MEASUREMENTS OF TD: HOW LOUD IS ALLOWED?

By H. Gustav Mueller & Ruth A. Bentler

Welcome to Page Ten. As mentioned by David Kirkwood in his Editorial, Page Ten is one of the many exciting innovations that you'll discover in The Hearing Journal for 1994. As editor of Page Ten, my goal is to present to you some of audiology's latest techniques and practices in a format that is comfortable and, hopefully, encourages your readership.

I am pleased to announce that for 1994, Page Ten's contributors will include such household names in audiology as Katie Bright, Jeff Danhauer, Gail Gudmundsen, Jay Hall, Patti McCarthy, Al Montgomery, Rich Seewald, Brad Stach, and Robert Sweetow. This impressive group promises to provide you with practical information and interesting reading on topics related to auditory diagnostics, hearing aid dispensing, and auditory rehabilitation. You'll know where to find them...Page Ten.

For our first Page Ten article, I have asked Ruth Bentler, PhD, to help me write about the topic of threshold of discomfort (TD) measurements. Ruth is an Assistant Professor in Audiology, Department of Speech Pathology and Audiology, at the University of Iowa. She has been actively involved in TD measurements for a number of years, both as a clinician and as a researcher.

In answering the following 20 questions, posed to us by a busy practitioner, Ruth and I will try to convince you that TD testing—along with the related selection and adjustment of the hearing aid's maximum output—is an essential component of every hearing aid fitting. See if you agree.

– Gus Mueller, Editor, Page Ten

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OAEs: Hands On with Katie Bright

1

My first question concerns the title of your article. Don't we already have enough terms for loudness measurements without the two of you introducing yet another new term?

You're right. Over the years, numerous terms have been used to describe the intensity at which a sound "elicits an unfavorable response."[1] Perhaps the most popular of these are "loudness discomfort level" (LDL) and "uncomfortable loudness level" (ULL or UCL). Notice, however, that both these descriptors use the word "loudness." We have chosen to use "threshold of discomfort" (TD) because we (especially RAB) are almost certain that dimensions other than the loudness of a perceptually abusive sound might elicit the unfavorable response. Those other dimensions may include annoyance, harshness, or noisiness, among others. Therefore, TD is not simply a measure of *loudness*. By the way, we didn't just make this term up. It has been used repeatedly over the years in other papers on this topic.[2-4]

2

Regardless of the terminology, do I, as a dispenser, really need to do these measurements when I order and fit hearing aids?

Consider what happens if you make a mistake and fit a hearing aid with an output that is too high. The patient will be forced to do one of the following: Turn the volume control wheel down *very* quickly whenever loud sounds are present, avoid listening situations where sounds are loud, or always use a low VCW setting so that input plus gain does not exceed his TD. We believe that any of these three choices can easily lead to reduced benefit from hearing aids and, in some cases, hearing aid rejection.

3

So what if I simply fit all my patients with hearing aids with a low maximum output? Won't that take care of the problem?

It might take care of some problems, but it creates others. A maximum output setting that is too low will limit the patient's useful auditory area. Unnecessary distortion will be introduced, and the patient may find the sound of his or her own voice annoying. Therefore, the maximum output can't be too high or too low. Studies have suggested that inappropriate output selection may be the leading reason for hearing aid rejection.[5,6] If so, then careful TD testing coupled with appropriate setting of the hearing aid's maximum output is one of your best investments toward a successful fitting.

4

Since I fit primarily custom ITC and ITE instruments, how does a manufacturer know what output my patient needs? Can manufacturers accurately predict this from the pure-tone audiogram that I mail them?

No. Although group data may suggest that this is possible, numerous researchers have reported that intrasubject variability is substantial for any given hearing loss or frequency tested—occasionally in excess of *30 dB*.[7-11] This convinces us that TDs cannot be accu-

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rately predicted from pure-tone thresholds. In fact, and only partly in jest, we might suggest that a patient's TD can be predicted more accurately from his personality type than from his audiogram: Extroverts have higher TDs than introverts,[12] anxiety levels reduce loudness tolerance levels,[13] and neurotic individuals are not very reliably tested on this measure.[14]

5

But I have heard that there is considerable variability in TD measures themselves. Isn't this a problem?

It can be if testing is not conducted carefully. To obtain reliable TD measures you need to use an appropriate psychophysical method, clearly stated instructions, and (preferably) frequency-specific stimuli, such as warble tones or narrow bands of noise. To ensure the appropriateness of the TDs obtained, we use a modification of the descriptive anchors and instructions provided by the TD (LDL) guru, David Hawkins.[6] When a systematic procedure is used, reliability should be within 3 dB or so.[11,15,16] Good reliability has been reported even with children, as long as age-appropriate instructions and tasks are provided.[17-19] So, you see, when testing is conducted carefully, the reliability for TDs is not much worse than for pure-tone thresholds.

6

It sounds as if I should consider sending some TD information along with my audiogram when I order my next set of custom instruments. If I do a speech TD for each ear, will that give the manufacturer enough information?

Probably not, although frequently that's all the information that manufacturers have to work with.[3] It's difficult for a manufacturer to select the appropriate maximum output without hav-ing frequency-specific information. Depending on the type or spectrum of speech used, the listener is reacting to that portion of the spectrum that is uncomfortable to listen to first, rather than providing a contour into which speech or any other signal can be amplified. For example, if the listener has considerably more tolerance for high frequencies than for low, the maximum output of the hearing aid will be limited by the negative reaction to the low-frequency emphasis of speech. That will unduly limit the instrument's high-frequency maximum output.

7

Does this mean that I need to do TD measurements at all the same frequencies that I do threshold testing? I have a busy practice, and I'm not sure that I want to invest that much time.

Naturally, the more measurement points obtained, the better you can select the desired maximum output contour. But, practically speaking, one measurement for a low-frequency range (e.g., 500 Hz) and another at the peak frequency of the hearing aid's maximum output (e.g., 2000 Hz or 3000 Hz) will often provide the necessary information to determine what maximum output to order. This adds only a few minutes to your prefitting evaluation. Unless you're fitting a multichannel instrument, the maximum output setting is dictated largely by the peak of the maximum output response. Because current hearing aids, even the most flexible programmable ones, do not allow for a frequency-by-frequency "tweaking" of the SSPL90, it may not be necessary to obtain TDs for all pure-tone frequencies.

8

So should I mail these dB HL TD values to the manufacturer when I order custom instruments?

You could, but as you know, the performance of hearing aids is expressed in 2-cm³ coupler SPL. We have found that it works best to make these corrections ourselves, and then select a corresponding matrix. There are various ways to make these conversions, and to some extent it depends on the type of earphones that you use.

9

I use the TDH earphones that came with my audiometer; aren't they considered the standard?

The TDH-series earphones are okay, and there are look-up tables that you can use to convert these HL TDs directly to 2-cm³ SPL values.[20] However, there are some distinct advantages to using insert earphones, and that is what we recommend. You can place your insert earphone in a HA-1 2-cm³ coupler and then measure the output of your audiometer in the coupler for each frequency of interest. The difference between the audiometer dial reading and the coupler output provides you with a value to convert your TDs from HL to 2-cm³ coupler SPL for each frequency.

10

You lost me on the last part of that answer. Do you mean I should set the audiometer dial to the patient's TD at each frequency and then attach the insert earphones to the HA-1 coupler and make a measurement?

It's really much simpler than that. Here's a step-by-step approach:

(1) Take the audiometer that you will be using for your TD measurements. (If you want, use a portable audiometer by your test box or probe-microphone system. If the audiometer is only used for this purpose, it doesn't even have to be in calibration). Attach an insert earphone to the audiometer and place the foam tip in the HA-1 coupler of your hearing aid test system.

(2) Pick a frequency such as 500 Hz and present a constant tone at this frequency at an arbitrary dial setting. (A setting such as 70 dB HL or 80 dB HL works well; the difference between dial reading and coupler output should not vary as a function of audiometer output intensity.)

(3) Determine the difference between the dial setting and the 2-cm³ coupler output. For example, if the audiometer dial is set at 70 dB for 500 Hz and the coupler output is 76 dB, then the correction for 500 Hz would be +6 dB.

(4) Repeat this procedure until correction factors have been obtained for all key frequencies. These corrections can then be applied to all subsequent TD measurements conducted with the insert earphones. You need do this procedure only once as long as the calibration of your audiometer doesn't change.

11

You haven't said anything about probe-microphone measurements. Is there any reason to measure the actual output in the ear canal when TD is obtained?

