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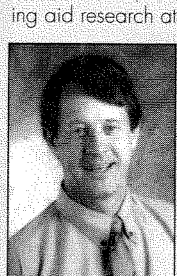
If you believe the television commercials, "Fosters is Australian for beer." A rather debatable statement if you regularly sample the barley beverages from down under. What's not debatable is that "the NAL is Australian for good hearing aid research." This definition is known from Beijing to Bittberger to Bud.

The crew from the National Acoustic Laboratories are probably best known for their extensive work in developing mathematical models for prescribing patient-specific hearing aid parameters. A few of you might recall the first prescriptive method from the NAL, introduced back in the mid-70s. Most of you have used the revised version of this original method, the NAL-R, which came along in the mid-80s, and the NAL-RP, which followed a few years later. Hearing aids change, and so do the accompanying theoretical algorithms for their selection and adjustment. We're pleased to present you with the first U.S. publication about the latest prescriptive method from the NAL, the NAL-NL1—a procedure for fitting non-linear hearing aids.

Our Page Ten author this month is **Harvey Dillon**, PhD, principal research scientist, hearing aid research at the National Acoustic Laboratories, Chatswood, Australia. Dr. Dillon is internationally known for his research associated with hearing aid circuits (you know his compression articles), fitting procedures, and outcome measures (e.g., the COSI—who would guess that someone with a degree in electrical engineering would come up with such a warm and fuzzy acronym). Keep your eye out for Harvey's forthcoming book on hearing aids (from Boomerang Press, no less). Although Harvey is the lead person for the new NAL-NL1 procedure, he is quick to point out that its development was a team project. His team members included Richard Katsch, Teresa Ching, Gitte Keidser, Scott Brewer, and a promising young audiologist named Denis Byrne.



You might be asking yourself, do we need another fitting method for non-linear hearing aids? As you read this excellent Page Ten article, you'll see that these researchers have taken the proven attributes of the NAL-RP procedure and added features to the algorithm to accommodate today's hearing aids. There are some similarities among this approach and the other commonly used non-linear methods, but there also are some distinct differences. Will the NAL-NL1 emerge as *the* method to fit non-linear hearing aids? No one knows for sure, but we do know that "the NAL is Australian for good hearing aid research."

Gus Mueller, Editor
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NAL-NL1: A new procedure for fitting non-linear hearing aids

By Harvey Dillon

1 Let's start with a simple question: What does "NAL-NL1" stand for?

Well, you probably already know that NAL stands for the National Acoustic Laboratories. The letters NL stand for non-linear, and the number 1 is because it is the first version we have released.

2 We already have FIG6, IHAFF, Scaladapt, DSL [i/o], and several other methods for prescribing non-linear hearing aids. Why do we need another one?

Existing published procedures for non-linear hearing aids are based largely on the principle of normalizing loudness.[1] That is, at each frequency, they aim for a hearing-impaired person to hear narrow-band test sounds at the same loudness that would be perceived by a normal-hearing person. We don't think that this is the best rationale for prescribing hearing aid responses.

3 Why not?

The loudness normalization rationale does not take into account the low-frequency emphasis of speech, the reduced ability of hearing-impaired people to extract information at frequencies where they have a lot of loss, nor the relative importance of different frequency regions to the intelligibility of speech. Empirically, making all frequencies have their normal loudness contradicts decades of research into what is needed for maximum intelligibility. We think it's possible to do better, and if you ask us the right questions, we'll tell you how.

4 I'll do my best. Maybe you could tell me what principle the NAL-NL1 method *is* based on?

The aim of NAL-NL1 is to provide the gain-frequency response that maximizes speech intelligibility while keeping overall loudness at a level no greater than that perceived by a normal-hearing person listening to the same sound. The gain-frequency response that achieves this varies with input level, so that's why it is a procedure for non-linear hearing aids. The principle includes the idea of normalizing loudness, but we apply this to the total or overall loudness, not the loudness at each frequency.

