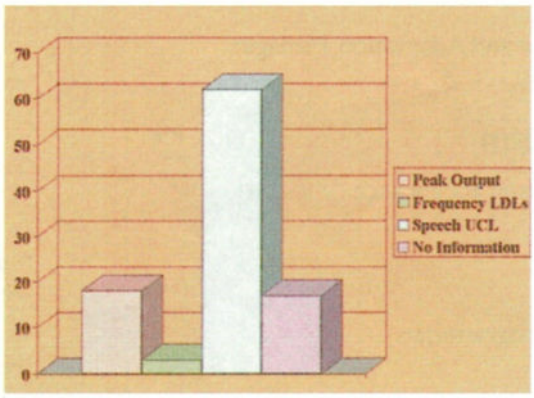

Fig. 1. *UCL and LDL information provided to hearing instrument manufacturers. This lack of data can be extremely frustrating for lab technicians who are trying to "build" an instrument for a client. (Adapted with permission from Mueller & Bright.[2])*

Additionally, hearing care professionals can choose from sound field measurement, manufacturer-directed fitting, fitting rules and SPL-O-Grams, as well as the output-based methods discussed in this article. It is hoped that the information presented here will provide keys in establishing output levels that do not exceed the comfort levels of the patients being fit.

The primary objective to utilizing outcome measures is to establish acceptable hearing instrument performance at the time of the initial fitting. Guaranteeing that the patient will be satisfied with their fitting is at the core of most prescriptive formulas, satisfaction/benefit questionnaires or other measures of performance verification.

Yet, one of the most-common reasons for rejection of hearing instruments relates not to frequency-specific gain requirements (the primary focus for prescriptions) but to the *loudness or output* from the hearing instrument. Franks and Beckmann[1] reported that 88% of their patients who rejected hearing instruments did so because the instruments made sounds that were "too loud." Yet, Mueller and Bright[2] reported that manufacturers are not receiving pertinent information regarding the patient's tolerance levels—information that could be used to design a hearing instrument with acceptable output levels. Fig. 1 demonstrates the information reported to have been included in orders to manufacturers. As is apparent, patients are not being tested via appropriate measures to obtain information that could assist in the selection of appropriate SPL output levels for patients.

Since it is apparent that excessive output will lead to hearing instrument rejection, this article is designed to address specific output measurement and verification.

Output Measurement Methods

Measuring outcome and aversiveness of sounds can be as simple as shaking a jar full of nails or pennies in a room. Having the patient walk around a very crowded shopping center, slamming a door or clapping one's hands can also effectively approximate bothersome noise levels.

Table 1: Conversion values from dB HL to dB SPL in 2cc coupler[5]

Frequency	TDH-39	TDH-49/50
250	20.7	21.7
500	9.9	11.9
750	7.3	7.8
1000	5.5	6.0
1500	2.5	3.5
2000	5.2	7.2
3000	5.7	5.2
4000	-0.05	0.5
6000	-0.2	-2.2

Other methods involve the use of standardized-speech *Uncomfortable Loudness* (UCLs) *Levels* or frequency-specific *Loudness Discomfort Levels* (LDLs), then verifying these measurements via sound field, real-ear, coupler or a combination of the three. *Real Ear Saturation Response* (RESR) measurements can also be used to verify that output levels of hearing instruments are within tolerable levels via a direct or indirect measurement approach.

A final method makes use of loudness growth data which can be obtained on a patient-by-patient basis or obtained via standardized data. This information can be combined with one of several non-linear fitting formulas to build/configure and verify a hearing instrument fitting *(information on this method is presented in the third article in this series, March '99* HR, pgs. 22-30*)*.

▶ *Loudness Discomfort Level (LDL) Measurements*: LDL measurements can be made for an individual, and the data can be converted from headphones or insert earphones to 2cc coupler data. The results can be used to select a hearing instrument which subsequently can be verified either directly in the patient's ear or indirectly in the coupler:

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1 Using calibrated earphones, the patient is asked to rank loudness on a scale until an uncomfortable level has been reached. Much has been written to indicate that the instructions provided play a critical role in how a patient responds.[3,4]

2 Puretones are presented in an ascending fashion using 2 dB or 5 dB increments until patients reach "level 7" of the descriptors as provided by IHAFF.[3,4]

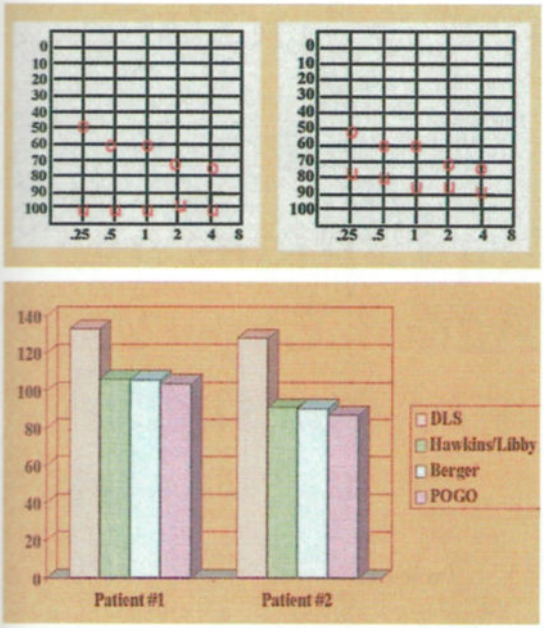

Fig. 2a-b. *Threshold and LDL information for two patients. (Bottom) The Prescriptive output levels for a variety of prescriptive methods for the two patients.*

3 The levels should be bracketed with the LDL recorded as the point midway between "level 6" (Loud but OK) and "level 7" (Uncomfortably Loud).