Probe-microphone measurements certainly have a very important function during the verification process, but yes, you can also use them to help determine the prescribed maximum output. It is possible to calculate the real-ear coupler difference (RECD) by comparing the output of a hearing aid in the real ear to the output of the same hearing aid in the 2-cm^3 coupler. By disabling the loudspeaker of your probe-microphone system, and placing the probe tube in the ear canal with your insert earphone, you can measure directly the ear canal SPL at the point of TD. An added benefit of recording ear canal SPL TDs is that they will give you target real-ear saturation response (RESR) values, which you can use as part of your maximum output verification procedure on the day of the fitting. There are recommended step-by-step methods for using your probe-microphone equipment for conducting these RECD and target RESR measurements. [3,21]

12

Let's move on to the fitting. If I do all these prefitting measurements, do I still need to conduct aided TD measurements?

Absolutely. You may have made an error in the TD measurements or in the conversion or correction process. Or, the manufacturer may have been unable to construct the hearing aid as requested. Also, if the hearing aid user has an unexpected peak in the RESR, the user may exhibit discomfort in a frequency region that was not tested. Some verification that the SSPL90 is appropriately set must be made during the fitting session. Essentially, you should be testing to make sure that no sounds are uncomfortable at the output settings you have chosen. Clanging spoons in a glass container or talking loudly into the hearing aid are examples of not-so-scientific, but reasonable real-world verification methods. For a good, quick check of the appropriateness of the output, use a swept tonal signal from your probe-microphone unit's speaker. Select a stimulus level of 85 dB to 90 dB (which usually ensures that the hearing aid is in saturation) and tell the hearing aid user to watch the screen and indicate if there is any frequency range for which the sound exceeds his/her threshold of discomfort. This method allows you to compare the contour of the measured RESR with that of your target RESR, while also confirming that the hearing aid will not allow too much output at any frequency.

13

Why use a pure-tone signal to verify the maximum output? Hearing aid users don't listen to pure tones in real life.

That's true. However, using the 90 dB pure-tone sweep provides you with information relative to the maximum possible output that the hearing aid can generate at each frequency tested. If the patient doesn't experience discomfort during that sweep, you can be reasonably confident that even the squeal of a siren, a telephone ring, or the narrow-band whir of a fax machine won't elicit an unfavorable response.[22]

14

So, will setting the output in this manner ensure that the hearing aid user will never experience discomfort in any environment?

We would like to give you an unequivocal "Yes!", but there is some evidence that levels judged to exceed TD in a clinical setting are not the same as levels judged to be "too loud" in more typical environments.[23] Also, some current research findings suggest that different TDs may be obtained for different environmental sounds.[24] For example, a patient may judge a baby crying or a toilet flushing as exceeding TD, while the same SPL from an orchestra tuning or a phone ringing may be acceptable to that patient. The importance or the meaning of the sound may affect how much is too much for a person. Nonetheless, verification of appropriate maximum output using the high-level tonal sweep is most likely to ensure minimal discomfort.

15

Is it necessary to reevaluate TDs over time in much the same way that we reevaluate hearing?

For some people, especially new users, TDs may increase after hearing aid use. This is one reason why it is important to check aided TDs on follow-up visits, and to fit hearing aids that allow for adjustment of the maximum output.

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What if I fit a lot of hearing aids that have AGC-I, limiting compression, or special types of automatic signal processing like the K-AMP™? Are aided and unaided TD measurements still necessary?

These circuits may help prevent you from making serious maximum output mistakes, but they don't relieve you from thinking about the desired or selected maximum output. In other words, many compression circuits do not provide for excessive output levels because of the nonlinear manner in which they amplify sounds. An input-compression hearing aid with a 2:1 compression ratio (fairly common nowadays) will only allow for only a 20-dB increase in output when the input changes from 50 dB to 90 dB, assuming a very low threshold of activation. If that hearing aid has 40 dB of gain for a 50-dB input, the output equals 90 dB. For a 90-dB input, the output will reach only 110 dB, which may not exceed the listener's TD. Without the input compression in the circuitry, linear amplification of the same signal would have resulted in a 130-dB output, which probably would exceed TD. But the prefitting measures of TD will still allow you to adjust the maximum output level or shape, and postfitting measures will ensure the appropriateness of those settings.

17

It seems that since I started dispensing programmable hearing aids, I have fewer complaints about loud sounds being uncomfortable. How do you explain that?

By the preceding answer. The main circuit advantage of the programmable products is that nearly all of them use input or output compression in their signal processing. It's not because they are programmable that you are having fewer complaints with these hearing aids. It's because of their compression circuits, which keep the output generally lower (as does AGC-I) or provide a relatively undistorted output (as does compression limiting). In fact, the linear peak-clipping hearing aids of the recent past (or still present?) may actually introduce enough saturation-produced distortion to elicit an unfavorable response, even though the maximum output was painstakingly set during the fitting session! You may have noticed that multichannel programmables with channel-specific adjustable compression ratios or kneepoints also allow us to start shaping the contour of the RESR to that of the TDs. That's something we'll probably be doing much more of in the future.

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You haven't talked about children? What are your recommendations for them?

As we noted earlier, it is important to use age-appropriate tasks and instructions with young children. We know, for example, that it is possible to obtain reliable TDs on children whose mental age is as low as 5 years, if we use training tasks that teach the concept of "too much."[18] There are no data to suggest that TDs can be obtained for younger children, in part because they are unable to make comparative judgments about size or order of magnitude. As we noted earlier, it is impossible to predict those TDs with great accuracy. Therefore, since small children are unable to give us that information, it is important to follow those hearing aid users closely for signs of either discomfort or overamplification.

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Can I assume, then, that if there is no shift in threshold levels, that the child is not experiencing loudness discomfort with the hearing aids, and vice versa?

No. Unfortunately, the measurement of TDs and subsequent setting of the output does not ensure that overamplification will not occur. Conversely, monitoring for absence of threshold shift does not ensure that the hearing aid is always operating below the discomfort zone. That's why parents and caretakers must watch for evidence of discomfort and the audiologist must be alert to evidence of threshold shift. Along with being unable to provide the necessary feedback, children are especially prone to excessive output in the ear canal, primarily because of the small residual cavity when the earmold or hearing aid is in place. Although there is little evidence that TDs are different for children than for adults, a hearing aid will usually produce more output in a child's ear than in an adult-size ear.25 It is impossible to know the maximum output that the child is experiencing without conducting probe- microphone measures.

20

So, are all of these TD measurements *really* worth my time?

Maximum output problems don't go away. Either you take care of them when you fit the hearing aids, or you take care of them with repeat visits, remakes, or returns for credit. It's your choice.

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PAGE TEN

Page Ten is back for another year. We're going to start off 2002 by revisiting a topic from the past—selecting the maximum output of hearing aids—more on that in a moment. First, I'd like to thank our Page Ten guest authors from 2001: Harvey Abrams, Gail Chermak, John Greer Clark, Jay Hall, Gary Jacobson, Mead Killion, Catherine Palmer, Patti McCarthy, and Ron Schow. Through their excellent contributions, we provided you with a wide variety of topics, ranging from digital cell phones to bone-conduction testing to auditory processing disorders to rehabilitative audiology. We have an equally impressive list of topics and authors lined up for you for 2002!

Now, back to selecting the maximum output of hearing aids. You regular Page Ten readers might recall that back in 1994 Ruth Bentler and I wrote a Page Ten article on this topic. Has anything changed since then, you might ask. We think so. The routine use of WDRC has changed the way we think about output limiting. Recent articles have provided new thoughts on predicting the LDL from the patient's hearing threshold, and there are always new and intriguing things to talk about regarding loudness summation, power (channel) summation. and binaural summation. And, perhaps the most important issue is what *hasn't* changed: We still are not very good at getting the hearing aid gain right for loud inputs for our patients. Fewer than 50% of hearing aid users are satisfied concerning "comfort for loud sounds."

So, Ruth and I thought we would pay another visit to the topic of "How loud is allowed?" **Ruth Bentler**, PhD, is an associate professor of audiology at the University of Iowa. When not writing articles for Page Ten, she is involved in a wide range of basic and applied research related to the selection and fitting of hearing aids. You'll find her publications in most any journal you pick up, and in fact, one of them recently was selected as *American Journal of Audiology's* top article of the year! When it comes to hearing aid performance, she's more apt to design a study to search for the truth than to assess the obvious—which is a good thing.

Ruth and I hope you'll agree that indeed there *are* some new things to think about regarding how loud is allowed. As our knowledge of this topic increases and our fitting practices improve, maybe we won't have to have a déjà vu all over again, again.

Gus Mueller
Page Ten Editor

How loud is allowed? It's déjà vu all over again

By H. Gustav Mueller and Ruth A. Bentler

1 I remember your Page Ten article on this topic from 1994. Don't you two know that it's 2002? Today, we're nearly always fitting programmable and digital hearing aids. I don't think we have to worry about TDs, LDLs, UCLs, ULCs, gain for loud inputs, OSPL90 settings, and all that loudness stuff.

Think again.

2 You don't understand. I'm always fitting multichannel WDRC, and usually AGCo, too. I'm using the latest prescriptive methods, and the manufacturer's software sets everything automatically. Why worry?