5 In practice, do NAL-NL1 prescriptions vary from those of the other non-linear procedures that I mentioned?

Depending on the audiogram, NAL-NL1 can give markedly different prescriptions from the other procedures you mentioned earlier. (Indeed, some of them differ markedly from each other.) It is common for NAL-NL1 to prescribe more low cut below 1000 Hz than the other procedures. This reflects the low-frequency emphasis of speech that we mentioned earlier. NAL-NL1 usually prescribes less gain than the other procedures in the region of greatest hearing loss. This arises from our research into the reduced ability of hearing-impaired people to extract information from speech even when it is audible.[2] For steeply sloping losses, NAL-NL1 will therefore prescribe less variation of gain across frequency than the other procedures do. It also tends to prescribe lower compression ratios than the other procedures.

6 Is there any evidence that NAL-NL1 prescriptions are better than those prescribed by the other procedures?

There is some indirect evidence, and some very preliminary direct evidence. We keep reading that NAL-R (or the more complete version for all degrees of loss, NAL-RP) is not suitable for non-linear hearing aids. Actually we believe that NAL-RP, and the research behind it, can tell us a lot about how to prescribe non-linear hearing aids.[1]

The research behind NAL-RP, and the various validations of that formula have mostly been carried out at a comfortable listening level. An optimal non-linear formula should therefore prescribe a response for mid-level inputs very similar to that prescribed by the NAL-RP formula. The indirect support for NAL-NL1 is that this new procedure does indeed give similar mid-level prescriptions to NAL-RP. The other procedures, by and large, do not.

7 You said you also had some direct evidence. What are these findings showing?

Direct evidence is only just emerging. We are comparing fittings done with NAL-NL1 to fittings done with the IHAFF method. So far, 17 subjects have reached the stage where they have to decide which they like. In quiet, 10 have chosen NAL-NL1, 5 had no preference, and 2 preferred IHAFF. In noise, 12 chose NAL-NL1 and 5 had no preference.

The NAL-NL1 response is also leading to significantly higher speech-recognition scores in noise for subjects with flat losses. This is very preliminary information, which so far is based only on laboratory preferences at a comfortable listening level. Also, one can never say that a procedure is correct, just that it is better on some criterion than something else.

8 We have talked about the basic principles and the end results. Without going into too many details, how did you get from a set of principles to a working method?

Let me briefly describe our procedure to you:

- First we adopted a method of calculating loudness that allowed us to calculate the total loudness, for a hearing-impaired person, of a speech signal of any level when amplified with any insertion gain curve that we specified.[3]
- Second, we modified the well-known Speech Intelligibility Index method (also known as the Articulation Index) so that we could calculate speech intelligibility for hearing-impaired people.[2] These modifications allow for the reduced analyzing ability that people have when hearing thresholds exceed about 40 dB HL. Corrections of this type have been called Hearing Loss Desensitization.[4,5]
- Third, we chose 52 audiograms that covered a wide range of shapes and severity of losses.
- Finally, we got the fastest computer we could afford and linked the loudness and intelligibility programs to what is known as a constrained numerical optimizer.

9 I was following you until you got to that "constrained numerical thing." Can you tell me how that works?

It works like this. We input the first audiogram, chose an overall speech level of 40 dB SPL, and let the computer loose. Essentially, it semi-randomly altered the gain at each 1/3-octave frequency and computed the total loudness and Speech Intelligibility Index that resulted. Over the next hour or so, it kept altering the gain characteristic until it found the characteristic that maximized the calculated speech intelligibility without exceeding the normal loudness for 40 dB SPL speech. We then repeated this for five more speech levels from 50 dB SPL to 90 dB SPL. Then we repeated all of this for the other 51 audiograms.

10 It sounds as if that might have solved the problem for those particular audiograms, but it doesn't sound too practical. What next?

The result of this long process was a set of 312 gain curves that we believed were appropriate for these audiograms and input levels. But, obviously, the procedure was far from practical for clinical purposes. So that the calculation could be done for any new audiogram and speech level in a few seconds, we expressed these insertion gain results as a formula. For the formula to accurately match the gain at any frequency, the formula used the values of:

- Hearing threshold at that frequency.
- Three-frequency average hearing threshold (500 Hz, 1000 Hz, and 2000 Hz).
- Slope of the audiogram from 500 Hz to 2000 Hz.
- Overall level of the speech input signal.