4 These LDLs should then be converted into SPL via the Hawkins[5] conversion figures (Table 1). Resulting values (in dB SPL) can be used to select a hearing instrument from matrix sheets or to order a custom hearing instrument which can be verified via one of the methods described later in this article.

▶ *Speech-Based Uncomfortable Loudness (UCL) Levels*: Generally, the speech-based UCL should be employed only when other output-based procedures are not available. This is due to its highly variable nature based upon the slope of the audiogram.

However, there are times when frequency-specific LDLs cannot be obtained, such as in the case of a young child or an adult with diminished cognitive capability. In these cases, a UCL can be made via headphones, insert earphones or soundfield speakers. Once again, instructions play a critical role in setting the level, and the IHAFF instructions could be used with the UCL set between "level 6" and "level 7." When completed, 20 dB should be added to this value to convert it to SPL and the resulting number can be used to ascertain that the primary peak of the hearing instrument falls at or below the resulting SPL value. For example, if "level 7" is 90 dB and "level 6" is 80 dB, the UCL value would be 85 dB plus 20 dB for the SPL conversion. This would indicate that a hearing instrument with a primary peak gain not to exceed 105 dB SPL should be placed on the patient. This value can then be verified via one of the verification methods discussed later.

▶ *Use of Standardized UCL/LDL Values*: Attempts have been made to predict patient LDLs or UCLs from speech or threshold information. While such predictions exist, when actual patient data is examined, a variation exceeding 20 dB in LDL with the same audiogram can be observed.[6] Based on these large variations, it is highly advisable to make direct measurements rather than base LDL measurements upon standardized values. Should standardized values be employed in the hearing instrument ordering process, a flexible hearing instrument with adjustable output should be specified and the resulting instrument verified on the patient.

To illustrate this point, Fig. 2a provides threshold and LDL information for two patients. While puretone air conduction thresholds are the same for both patients, the LDL information differs greatly and requires different considerations with hearing instrument fittings. Additionally, when using standardized values, it is difficult to ascertain which set of values should be used. As can be seen in Fig. 2b, several prescriptive formulas have been employed for the two patients. Depending upon which formula is used, very different output levels are prescribed. This points to the veracity of the observations made by Kamm et al.[6] that individually obtained patient data is far less problematic than attempting to predict LDL values from puretone thresholds or speech-based information.

Table 2. Loudness Rating Scale for IHAFF[4]

7 Uncomfortably loud.
6 Loud, but o.k.
5 Comfortable, but slightly loud.
4 Comfortable.
3 Comfortable, but slightly soft.
2 Soft.
1 Very soft.

Output Verification Methods: Real Ear/ Coupler Verification

▶ *Direct RESR*: As already discussed, a 90 dB swept puretone can be used to verify output of the instrument while it is in the patient's ear through the use of real ear measurements. The volume control of the hearing instrument should be set slightly above typical use to ensure that sounds remain comfortable, even if the patient turns the instrument volume up and then experiences a loud sound. The values at octave frequencies can be compared to those obtained from LDL measurements to ensure that the output of the hearing instrument does not reach uncomfortably loud levels.

▶ *Indirect RESR*: Obtaining a Real Ear to Coupler Difference (RECD) allows for an *indirect RESR* to be made. The RECD is obtained by obtaining a Real Ear Aided Response (REAR) from the patient with the volume control set at approximately half-on and a signal level presentation of 60 or 70 dB SPL. The hearing instrument is removed from the patient's ear and run in a coupler at the same volume control setting using the same intensity and type of signal. The values obtained in the coupler are subtracted from the REAR, rendering a RECD. The LDLs for the patient are converted into SPL as directed above. The hearing instrument is then run in the coupler with a 90 dB SPL stimulus. RECD values are added to those obtained in a coupler, rendering the approximate intensity levels obtained in the patient's ear canal. The resulting values can then be compared to the LDL values measured for the patient to ensure that the ear canal values fall at or below those provided by the patient with LDL measurements. *(For an in-depth discussion of real ear measurements, see Part 2 of this series in the Feb. '99 HR, pgs. 42-48. The reader is also referred to the article on using real ear measurement transformations in Revit[7]).*

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Output Measurements

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► *Soundfield Verification*: As in the direct RESR approach, a pure-tone signal of 90 dB SPL is used to verify the appropriateness of output levels for a given hearing instrument. Using a soundbooth, the patient is placed in front of a loudspeaker in the location used to calibrate the loudspeakers. The volume control of the instrument should be set slightly above that of normal use. The audiometer attenuator should be set to the appropriate HL settings that generate 90 dB SPL in the soundbooth (the appropriate levels can be obtained during the calibration process or a sound-level meter can be placed in the sound booth and the dial systematically raised until 90 dB SPL is reached). Once again, the sound levels should remain between "level 6" and "level 7."

Summary

Output concerns remain one of the largest obstacles to customer satisfaction and continues to be an overlooked part of hearing instrument fitting. Consequently, when selecting hearing instrument verification methods, the use of a method that employs output as a measured entity becomes critical. Incorporating RESR or soundfield verification as part of other fitting practices should allow dispensing professionals to ensure that patients will not be bothered by overly loud sounds. Eliminating bothersome levels should lead to increased hearing instrument satisfaction and decreased rejections of what are otherwise appropriate fittings. ◆

References

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