True, compared to linear amplification, WDRC does have the overall effect of reducing gain for high inputs, which means that it is less likely that the hearing aid output will exceed the patient's LDL. Sometimes, in fact, it reduces gain too much, which is not a good thing either.

But let me ask you this: If we're so good at setting the maximum output and gain for loud inputs for modern hearing aids, how do you explain the results of Sergei Kochkin's most recent survey of people using hearing aids that were only 3 to 12 months old?[1] He reports that *only 44%* were satisfied when asked about "comfort with loud sounds." Moreover, of the 25 categories on the survey related to hearing aid performance and different listening environments, only two items received a lower satisfaction rating than comfort with loud sounds: use in noisy situations and listening in a large group. I don't know about you, but if only 44% of our patients are satisfied, I think we still have some work to do, and maybe we *should* worry.

And, by the way, the satisfaction results we mentioned were for people *using their hearing aids*. The "hearing-aids-in-the-drawer" group had satisfaction ratings for "comfort with loud sounds" that were much lower, which just might explain why the hearing aids were in the drawer.

3 The satisfaction rates for *my* patients, of course, are much higher than that. But for the benefit of your other readers, what do you suggest we do to make things better?

For starters, we'll say something that has been said many times before. Before the patient leaves your office with his new hearing aids, be sure that loud inputs do not result in aided outputs that are either too soft or uncomfortably loud.[2-4] There are several clinical protocols published regarding aided loudness testing.[5-7]

It's generally assumed, however, that if you do a fair amount of pre-fitting testing (e.g., frequency-specific LDLs) and these values are entered into the hearing aid fitting software, the automated "first fit" of the hearing aid should get you pretty close to the correct amount of gain for loud sounds. Post-fitting tweaking, therefore, should be minimized.

If you use the patient's hearing thresholds to predict LDLs, then expect to conduct more post-fitting tweaking. For example, Elberling estimated that the slope of the measured loudness function can be predicted from the hearing loss with an accuracy corresponding to a +/-5-dB fine-tuning of the gain for about 70% of hearing-impaired individuals.[8] He labeled the remaining individuals as either "sound sensitive" (12%) or "sound addicts" (17%). These data suggests that if you predict LDL from threshold, around 30% of your patients will need some post-fitting tweaking for loudness-related issues. That's assuming that a +/-5-dB window is okay, which might not be true for some patients with narrow dynamic ranges.

4 Do you really think that measuring unaided LDLs will get me any closer to the correct output? I've heard that the reliability of LDL measurements is pretty flaky.

That depends on what you call flaky. In several studies, the test-retest for LDL has been shown to be about the same as that for pure-tone thresholds![9,10] If you're using a 2-dB step-size, test-retest (within a given session) will be even better. This assumes, of course, that you're using a well-accepted structured protocol.

Many dispensers today use the instructions and loudness anchors of the Cox Contour Test.[11,12] Palmer and Lindley examined the test-retest reliability of this procedure using subjects with hearing loss.[13] They reported a mean test-retest difference of 2.6 dB across five test frequencies for the "Uncomfortably Loud" rating; 94% of test-retest differences were less than 10 dB. Granted, there are some people who just can't do this test, but for the average patient, do you really think you can do better than this by predicting LDL from the audiogram?

5 Hey, I thought I was asking the questions. Are you suggesting that predicting LDLs from the patient's threshold is a bad thing?

Not really, although it would be fun to go head-to-head with Mead Killion and Harvey Dillon—both of whom promote predicting LDLs from hearing thresholds in their respective prescriptive fitting methods. But we do want you to recognize the potential errors that can result if your prediction is off the mark.

For example, many fitting algorithms calculate the MCL based on the difference between threshold and LDL. This MCL value is then used for determining gain for average inputs, and this derived gain value is then used for determining WDRC kneepoints and/or ratios. Hence, if your predicted LDL was 10 dB to 15 dB higher than the true LDL of a given patient, post-fitting tweaking would not be simply a matter of a few mouse clicks to lower the AGCo kneepoints across channels, since you also have to change gain for almost all inputs other than soft. If you're fitting a hearing aid with multiple channels of compression, don't plan on making it to the 5 o'clock happy hour!

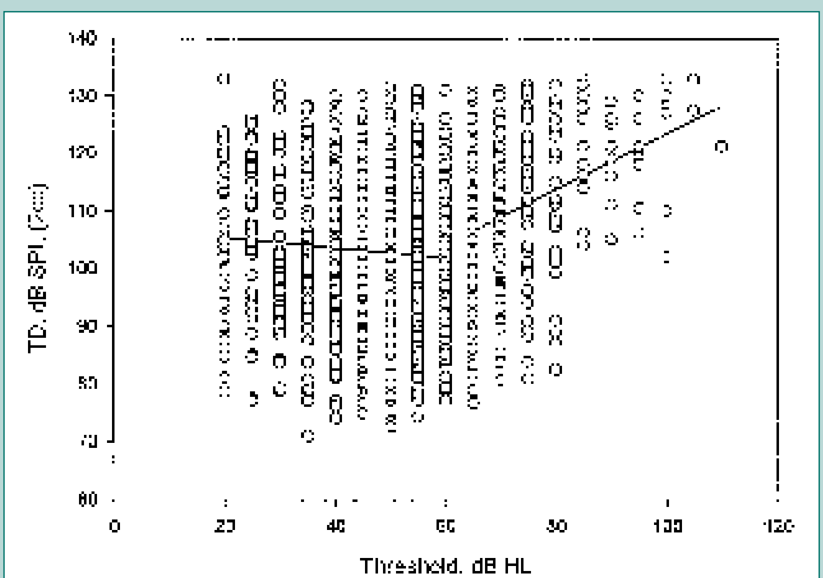

Figure 1. *LDLs as a function of hearing level for subjects with hearing loss (total of 607 ears).*

6 But, are the LDLs of people with the same hearing loss really that variable?

Are they ever! A long-term investigation at the University of Iowa recently was completed on that very topic.[14] Pure-tone LDL data were compiled across five investigations for a total of 433 subjects (total ears = 710). The LDL measures were obtained using two adaptations of the ascending method of limits (one with loudness categories and one without).

The results (as a function of hearing level) are shown in Figure 1. Take a look at the group of subjects who had a 50-dB-HL hearing loss (a common degree of loss for someone being fitted with hearing aids). Note that their LDLs, expressed in 2-cc-coupler output, range from 74 dB to 132 dB! For the thresholds from 20 dB HL to 60 dB HL (re ANSI, 1996), 1176 data points suggest an *average* LDL (re: 2-cc-coupler output) of between 100 dB SPL and 105 dB SPL. Using the +/- 5-dB acceptable error suggested by Elberling,[8] it is apparent that fewer than 50% of the data points fall within that interval. In fact, the data from this study suggest that *less than 1%* of the variance (for thresholds from 20 dB to 60 dB) can be explained by threshold alone—not a very accurate prediction! The situation is a little bit improved for those people with greater hearing loss (11% of the variance could be accounted for).

7 Okay, you're starting to get my attention. Didn't David Pascoe do a similar study back in the 70s or 80s?

Yes, he did, and it was of particular interest to us to compare the University of Iowa results to the Pascoe data.[15] It sounds as if you recall that famous graph wherein mean comfort and discomfort levels for pulsed pure tones are shown as a function of hearing loss. These data have been used in several prescriptive methods and manufacturer's fitting algorithms over the years to determine gain for loud inputs and to set the maximum output levels for hearing aids (for a given hearing loss).

If you look carefully at the graph from Pascoe (and we have!), you'll see that the average LDL for hearing levels of 20 dB HL to 60 dB HL falls somewhere between 100 dB HL and 110 dB HL. If you're not too facile at making the correction back and forth from HL to 2-cc coupler (check out Bentler and Pavlovic for assistance[16]), that translates to about 105 dB SPL to 115 dB SPL (re: 2-cc coupler) or 10 dB higher than the University of Iowa data set shown in Figure 1. We think we can explain the discrepancy, as Pascoe used methodology that intentionally forced the LDL upward. First, consider that Pascoe's protocol had three categories of loud:

"Loud," Very Loud," and "Too Loud." More importantly, his procedure was designed to push the LDL upward. Pascoe states:[15]

"Several ascending sequences are presented at each frequency, usually *starting at progressively higher levels*. This procedure forces the 'thresholds of discomfort' toward higher levels than initially chosen and also expands the range of 'comfortable' judgments, thus raising the mean comfort level. The set of sequences for each frequency is terminated when the discomfort judgment is not raised any further." (page 132)

This difference in methodology alone could account for the nearly 10-dB difference. We believe, however, that in the real world, most hearing aid users react to their first impression of a loud sound, and that using predictive values taken from LDLs that intentionally have been forced upward easily could result in prescribed hearing aid gain that is too high for loud inputs.

8 If I'm going to do some pre-fitting loudness testing, what about *in situ* measures of loudness. Would they help me ensure that gain for loud inputs is okay?