The result therefore comes down to a very long formula that prescribes insertion gain at each frequency, for each speech level. Interestingly, the gain at any frequency ended up depending on the hearing loss at several frequencies, rather than only the frequency in question, just as with its NAL-RP predecessor.

11 That sounds complicated. Is the NAL-NL1 method complicated to use?

Not really. The underlying formula is certainly complex, so we have built it into software in which the formula is buried far from view. The software is easy to use and it prescribes compression parameters in ways that clinicians are familiar with.

Despite the simplicity of the software, prescribing and adjusting non-linear hearing aids (with any prescription method) is definitely more complex than prescribing and adjusting linear hearing aids using NAL-RP or any other linear formula. Non-linear hearing aids are inherently more complex than linear aids. In non-linear hearing aids, gain is simultaneously affected by at least two characteristics of the signal (intensity and frequency) and potentially by two others (bandwidth and signal dynamics). To know what a hearing aid will do one must know how each of these four signal characteristics interact with the hearing aid's characteristics (compression ratio, compression threshold, gain in the linear region, attack and release times, number of compression channels, and channel bandwidths).

For linear hearing aids, most of these hearing aid characteristics do not exist and, of the signal characteristics, only frequency affects the gain. Because of this inherent complexity in non-linear hearing aids, we have tried to make the NAL-NL1 software as simple to use as possible.

12 How do clinicians actually use the NAL non-linear prescription software?

The clinician's software is already available. We anticipate that many manufacturers will incorporate a special manufacturer's version of this software in their own fitting software, but this will take some time. The clinician's software has four screens:

- Client data entry—containing non-essential administrative data about the patient.
- Audiological input—which allows the audiogram and, optionally, some other information to be entered.
- Selection screen—which enables the user to enter very basic information about the hearing aid.
- Target screen—which displays the prescription targets.

To use the NAL non-linear software, the clinician has to enter:

- The audiogram (bone conduction is

optional).
- The number of channels of compression in the hearing aid.

13 Wait a minute! Sorry for interrupting, but I didn't hear you say that you have the clinician enter the patient's frequency-specific LDLs? I've heard that these values differ significantly from patient to patient. Aren't these values necessary for calculating target gain?

A couple of years ago I would have said that LDLs were needed to prescribe maximum output, or equivalently, the gain that is applied to high-level signals. Then we did an experiment.[6] This convincingly showed that if SSPL was prescribed on the basis of pure-tone thresholds, measuring an individual's LDL made almost no improvement to the accuracy with which the optimal SSPL for that person could be prescribed. One reason for this is that there is more to finding the best SSPL setting than knowing LDL; a second is that it is difficult to measure LDL reliably and accurately. So no, gain is prescribed solely from threshold, and with good reason.

14 Okay, I guess you've convinced me. Go on with your description of the software.

Once you have entered the information I mentioned earlier, the Results screen will show targets such as real-ear gain-frequency curves as a function of level and real-ear input-output curves as a function of frequency. A tabular output also gives various targets for each channel.

Most users will look at the graphs to get some conceptual understanding of the amplification provided, but then actually use the values in the table to program or manually adjust a hearing aid. Reading the compression ratios or low-level and high-level gains from the NAL-NL1 software and then typing them into a manufacturer's program is a bit antiquated, but not difficult. It will be a lot smoother when manufacturers have NAL-NL1 embedded in their own software.

If the user wants to obtain reasonably accurate prescriptions expressed as 2-cc coupler responses or ear-simulator responses, it is necessary to also type in:
- Date of birth of the patient (if the patient is under 5 years of age).
- Type of hearing aid (BTE, ITE, ITC or CIC).
- Vent size (if any).
- Sound bore type (if a BTE).

