How loud is too loud? Using LDL measures for hearing aid fitting and verification

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Before we get seriously started, a little terminology:

- LDLs: Loudness discomfort levels; what many of you might call UCLs (although no one is too sure what the "C" stands for). TDs (thresholds of discomfort) are the same thing too.
- ULCs: Upper level of comfort; #6 of the 7-point Cox Contour Anchors. Important because you really want the output at or only slightly above the ULC, not at the LDL.
- MPO: The maximum power output of the hearing aid. Usually determined by the AGCo setting, but can be determined by the AGCi setting.
- OSPL90: The MPO of a hearing aid measured in a 2-cc coupler (what you often see in manufacturer's spec's)
- RESR: Real ear saturation response; the maximum output measured in the real ear using probe-mic equipment.

Before we get seriously started, a little terminology:

- RETSPL: Reference equivalent thresholds in SPL; values used to convert HL LDL to 2-cc coupler (so you can talk to your fitting software). Different for different earphone types.
- RECD: Real ear coupler difference; values used to convert from 2-cc coupler to earcanal SPL.
- REDD: Real ear dial difference. This is the addition of the RETSPL and the RECD; using this you can convert from HL LDL to earcanal SPL. This provides the output targets you se...
- AGCi: ... DRC, which ... t if kneep... enough.
- AGCo: ... ting—the most c... tput.

And don't forget . . .modern hearing aids have *multichannel* AGCo. This allows for increased headroom throughout the frequency range, as AGCo kneepoints can be closely matched to the patient's LDLs for different frequency regions.
Stay tuned to the Siemens Channel: More on this in Part II of this exciting topic!

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- REDD: Real ear dial difference. This is the addition of the RETSPL and the RECD; using this you can convert from HL LDL to earcanal SPL. This provides the output targets you see on the probe-mic fitting screen.
- AGCi: Input compression often referred to as WDRC, which can be used to control the maximum output if kneepoints are low enough and the ratios are big enough.
- AGCo: Output compression or compression limiting—the most common method to control the maximum output.

By The Numbers

100% Hearing aid "Best Practice" guidelines that state you should conduct frequency-specific pre-fitting LDLs

100% Hearing aid "Best Practice" guidelines that state you should conduct aided loudness measures during the fitting process.

58% Hearing aid users who said a "highly desirable" improvement in new hearing aids would be that new products would make loud sounds "less painful."

56% Hearing aid users who state they are "satisfied" with "comfort with loud sounds" when using their hearing aids.

By The Numbers

42% Audiologists/HISs who routinely conduct loudness verification measures at the time of the hearing aid fitting.

16% Audiologists/HISs who routinely conduct pre-fitting frequency-specific LDLs.

15% Individuals who own hearing aids, but never put them in their ear.

0% Audiologists/HISs who can consistently predict a patient's LDL based on the audiogram, or predict whether the hearing aid's output setting is correct.

What we know #1:

- "Getting the loudness right" is an important component for hearing aid benefit and satisfaction. If, for example the MPO exceeds the LDL, what we might expect:
  - The patient will turn down gain to make loud sounds "okay."
  - With gain turned down, they will have reduced audibility, and may conclude that hearing aids don't work.
  - They will stop using their hearing aids!
  - (if you don't give them a way to change the gain, they will stop using their hearing aids even sooner)

What we know #1:

- "Getting the loudness right" is an important component for hearing aid benefit and satisfaction. If, for example the MPO exceeds the LDL, what we might expect:
  - The patient will turn down gain to make loud sounds "okay."

An MPO that is too low isn't a good thing either, as it unnecessarily restricts the patient's dynamic range, reducing speech quality and possibly understanding. If these are both reduced, you have the same outcome: the patients will stop using their hearing aids.

What we know #2:

- A large percent of people using hearing aids are not satisfied with how the hearing aids handle loud sounds.
- Neither audiologists or HIS's are very interested in conducting LDL measures, or using these measures when fitting hearing aids (in case you're wondering, unaided speech LDLs are of little use, as you can't really use them for programming the hearing aids).