By *in situ*, we assume you are referring to conducting loudness measures using the patient's own hearing aid as the sound generator. This is an option available with several of today's digital products. Ben Hornsby of Vanderbilt University recently examined five commercially available digital hearing aids that are capable of utilizing *in situ* techniques to prescribe output.[17] Using the manufacturers' recommended procedures for programming maximum output based on *in situ* findings, Hornsby found that for individual patients the resulting RESR varied by as much as 17 dB depending on what manufacturer's procedure/hearing aid was used.

Of interest, however, is that the *in situ*- derived maximum output agreed quite well with the output that would have been prescribed by a specific manufacturer if the patient's earphone hearing thresholds had been used. In other words, it appears that when hearing aid maximum output is concerned, a given manufacturer's fitting philosophy might be more important than the loudness assessment tool used by the clinician. With an RESR range of 17 dB among manufacturers, it seems unlikely that the output from all five products would have been judged by the patient as "loud but okay" in the real world.

9 You keep talking about the real world, but are these clinical measures of unaided and aided loudness really valid?

If you mean, do these clinical measurements of LDL relate to real-world LDL experiences, our answer is *probably*. We do know that in the real world there are a number of factors related to the acoustic signal that can influence a patient's judgment of discomfort, and we recommend using self-assessment tools such as the APHAB or the PAL to validate clinical loudness measures (see Mueller and Hornsby for review[17]). As shown by Warner and Bentler,[18] however, the dominant factor, which accounts for nearly three-fourths of the variance, is simply individual variability.

The work of Munro and Patel supports this notion.[19] These authors found a significant positive correlation between patient ratings of loudness for long-duration sounds (e.g., traffic and wind noise) and differences between the patient's RESR and clinically measured LDLs. That is, subjects were more likely to report experiencing loudness discomfort in the real world when their RESR values exceeded clinically measured LDLs. Eighty-three percent of subjects whose RESR exceeded their clinically measured LDL reported these long-duration sounds as too loud. Only one of eight patients with an RESR set below their LDL reported that traffic or wind noise was too loud. There was no significant relationship, however, between loudness judgments of short-duration sounds (cutlery and door slamming) and the RESR-LDL differences. So, at least for long-duration sounds, clinical findings appear to be a fairly good predictor.

10 I'm sitting here looking at the data in Figure 1. I'm betting this is just for people with cochlear pathology. What if my patient has a conductive or mixed loss?

You're right. All of those 710 ears we talked about had normal middle ear function (or at least normal based on otoscopic examination and immittance findings). In general, we would assume that an external or middle ear condition would simply elevate the LDL by the amount of the patient's air/bone gap. Dillon, however, suggests that it actually increases the LDL by .875 of the air/bone gap.[20] This sounds so darn precise that we'll adopt this correction for the time being. Of course, you could also just conduct LDL testing.

11 I've heard that before. Let's go back to that University of Iowa study. Were there any other findings that might interest me?

We think so. There have been anecdotal reports that women have lower LDLs than men, and that older people have lower LDLs than younger people. These were two topics addressed in the Iowa study. In this large data set (466 data points from male ears, 1531 data points from female ears), no difference in LDLs as a function of gender was present. The subjects in this data set ranged in age from 11 to 97 years. No change in average LDL was found as a function of age.[14]

12 Interesting. Guess I'll have to develop a new theory regarding why my mother-in-law doesn't like my loud music. What else is new in LDL research?

Here's something for you to think about. For years we have believed that LDLs for hearing-impaired listeners are higher than those for normal-hearing listeners. (Recall the often-cited publications that say that LDLs increase with hearing level[15,21,22]). Most of these earlier studies, however, were carried out with pure-tone stimuli only. Consider that if listeners with hearing loss exhibit greater loudness summation than normal listeners, the use of complex stimuli may result in lower estimates of LDL for that group. In fact, there was some research from the 1980s that indicated just that.[23,24] And, there has been some recent evidence…

13 Wait, let me guess. You're going to tell me about another study from the University of Iowa?

As a matter of fact…yes! In a recent study by Bentler and Nelson, forty subjects were tested for LDLs using pure tones and complex stimuli.[25] Twenty of those subjects had normal hearing and 20 exhibited hearing loss sloping from 30 dB HL to 60 dB HL across the speech frequencies. Although the LDLs for the hearing-impaired group were slightly higher for the pure-tone stimuli, the opposite was true for the complex stimuli. That is, the subjects with hearing loss appear to have more loudness summation (across wide-band stimuli) than normal-hearing listeners.

Another objective of that study was to see if the spectral shape or content (e.g., speech, pure-tone complex) would alter the measured LDL; the results suggested that the rms (measured level of the signal), independent of the spectral shape or content, determined the level of loudness discomfort.

14 Now I'm getting confused. I thought the two of you always have preached that we should use frequency-specific signals to measure unaided LDLs. Are you now saying that I should measure LDLs using some complex signal?

Not really. We will continue to argue that obtaining LDLs for two or more frequencies will provide evidence of reduced tolerance for loud sounds (if it exists) in those frequency regions. The Bentler and Nelson study suggested that LDLs at 750 Hz and 3000 Hz are the best predictors of LDLs for the complex stimuli encountered in real-life situations (e.g., speech, noise), so you might try using these frequencies. While complex signals might provide useful information, it would be difficult to calculate channel-specific gain for loud inputs, RESR, and OSPL90 targets without frequency-specific LDLs to refer to.

15 Speaking of loudness summation, should I be thinking about binaural summation for high inputs when I'm fitting two hearing aids?

That's an area that needs to be looked at very carefully. Binaural summation refers to the fact that the loudness of a sound is *greater* if the sound is heard by two ears than if it is heard by one ear. The amount of binaural summation seems to depend on the level of stimulation, ranging from 3 dB at threshold to 6 dB or more at moderate and high intensities.

While there have not been many hearing aid-related studies of binaural summation for high-intensity inputs, this was part of the previously mentioned Bentler and Nelson research.[25] They state that irrespective of stimulus type (pure-tone or complex), complex shape or content, an average 6-dB difference was noted between monaural and binaural estimates of LDLs for both normal and hearing-impaired listeners. That finding would encourage the use of a binaural correction for fitting hearing aids.

16 So, do most prescriptive formulas apply a binaural correction?

For gain calculations, many current prescriptions apply a correction of 3 dB to 5 dB for bilateral fittings. However, for setting the OPSL90 (or even the gain for high inputs), this correction is sometimes ignored. To confuse the issue, there is some research to suggest that there is little or no difference between monaural LDLs and binaural LDLs.[24,26,27] Those findings would suggest that no correction is necessary for setting gain for high inputs. On the other hand, as we've stated, other research suggests the need for such a correction.[24,25]

It appears that these conflicting findings are related in part to the methods used to obtain the LDL measurements—earphones versus sound field being one of the factors. Whether or not we correct prescriptive gain, we'd better verify in the fitting stage that the output is set appropriately for any binaural summation that may occur (see Mueller for review[2]).

17 What about multichannel hearing aids? Is multichannel summation different from loudness summation and binaural summation?

You bet it is. This is often referred to as *power* summation. When the output of the hearing aid is independently limited in multiple channels, the power summation across those channels must be considered.

We'll illustrate with a simple example: If the output of a single-channel hearing aid is set to limit at 110 dB (re: 2-cc coupler), then the maximum output of the hearing aid is (hopefully) 110 dB (re: 2-cc coupler). That was the easy part! If each of two channels has that same 110-dB maximum output level, then the sum of those two outputs will be 113 dB (remember that class long ago on adding dB?). If the hearing aid has four independent channels set to 110 dB, the sum of all four (assuming the output from each channel was, indeed, 110 dB), would be 116 dB SPL. And so on. Add to that the loudness summation that occurs with wide-band stimulation and the loudness perception will be even greater.

In a study that looked at this combination of loudness summation and power summation (without trying to parcel out the pieces), it was concluded that a reduction in (dB) OSPL of 3.95 + 12.88log (n) where n can be interpreted as the number of channels of the hearing aid, should be applied to the output of the hearing aid.[23] Such a formula would suggest an output reduction of almost 8 dB for two channels, and 12 dB for four channels, assuming equal output from multiple channels. Since that is rarely the case, Dillon suggests that reduction should be 5 dB for two channels and 9 dB for four channels.[20] As we noted back at the beginning of our "summation" discussion, this whole area needs some serious consideration by industry and clinicians alike.

18 But even if my summation calculations aren't great, and my loudness verification techniques are a bit shabby, won't patients simply acclimatize to the loudness levels that I give them?