The software uses the date of birth to look up age-appropriate values of real-ear-to-coupler difference (RECD) and real-ear unaided gain (REUG). For even more accurate prescriptions of coupler gain, values of RECD and/or REUG measured for an individual patient can be typed in. We recommend going to this trouble only when ordering inflexible, non-adjustable hearing aids or when prescribing and adjusting hearing aids for infants.[7,8]

15 What sort of amplification targets does the NAL-NL1 method generate?

The software calculates targets in just about any form one might want. The graphs can be gain versus frequency, or output versus input. The gains can be insertion gain, real-ear aided gain, 2-cc gain, or ear-simulator gain. Output levels can be real-ear, ear-simulator, or 2-cc SPL. Test signals can be pure tones or broad-band speech-shaped noises. And, yes, the software does prescribe different targets for the two different types of signals. Most people have a favorite way of working, so whichever choices you make will appear every time you use the program, until you choose some other options.

16 Does NAL-NL1 prescribe cross-over frequencies, compression ratios, compression thresholds, low and high level gains, and compressor attack and release times?

Yes, yes, yes, yes, and no. We do not think there is yet sufficient evidence to be dogmatic about whether compressors should have fast or slow attack and release times. Our best guess is that hearing aids need a combination of fast and slow compression if they are to offer maximum benefit in all situations. We have a couple of research projects under way investigating what compressor attack and release times should be. Until we have some more definite information, we will not be saying what should be used. We believe that NAL-NL1 can be applied to either type of compressor, although the attack and release times used will have some effect on the loudness of speech.

In regard to the other parameters you mentioned:
- Compression ratios: The graphic display shows the input-output curve at any of the standard frequencies. This enables us to see whether the compression ratio should change as a function of level, as well as frequency. For most hearing aids, however, we need only a single compression ratio for each compression channel, and this information is printed in the results table.
- Compression threshold: The default assumption in the software is that all compression channels should just go into compression when the overall level of a speech signal is 52 dB SPL. The user can change this to any value between 0 and 100 dB SPL, or can change the compression threshold for individual channels.
- Cross-over frequencies: These are prescribed by NAL-NL1 on the basis of the shape of the audiogram. The software prescribes frequencies so that within each compression channel, the hearing loss varies as little as possible. If the frequencies prescribed are not achievable in the hearing aid you are prescribing for, you can change the cross-over frequencies in the prescription to ones that are achievable. This is worth doing, because the software takes the channel bandwidths into account when it calculates compression threshold. NAL-NL does not attempt to tell the user how many channels of compression there should be; the user tells NAL-NL1 how many channels it should prescribe for.
- Low- and high-level gains (for 50 dB SPL and 80 dB SPL, respectively): The low- and high-level gain values are just the consequence of all the other bits of the prescription. They are displayed for convenience because many non-linear hearing aids are adjusted in terms of these parameters.

17 You say that the default compression threshold is 52 dB SPL. That seems a bit higher than is popular today. How was this value derived?

We have conducted two experiments to examine the compression thresholds that people prefer when they wear hearing aids for extended periods in everyday environments.[9,10] Both reached the same conclusion: Compression thresholds above 60 dB SPL are preferred by more people than compression thresholds below 50 dB SPL. That is why we have gone for something a bit higher than many people are saying is good.