Don't count on it. We don't think it's possible to "toughen up" ears, if that's what you're referring to. While hearing aid users do "acclimatize" or "adapt" to some new sounds and LDLs have been shown to increase in the laboratory after training,[28] it's unlikely that there will be much of a change in the patient's LDL following hearing aid use (see Lindley[29] and Mueller and Powers[30] for recent reviews on this topic). In general, research has shown that LDLs remain constant after long-term hearing aid use.[31] Besides, knowing that "comfort for loud sounds" is one of the leading reasons that patients reject amplification during the first few months of hearing aid use, are you really going to fit someone with an output that is too loud and then say "Don't worry, buddy, you'll acclimatize to this in 2 months"?

19 Okay, okay. Before we quit, anything new about loudness and children?

Good question. We have been talking mostly about loudness measures with adults, although many of the things we've discussed apply to both adults and children.

Regarding children (and infants), we're pleased to say that the RECD certainly is understood and used more today than when we were here on Page Ten talking about loudness 8 years ago.[3] That's a good thing! And, as with adults, we think it sometimes is worth the effort to try to measure the LDL with older children. We've been intrigued by recent research suggesting that cross-modality matching (CMM) can be used successfully for loudness measurements in young children.[32,33] For example, Serpanos and Gravel used CMM for loudness and line lengths—eight different smiling caterpillars varying in length from .52 cm to 65 cm (a ratio of 125:1).[33] These authors report that the CMM method is a valid and reliable technique to assess loudness growth in children as young as 6 years of age with sensorineural hearing loss. Look for more research in this area.

20 So maybe "how loud is allowed" really isn't déjà vu all over again?

Sometimes it seems that it is. We've been talking about binaural summation forever, and we still don't know the right numbers. Loudness verification procedures, which have been recommended since the 1930s, are still seldom used. Other issues, such as loudness judgments based on *in situ* testing and power summation with WDRC multichannel digital instruments, are relatively new concerns. We can assure you, however, that as long as large numbers of patients are dissatisfied with the way their hearing aids amplify loud sounds, "how loud is allowed" will be a topic that we'll keep talking about.

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Let's take a quick trip back to January of 1994. Bill Clinton was delivering his first State of the Union address, the Cowboys were beating the Bills in the Super Bowl, and Lorena Bobbitt was being found not guilty regarding her little incident with her husband. In the world of audiology, the first AuD programs had just opened at Baylor and Central Michigan Universities, FDA commissioner David Kessler's name was being bounced around, and here at the *Journal* a new monthly feature appeared on page ten—titled, *Page Ten*.

At the time, people fitting hearing aids were pretty excited about "programmable," WDRC, and this new style of hearing aid that fit completely in the canal. Ruth Bentler and I had a discussion about how it seemed that people had forgotten about one of the fundamentals of fitting hearing aids—getting the output right. So "How loud is allowed?" became the topic of the *Journal's* first Page Ten.

Seven years later Ruth and I had another discussion about what had changed regarding the attention paid to the selection and fitting of maximum output. Our conclusion was not much, so our second Page Ten article on the topic was born: "How loud is allowed: It's déjà vu all over again."

Well, 14 years have now passed since our original article. Unfortunately, many of the problems associated with maximum output selection haven't gone away, so we're back for the hat trick. Unlike the original hat trick, getting the output right isn't like pulling rabbits out of a hat—it doesn't happen magically. Rather, you have to use a little bit of science and some second-grade math.

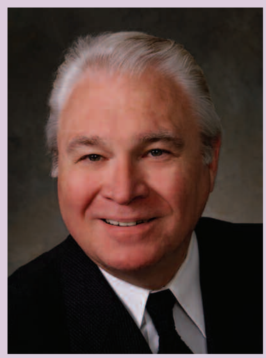
My co-author, **Ruth Bentler**, PhD, is professor of audiology at the University of Iowa. As you know, she is a noted researcher, writer, and international workshop lecturer. Since our last Page Ten together, she's gained even more international fame through her intriguing posting at www.earTunes.com. And when not singing, she has found time to work in extended teaching assignments in Hong Kong, the University of Western China (Chengdu), and the University of Canterbury (Christchurch, New Zealand). She's also become a regular participant in the Healthy Hearing component of the World Games of the Special Olympics.

Although we've said it before on these pages, our message is pretty simple: Don't forget about maximum output when fitting hearing aids. And who knows, if things don't change, maybe we'll be back for a "quad-row!"

GUS MUELLER
Page Ten Editor

How loud is allowed? It's a three-peat!

By H. Gustav Mueller and Ruth A. Bentler



H. Gustav Mueller

Ruth A. Bentler

1 I think the two of you have written about this topic on Page Ten before. Aren't you ever going to give up?

We may give up someday, but not yet. You're right, we did talk about loudness measures and hearing aid maximum output selection on these pages in 1994 and again in 2002,[1,2] and we've also addressed the issue in a few other articles in this Journal.[3-5] The reason we keep pounding on this topic is that we think a lot of patients are still not being fitted with the maximum output that is best for them.

2 But haven't a lot of things changed in technology and fitting techniques since you wrote your last paper 6 years ago?

Let's address the testing and fitting issues first. Back in the late 1990s, just preceding our last Page Ten article, there were guidelines stating the need to measure loudness discomfort and to set the hearing aid's maximum output appropriately. Yet, as we reported then, surveys showed that most dispensers did not follow these recommendations, and we learned from Sergei Kochkin's 2000 MarkeTrak V report that only about 50% of hearing aid users were satisfied when asked about "comfort with loud sounds."[6]

So, what has happened since? Well, for starters we have new evidence-based hearing aid fitting guidelines from the American Academy of Audiology.[7] And guess what? Consistent with previous guidelines, they recommend conducting pre-fitting frequency-specific LDLs and conducting verification of loudness at the time of the fitting. And yes, surveys continue to show that only 20%-30% of people fitting hearing aids follow these guidelines.[8,9] As you also might guess, the recent MarkeTrak surveys of Sergei Kochkin (e.g., MarkeTrak VII) continue to show that only 60% of hearing aid users are satisfied when asked about "comfort with loud sounds."[10]

3 I see the point you're trying to make, but hasn't a decade of digital technology mostly solved this problem?

First, consider that the disappointing MarkeTrak data we just mentioned were collected in 2005—only 3 years ago. Granted, some of the hearing aids the respondents were using were 5 years old, but there really hasn't been much change in hearing aid compression limiting and output control in the past 10 years. We agree with your thought that we have the potential to adjust the output to appropriate levels with today's technology. Even the "entry-level" products now have adjustable AGCo kneepoints. And, nearly every hearing aid can be programmed to be WDRC, which indirectly can be used to select the maximum output range (although influenced by VC changes).

But just because the circuitry is there doesn't mean that it's being used any more appropriately with today's technology than it was in the past.

4 Maybe so, but if nothing else, I would think that with all the open-canal fittings there are fewer loudness problems, right?

Well, the mini-BTE open-canal (OC) products certainly are popular—maybe as much as 25% of all fittings last year. It might be short-sighted, however, to assume that just because these hearing aids tend to be low power, and the canal is open, there won't be any maximum output problems.

Consider that if the canal is left open (e.g., you don't use one of the tighter fitting domes), much of the open-ear resonance remains. On average this is probably around 12-15 dB in the range of 2000-3000-Hz.[11] This often is considered a benefit when we're thinking about high-frequency gain, but it might not be a benefit regarding loudness discomfort. And the real-ear maximum output for an open fitting is difficult to predict from 2-cc coupler data, as the residual ear canal effects are quite variable. In addition, with an OC fitting there could be some summation effects at these higher levels (e.g., the direct flow SPL and the hearing aid output SPL might be similar).

5 So are you telling me that loudness discomfort is a real problem with OC fittings?

No, we're simply saying that giving some thought as to whether or not the maximum ear canal SPL exceeds the patient's LDL for an open fitting is probably just as important as when a more closed fitting is used. We've certainly heard many anecdotal comments about OC users "not liking a lot of gain." We wonder, was it the gain or the hearing aid's maximum output that they didn't like? These are two different issues that usually require different treatment strategies. We're not aware of actual research data, but we do have case studies showing REAR90 outputs that are 10 dB higher with an open fitting than with a closed fitting for the same hearing aid settings in the same ear. Does 10 dB matter? We think so.

6 Okay, I understand. But let's get back to maximum output selection in general. Isn't this predicted fairly accurately by prescriptive fitting methods?

If you are referring to NAL-NL1 (soon to be NL2) and the DSL *m*[i/o] v5.0a, the only two validated methods we have, the answer is yes—sort-of. If you're only going to enter pure-tone thresholds, it depends on how well you believe that LDLs (or the hearing aid's maximum output) can be predicted from the patient's hearing loss, and how big a mistake you believe you can make with the maximum output selection and still be okay.

As we discussed in our 2002 article, there are data suggesting that if you consider +/-5 dB a reasonable window of acceptance, then you'll be okay about 60%-70% of the time if you set the output by predicting from the hearing loss.[2] Other data, however, such as those from Bentler and Cooley,[12] are not this encouraging. They show a larger spread for LDLs, and the +/-5-dB acceptance window includes fewer than 50% of their 433 subjects.

7 You're talking average values, but what if I were to tell you that I was one of those people who entered frequency-specific LDLs into the fitting software?

We probably wouldn't believe you! But, just in case you're serious, that's a tough question to answer. The reason is, most people like you don't use the "true" NAL or DSL software; they use an implementation of these methods that is embedded in their favorite manufacturer's fitting software.

Let's take NAL-NL1 for example. What we're saying is that it's possible that you could select "NAL-NL1" as your desired fitting method in the manufacturer's software, and this prescriptive method would then be used to select gain and compression characteristics. But it's also possible that the manufacturer uses a different fitting strategy to select the AGCo kneepoint (which would then control maximum output). Therefore, entering the patient's LDL might make a difference, but maybe not. This is something you can easily check out in the fitting software by altering the LDLs (e.g., 80 versus 120 dB HL) for the same hearing loss and then observing if the AGCo kneepoint setting changes accordingly.

8 And what if I were using the "real" software?

Here's a simple example using the DSL software (v5.0a), which provides the option of entering patient-specific LDLs. For starters, we'll say that your patient is an adult, has a 50-dB-HL hearing loss at 2000 Hz, and you do not enter in his LDL. The software would then prescribe an OSPL90 setting of 97 dB, and your REAR90 target would be 106 dB.

Now, if you did some testing and found that your patient had an LDL of 90 dB HL at 2000 Hz, a fairly common finding for someone with a 50-dB-HL hearing loss, and you entered this into the fitting software, these target values would be 10 dB lower. Does 10 dB matter? We think so.

9 So how do manufacturers' output selection methods differ from what we've been discussing?

Good question, especially because that seems to be the most popular selection method. George Lindley, using survey results from over 200 dispensing audiologists, reported that 71% of this group stated that they pre-program hearing aids to "manufacturer's recommendations" compared with only 38% who said they pre-program to a "specific fitting strategy" (respondents could select more than one category).[9]

It's hard to give you a specific answer, however, because for some manufacturers their recommended (default) fitting is a recognized fitting strategy. Moreover, a manufacturer could use its proprietary method for selecting gain and compression characteristics, but then use a more well-established (or time-honored) method for selecting maximum output. It differs from manufacturer to manufacturer.

10 But do you have a hunch whether or not you would end up with about the same output settings with different manufacturers?

We have more than a hunch. You would not. We've recently been looking at how different manufacturers select the hearing aid's maximum power output and, in fact, we just published some data on this topic last month in the *Journal*.[5]

We were a little surprised to see that if you enter the same audiogram into the software of six leading manufacturers, you end up with hearing aids programmed with maximum outputs differing by as much as 15 dB. We simply used a 50-dB-HL hearing loss and the manufacturer's default settings; the resulting programmed outputs (input: 90-dB-SPL swept pure-tone signal) ranged from around 90 dB SPL to around 105 dB SPL.

11 Do you think the agreement would have been better if you had entered frequency-specific LDLs into the fitting software?

We did that. After those initial measurements, we entered an LDL of 90 dB HL for all frequencies. The agreement actually became worse. For two products, the maximum output was reduced by ~10 dB, and in two other products, including the one with the initial highest output, the maximum output didn't change. Another important finding was that for two of the six hearing aids, the maximum output displayed on the fitting screen was quite different from what we measured in the coupler.

It all seems to go back to the same general theme: The only way to get things right for a given patient is to do some testing. Using pre-fitting LDLs to set the maximum output should get you close (by making your own corrections from HL to 2-cc coupler), and aided verification will get you even closer!

12 It's clear that the two of you think there is a link between clinical measures and real-world benefit and satisfaction. Is there any proof of this?

That is the real question, isn't it? We think so, and in fact, that was a topic we addressed in a 2005 *JAAA* paper.[13]

We conducted a systematic review of peer-reviewed published research for two related topics: the use of unaided LDLs for setting the maximum output of hearing aids and the use of aided LDL measurements for adjusting the maximum output. In both cases, we then questioned if there was real-world evidence to support the practice.

Following principles of evidence-based practice (EBP), we limited our selection of articles to studies involving adults that were published from 1980 to 2005 using either a randomized control, a non-randomized intervention, or a non-intervention descriptive research design, including either unaided or aided LDL measures, and using self-report measures following real-world experience with the hearing aids. We searched a number of databases and found 187 articles of potential relevance. By first reviewing the abstracts, it was clear that 173 of the "hits" did not meet our criteria for inclusion; after more careful scrutiny, we found that only three articles could be included.

13 Three? Out of 187 articles?

You're right, you'd think that for something that has been an issue for as long as setting the maximum output of hearing aids there would have been a lot of studies that qualified. Remember, however, that we had fairly strict criteria, and many otherwise good studies didn't meet the criterion of having the real-world component.

One that did was a large clinical trial undertaken by NIH (NIDCD) and the VA.[14] In this study, the maximum output of the hearing aids was set following frequency-specific measures of loudness discomfort and RESR verification. The results were interesting on many levels, but of particular interest to us was the finding that only 10% of the time (across 330 subjects) did the measured RESR exceed LDL by 5 dB or more at one or more frequencies, and only one subject (of that 10%) complained of loudness discomfort during real-world use.

In all, the limited evidence we gathered in this review supported the use of clinically measured frequency-specific LDLs for selecting the real-ear maximum output of hearing aids. However, the dearth of studies, the low statistical power of the studies, and the level of the evidence did not allow us to make a *strong* recommendation supporting this clinical procedure.

14 That was 3 or 4 years ago. Anything new to support or refute your conclusions?

Not much, really. As you know, with all the new digital technology and algorithms today, clinical investigations related to setting the maximum output of hearing aids just don't seem to rise to the top of the heap for researchers or the people funding the research. There are a couple studies, however, worth mentioning.

For example, Carol Mackersie took a look at clinical protocols used to set the hearing aid maximum output for adult hearing aid users.[15] In that retrospective study, patients were fitted according to the clinic's standard protocol, which was a method that predicted the hearing aid output based on the patient's hearing loss. Importantly, this method also included an alteration of the prescribed output values based on verification results (e.g., probe-microphone measures and loudness judgments for everyday sounds).

After the initial fitting session, the patients were seen again for a minimum of two follow-up visits prior to the final evaluation. The paper reports that adjustments of gain and/or output were made for 15 of the 28 subjects (54%) during those follow-up appointments based on comments regarding their real-world experiences. The good news was that at the final outcome assessment, only one participant had average RESR values that exceeded his ear canal SPL LDL by more than 5 dB, and no one reported discomfort to the high-intensity pure-tone sweep.

The message of this research seems to be that you need to do a lot of tweaking to get the output right. We, of course, wonder what the outcome would have been if the maximum output had been simply set to correspond to the patient's LDL in the first place. Just maybe some of that post-fitting tweaking could have been avoided.

15 Anything else that might convince me to do more loudness testing in my office?

There was another study from some Syracuse University researchers that caught our eye.[16] They compared two different protocols for hearing aid fitting: one that included LDL testing along with aided loudness measures, and another that didn't.

Those subjects fitted with hearing aids using the protocol that included loudness measures returned for fewer adjustments within the first 45 days. We also would like to point out (mostly because we like it when data agree with what we believe should be right) that after 3 months of hearing aid use the group that did not have the loudness measures included in their fitting protocol had reduced satisfaction scores compared with the group that had the testing!

16 I'm almost convinced, but let's move on. The topic of acclimatization for loudness and hearing aid use has always interested me. Anything new on that front?

Actually, there is. Here are some recent data we found quite interesting. Remember that big NIDCD/VA study that we talked about earlier? Well, in a follow-up study, 190 subjects from the original study were re-evaluated 6 years later.[17] As you would expect, RESR measures remained unchanged from the earlier findings (for those 81 using their original devices). That is, the output of the hearing aids didn't change over time.

The interesting finding is what *did* change. The LDLs obtained in this follow-up study were significantly *lower* than those measured at two different times in the original study (pre-fitting and at the conclusion). The change was not only statistically significant, but big enough to maybe make a *clinical* difference. The average reduction in LDL across test frequencies (500-4000 Hz) was 4.6 dB compared with the initial LDLs of the original study, and 6.4 dB compared with the final LDLs of the original study.

17 Isn't it strange that hearing aid use *reduces* LDLs?

Those findings have us puzzled too. It's tempting to think they changed the LDL test protocol or instructions, but the authors say no. The subjects were 6 years older, but we know that LDLs do not change as a function of age.[12]

But before you put the results of that study into your permanent memory, we have another one for you that tells a somewhat different story. It's about LDLs and wearing only one hearing aid. Kevin Munro and June Trotter compared pre-fitting LDLs to the patient's LDLs after several years of *unilateral* hearing aid use.[18] Although hearing thresholds were unchanged, the average LDLs (2000-4000 Hz) increased by 14.5 dB in the fitted ear, and 7 dB in the unaided ear. The authors acknowledge that there might have been minor alterations in the wording of the instructions for the two test sessions, but even so this wouldn't account for the 7.5-dB difference between ears. So, in this case, we see LDLs *increasing* after hearing aid use.