I don't think there is any other direct evidence on what compression threshold

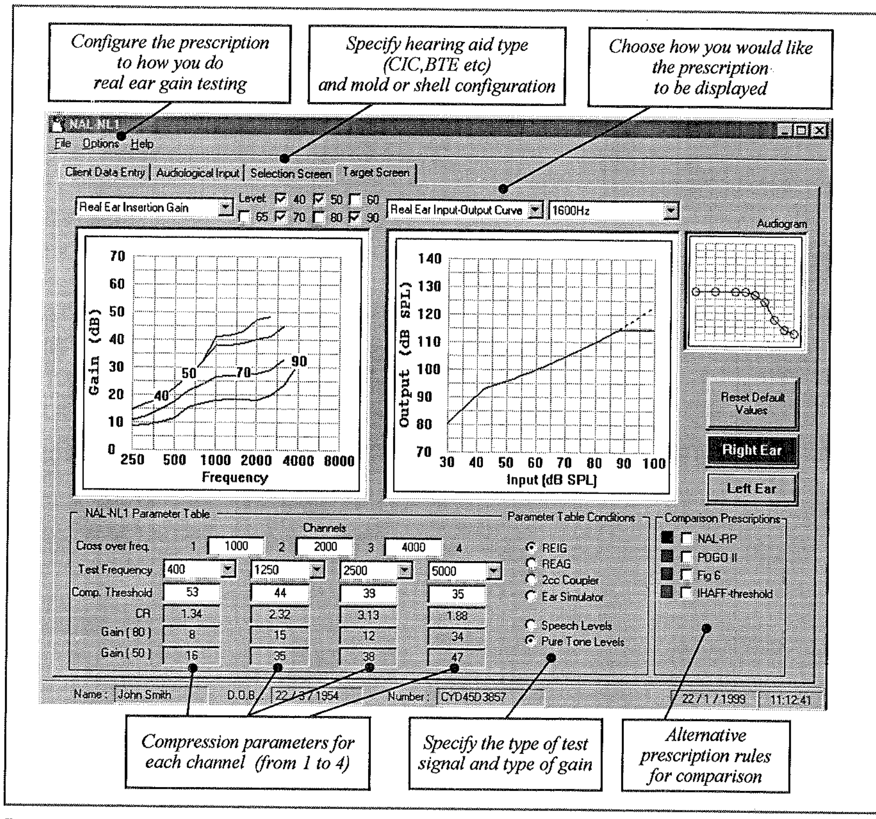

Figure 1. *The Results screen from the NAL-NL1 fitting software.*

people prefer. You should note, however, that if *speech* at 52 dB SPL is just into compression, the *pure-tone* compression thresholds in the higher frequency channels of a multi-channel hearing aid will need to have considerably lower thresholds. This is just what NAL-NL1 prescribes.

18 Is there anything more you would like to say about the clinician's software?

Perhaps a picture would help. Figure 1 shows the target screen. The two graphic widows can be selected to display any of the nine types of target curves. One useful combination would be to have a real-ear I-O curve in one window and a real-ear gain curve in the other. Some people will like the SPL-O-gram, which displays threshold and speech information in the simulated ear canal, with the effect of limiting taken into account.

Notice that FIG6, IHAFF, POGO-II, and NAL-RP are listed down in the right-hand corner. We thought that clinicians might like to see how much difference the choice of selection procedure makes. If the box next to each of these procedures is checked, the prescription for that procedure is superimposed in a different color, over the NAL-NL1 prescription. We don't intend these as a substitute for other programs; it's more for curiosity value. We definitely don't recommend fitting at random and then justifying the fitting by finding the prescription formula that best matches what you have already done!

19 Most of the talk so far has been about gain. What about maximum output?

A prescription is included. It is based on the same principles and data as the NAL-SSPL prescription procedure.[11] Because non-linear hearing aids are mostly multi-channel devices, they sometimes allow SSPL to be adjusted independently at each frequency. The actual procedure in the software thus prescribes SSPL at each frequency rather than three-frequency average SSPL. The prescription also includes an adjustment based on the number of channels so that loudness summation effects across channels are taken into account.[7]

20 Where can we get more information about the NAL-NL1?

The most direct source of information is the instruction manual that comes with the clinician software. This describes each of the screens, the inputs, the outputs, and all of the options. Along with practical information on how to use the software, the manual gives some theoretical background on the procedure. We also have a series of articles under way, of which this is the first. These can be downloaded, as soon as available, from the NAL web site: http://www.hearing.com.au/research. These articles will cover:

- How to use the software with a few representative hearing aids.[12]
- The derivation of the NAL-NL1 procedure.[13]
- A comparison of the principles behind NAL-NL1 to that of other procedures, and a comparison of the results.[14]
- A discussion of the implications of allowing, or failing to allow, for hearing loss desensitization when prescribing hearing aids.[15]

HJ

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Note: For further discussion of the NAL-NL1, see article starting on page 32.

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