18 Could this be some type of adaptive plasticity for loudness?

Hard to say. This same group has conducted two other studies with people fitted unilaterally (different subjects).[19,20] In one study, they found that the patient's acoustic reflex threshold (in addition to loudness discomfort) increased in the aided ear (compared with the unaided ear), and in the other study, they observed differences in the ABR between ears—an increase in the mean wave V to SN10 peak-to-peak amplitude in the fitted ear. Both studies had small samples, but stay tuned.

19 Interesting stuff. I'm almost out of questions. Any late-breaking loudness data you can tell me about?

Mueller: Ruth, how about that study you've been working on the past 2 years. Something you can talk about?

Bentler: Sure, we're writing it up right now. What Gus is referring to is a long-term consortium study that we have been involved with at the University of Iowa. The other investigators are at the University of Giessen (Germany) and the National Acoustic Laboratories (Australia).

One thing we examined was the relationship between measures of discomfort obtained in laboratory (or clinical) settings and self-reported discomfort from real-world aided experiences. This relates back to our earlier discussion on evidence-based practice, and the *JAAA* article Gus and I wrote.[13]

In this consortium study, we were particularly interested in using ecologically valid stimuli (real-world sounds like traffic, cutlery, etc.), but also included some ratings for narrow and wide bands of noise. We're still going through the data, but a couple of our preliminary findings are interesting:

First, *many* subjects recruited for this study (in all three parts of the world) reported experiencing loudness discomfort when wearing their current hearing aids, despite the average output being lower than a widely used prescription for maximum output.[21] Also, we found that measurement of aided "loudness discomfort" using a 1500-Hz narrow-band noise stimulus was the best predictor of self-reported real-world discomfort. We believe this finding gives further credence to the use of frequency-specific measures of loudness discomfort, either in the fitting stage (to get it right) or in the verification stage (so you can adjust it to get it right)!

20 So, we're at the very end, and the two of you are still trying to convince me that loudness measures are worth my time.

Well, when we wrote our first Page Ten article on this topic 14 years ago, we closed by saying: *"Maximum output problems don't go away. Either you take care of them when you fit the hearing aids, or you take care of them with repeat visits—or returns for credit."* We haven't changed our minds.

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P A G E

TEN

We'll start the new year off with a question: Was there really anything that happened in 1998 that was more exciting than *Page 10?* I know, early in the year we had the introduction of those magic blue pills, and you probably had to put down the May issue for a few minutes to watch the last episode of *Seinfield*. And, of course, you might have heard of the "intern" incident.

But admit it, those events pale in comparison to our journey from auditory neuropathy to speech audiometry to hyperacusis to digital hearing aids to educational audiology.

While the rest of the world had Mark, Sammy, and Cal, we had Brad, Carl, Catherine, Cheryl, Jay, Linda, Marshall, Mike, Patti, and Ruth. Quite a team, on and off the field—and I want to extend my personal thanks to our guest authors for providing us with a great selection of excellent articles.

As you may have noticed, some of our '98 authors were making a Page 10 repeat performance, and we're going to try that again in '99.

We're going to start off our sixth year of Page 10 with an article about hearing aid verification. For most people who fit hearing aids, verification refers to the aided testing that is conducted on the day of the fitting—the results of which determine if changes in the fitting need to be made before the patient is allowed to leave with the instruments. Usually, but not always, verification is designed to *verify* that a given fitting philosophy has been met.

Fitting philosophies come in various shapes and sizes, but one popular belief is that the hearing aids should provide loudness normalization. In other words, sounds that are soft, average, or loud to a normal-hearing person should be soft, average, or loud, respectively, after the fitting of hearing aids, to a person with a hearing loss. Often this fitting philosophy relates to the use of prescriptive algorithms such as the IHAFF, FIG6 or DSL[i/o] and wide dynamic range compression hearing aids.

Probe-mic measurements provide a reliable verification method. However, they do not directly assess if loudness normalization has been accomplished. Moreover, our own *Hearing Journal* survey shows that most of you do not use these measures routinely. In this month's Page Ten article, we review some alternative verification techniques for loudness normalization that can be easily incorporated into your hearing aid fitting protocol.

Stay tuned to *Page Ten* for the rest of '99, as you'll hear about some other fitting philosophies and verification strategies.

Gus Mueller, Editor
Page Ten

Just make it audible, comfortable, and loud, but okay

By H. Gustav Mueller

1 Good to see you again—we always seem to meet up in January. It sounds as if this year's topic is loudness. I assume your title refers to some type of aided testing at the time of the hearing aid fitting. Is that right?

Exactly. If your hearing aid fitting goal is to have your patient hear speech and environmental sounds at the same, or nearly the same, loudness level at which normal-hearing people hear these sounds, then I believe you should verify that this is happening before the patient leaves your office.

2 I know I get to ask 20 questions, but if you're going to tell me that I have to buy a new computer, 10 sets of cables, and a whole new batch of software to do this, we might as well stop now.

It might be efficient to automate some of this testing, but the techniques that I have in mind can easily be conducted using the equipment you already have sitting in your clinic.

3 Good. Now you've got my attention. Back in the old days I used to validate my fittings using PB words, and I really have been looking for a new way to validate...

Whoa—hold on a minute. Sorry to interrupt, but you're using the word *validate*. We're talking about ways to *verify* your hearing aid fitting.

4 Verify, schmerify, validate, schmalidate. They're all the same aren't they?

Not to my way of thinking. Let's see if an example will clarify things. If I believe that the FIG6 prescriptive method is a good way to program hearing aids for a given patient, then a reasonable *verification* procedure would be to measure REIGs for three different input intensities. If I attain the desired gain values across frequencies for this range of inputs, the fitting would be *verified.*

Validation, on the other hand, would not occur until the patient reported to me, probably through the use of one or more self-assessment scales, that the hearing aids were providing benefit, and that he or she was satisfied. I think of validation as more or less the same as outcome measures.

5 I think I get it, but how about one more example?

This one might be more to your liking. It's Sunday afternoon, and you've decided to make a batch of chocolate chip cookies just like your mom used to make. You use your mom's recipe—a prescriptive method, right?—and carefully measure the butter, flour, sugar, salt, soda, and vanilla. You make sure that the oven is at 375 degrees and that the dough bakes for precisely 10 minutes (adding altitude corrections, of course). This is all a *verification* of your mom's recipe. The *validation* of the recipe occurs when you take the first bite.

6 Okay, I'll take your word for it that we're doing verification not validation. Does it matter which prescriptive method I use to begin with?

Different prescriptive methods have been designed with different objectives in mind, so yes, it does matter. Let's say that your loudness-verification procedure includes aided ratings for soft speech. If you were using a prescriptive method that was

designed only to place average speech at the patient's MCL, it's possible that soft speech would not be audible. The patient then might fail your verification procedure.

Your prescriptive method also should prevent surprises during the verification process. Take the DSL4.1 fitting software. You know that the patient's LDL or ULC will affect the gain that the algorithm selects for average speech. It could be that your patient's uncomfortable levels are 10 dB below the predicted ULC values based on his pure-tone thresholds, which, by the way happens quite often. If you use these predicted values rather than the patient's true ULCs, the hearing aid will be programmed with about 5 dB more gain than might be necessary for average speech. Will this affect your verification ratings? Probably. This is why shortcuts are risky. In general, your verification procedures should relate back to your prescriptive methods, which in turn should relate back to your fitting philosophy.

7 So you think I have a fitting philosophy? I do know that I like the results I've been getting with WDRC instruments, although a few years back I was fitting mostly linear. How does circuit type relate to my aided loudness verification?

There's a pretty strong relationship, especially if your verification is based on loudness normalization—that is, sounds that are soft, average, or loud to a normal-hearing person should be soft, average, or loud, respectively, after the hearing aid fitting, to a person with a hearing loss.

Let's take a patient with a flat 50-dB cochlear hearing loss. Many prescriptive methods would suggest that you give this person 20 dB to 25 dB of gain for average speech, which for a linear processing hearing aid would be the gain for other input levels as well. If you're trying to normalize loudness, you might be happier with the aided loudness judgments obtained with WDRC processing, as the resulting input-dependent changes in gain will more closely resemble the differences between your patient's loudness contour and the loudness contour of people with normal hearing.

8 You're talking about comparing my patient's loudness growth to that of people with normal hearing. Isn't that what the IHAFF protocol is all about?

Yes, I think it's safe to say that the IHAFF protocol is a "loudness normalization" procedure. And relating back to our discussion of WDRC, as you probably know, when you use the Contour Test in conjunction with the VIOLA, you'll nearly always select a low compression kneepoint, i.e., WDRC, to simulate an I/O function that will be the best match for the three different targets for a given frequency. If the actual real-ear I/O function were similar to that which was simulated, then you would predict that loudness has been normalized.

9 I've heard of loudness "equalization." Is that the same as loudness "normalization"?

Not in theory, and probably not in practice, especially if we consider narrow rather than broad bandwidths. I've already mentioned what normalization is all about. Equalization refers to the fitting goal of equal loudness across frequencies: Speech is amplified to approximate the MCL contour. FIG6 is a normalization approach, whereas the new NAL-NL-1 is based on equalization. DSL4.1 is described as an "acoustic mapping algorithm," although the manual says it can be used for either equalization or normalization. Does that help?

10 Sorry I asked. It does sound as if I need to have a basic understanding of how normal-hearing people rate loudness if I'm going to use these procedures prior to my hearing aid verification.

Absolutely. Your definition of "normal" could have a significant impact on the gain and compression characteristics that you select. There are several research studies that should give you a good idea of how normal-hearing people judge the loudness of both speech and narrow-band signals. The psychophysical procedures and the stimuli that are used *do matter*, so you might see different results from different studies.

The seven-item loudness chart from the Contour Test is used in many clinics, and Robyn Cox and her colleagues published normative data for the Contour Test in *Ear and Hearing* back in 1997.

11 I know. I read that article to prepare for this question-and-answer thing we're doing. So I could use Robyn's norms as "targets" for my aided loudness verification, right?

That certainly is tempting, but it might not be that simple. First, this would assume that your fitting goal is based on loudness normalization—you seem okay with that. Second, to use the Contour Test norms, you would need to use the same descriptive anchors, instructions, procedures, and speech stimuli as used in the original research. You could probably do this without too much trouble. Third, and this is the area I'm not too sure about, is whether you can take loudness data obtained with insert earphones and make a direct leap to soundfield, which is what you would like to do. Your soundfield loudspeakers probably have a different frequency response from that of insert earphones, and soundfield listening really is a different type of "listening experience."

12 So what norms am I suppose to use for my aided loudness scaling?

Let's step back a minute. You use the term "scaling," which to me suggests obtaining loudness judgments in fairly small steps for a wide range of inputs—procedures like the Contour Test or the LGOB. While this might be useful for hearing aid selection—and even that is debatable—I think comprehensive aided loudness scaling is a bit of overkill for clinical practice. By "comprehensive" I mean using a structured scaling procedure for both narrowband signals and speech.

I don't think the results of this testing will provide you with that much additional assistance for making fine-tuning adjustments to the fitting. We're not even sure if loudness normalization is the best way to fit hearing aids. And, of course, you also need to consider the efficiency of the testing, as there is a significant time investment.

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13 What do you recommend?

I favor an abbreviated scaling procedure using speech only. I would suggest using a chart that displays numbered categories of loudness, like the one used for the Contour Test, and then simply presenting continuous-discourse speech to the patient at three different levels: 45 dB SPL, 65 dB SPL, and 85 dB SPL, which represent soft, average, and loud speech, respectively. Notice I said *SPL*, not *HL*, so you'll need to take out your sound level meter to determine the corresponding HL setting.

14 Are you just making up these numbers?

No, this is part of the verification procedure that was recommended by the IHAFF members 5 years ago.

15 Did they make up the numbers?

Knowing that group, I'm sure all decisions were based on hard science. Actually, there's not a lot of research into how normal-hearing people rate loudness for meaningful speech presented in the soundfield.

I did notice, however, that the University of Western Ontario presented a paper at last year's AAA meeting which showed soundfield judgments for speech that were very similar to the levels I mentioned. Catherine Palmer from the University of Pittsburgh presented soundfield normative data at the 1997 NIH Hearing Aid Conference that also was very similar, so I don't think we're too far off when we use 45, 65 and 85 dB SPL.

Calibrating soundfield speech signals can be a bit tricky, so I'd recommend that you try out the procedure with a few people with normal hearing before you start using it with your patients.

I recall your telling me that you have a satellite office where you don't have a soundfield system. What you could do in that setting is obtain a CD with a calibration signal on one track and continuous discourse recorded on three other tracks: Track #1 would be the calibration signal, Track #2 would be for average speech, Track #3 would be recorded 20 dB softer than Track #2, and Track #4 would be recorded 20 dB louder than Track #2. You could then use a portable CD player with appropriate speakers–a good "boom box" probably would work okay–and once you have calibrated Track #2 to 65 dB SPL, you should have 45 dB SPL and 85 dB SPL on the other two tracks. Again, check this out with some normal-hearing people after your calibration.

16 Since I'm doing a verification procedure, what ratings from the patient would be considered acceptable?

Consider that 45 dB SPL, 65 dB SPL, and 85 dB SPL are median values—speech scaling with normal-hearing individuals usually shows a range of 20 dB or more for these categories. Accordingly, there is a range of responses that would be considered acceptable.

Let's say you're using the seven loudness categories from the Contour Test, and you present the 45-dB-SPL speech signal to the patient. Your target rating would be 2, but 1 or 3 also would be okay. I'd start thinking about changing the gain of the instrument if the patient didn't hear the speech, or gave me a 4 rating. The same range would apply to average speech, where your target rating is 4; a 3 or 5 rating would be okay.

The range for the loud speech rating is a little different when you use the Contour Test—your target is 6 and a 5 rating is okay. However, one category above the target is "uncomfortable," and you probably don't want to send the patient out the door if he's giving you this rating for loud speech.

The loudness chart used by the University of Western Ontario group has eight rather than seven categories, which allows for three levels of "loud" before the uncomfortable rating is reached. Is this better? I don't know.

17 This all sounds pretty good, but it seems to me that a patient could rate soft speech "soft," yet be responding to only the low-frequency components of speech. How do you deal with that?

I can answer that in three words and a hyphen: probe-mic measurements. If you're using a Seewaldesque SPL-O-Gram approach, as most people are today, you should be able to tell from the REAR generated by your low-level inputs (e.g., 50 dB SPL) whether or not you have made speech audible across the entire frequency range.

But that was a good question. It's obvious that you understand that if you use only speech signals for your loudness verification, you probably need some supplemental verification procedures. If you don't have probe-mic equipment, you could conduct aided soundfield testing. If your thresholds are coming in at 20 dB HL to 25 dB HL across all speech frequencies, then you know that it's not just the low-frequency components of soft speech that the patient is hearing.

18 Here's another problem, which just happened to me last week. When I presented the 85-dB-SPL speech signal, the patient said it was uncomfortably loud. How do I know which frequency range was causing the problem?

You don't. In a case like this I would present narrow-band signals at a high level, say 85 dB SPL, for key frequencies such as 500, 1000, 1500, 2000, and 3000 Hz, and have the patient rate the loudness. If a single region is causing the problem, you'll probably obtain an uncomfortable rating for that frequency.

It is possible, of course, due to loudness summation, that no single band is uncomfortable, yet speech is. In this case, you would have to reduce the output for a broader region. I'm assuming you're fitting multichannel instruments, since with single-channel hearing aids you're often forced to make a broad-band adjustment even when you know the frequency range you want to tackle. It's probably obvious, but in these cases we're talking about adjustments to compression, not gain. Gain adjustments are reserved for corrections when the soft speech loudness judgment is inappropriate.

19 Should I be doing these aided measurements for each ear separately?

Yes, that's definitely the best approach. That will provide you with ear-specific information in case tweaking is necessary. After the monaural measurements, I would then do the three-level speech scaling for binaural, since individual binaural summation is difficult to predict. If

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you're really in a time crunch, I guess you could simply do only binaural, but if the results aren't satisfactory, you really don't know if the problem is the right ear, the left ear, or some combined effect.

20 Before we finish, let's go back to our discussion of 15 questions ago. Doesn't all this loudness stuff have to be validated?

Funny you should ask—that was the topic of the Page Ten article that Catherine Palmer and I wrote a year ago–in fact, we were answering your questions! Remember the Profile of Aided Loudness, our new PAL for '98? Well, all the research collecting normative data is completed and the PAL is now ready to roll.

The final version has a total of 12 items, four each for soft, average, and loud sounds. In addition to rating their aided loudness perceptions of the sounds using the loudness categories of the Contour Test, patients also rate whether they believe their loudness perception is appropriate for that particular sound.

So far the results have been encouraging. People fitted with WDRC hearing aids who passed our clinical verification of probe-mic testing and loudness scaling also showed "normalized" loudness for the PAL–and most are pleased with the loudness that the hearing aids are providing. So maybe if we locate a great recipe, follow the recipe correctly, that first bite of the cookie is pretty good!

Along with being Editor of Page Ten, **H. Gustav Mueller**, PhD is Contributing Editor of *The Hearing Journal*. He is also Adjunct Professor at Vanderbilt University and Senior Audiology Consultant to Siemens Hearing Instruments.