What we know #2:

- A large percent of people using hearing aids are not satisfied with how the hearing aids handle loud sounds.
- Neither audiologists or HIS's are very interested in conducting LDL measures, or using these me
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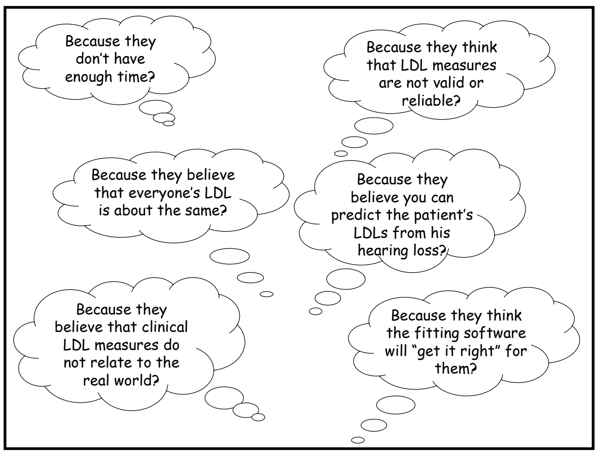
What we don't really *know*, but logic certainly would suggest it is true: If dispensers put more effort into getting the output "right", hearing aid users would be happier (and the world would be a better place!)



TIME is a factor?

- On average, you can conduct frequency-specific LDLs for two frequencies, for both ears, in 5-10 minutes.
- For a pair of hearing aids, that typically sell for several thousand dollars, this does not seem like an excessive amount of time, *assuming* that the findings assist in getting the fitting "right." (Consider that even at Wal-Mart, they conduct 20 minutes of testing just to fit a $150.00 pair of glasses!)

TIME is a factor?

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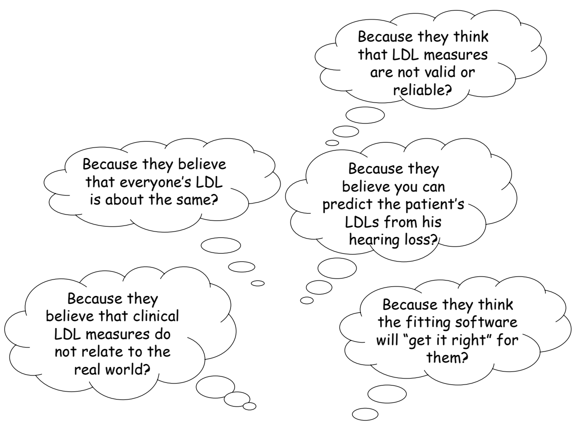
- For a p … ell for severa … eem like an exc … hat the finding … (Consi … nduct 20 minutes of testing just to fit a $150.00 pair of glasses!)

Clearly, TIME shouldn't be an issue.



Are LDL measures valid and reliable?

- Ricketts and Benter (1996): Average test-retest difference of 3-4 dB.
- Hawkins et al (1987): Differences of 3-4 dB over 4-day period.
- Palmer and Lindley (1998): Test-retest for the #7 rating of Cox Contour anchors was 2.6 dB. Test sessions were separated by two weeks.

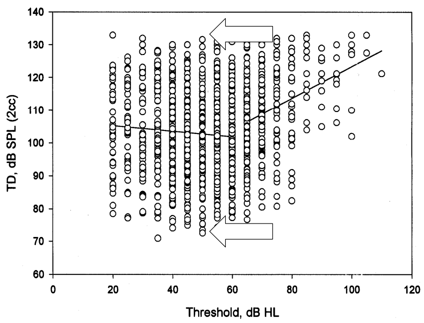
So, what do these studies tell us?

- In a controlled setting, test-retest for LDLs is about the same as for pure-tone threshold testing.
- Yes, we would expect that it could be slightly higher (~5 dB) in a busy clinic.
- And yes, for a typical clinic caseload, with a high mix of elderly patients, there will be some (~5%) who simply don’t understand the test protocol. Others (~5%) might need a little extra instruction during the testing. Using the right procedures is the key—more on that later!

Is everyone’s LDL about the same?

- It is certainly true, that LDLs do not vary as much as hearing loss—e.g., if your hearing gets worse by 50 dB, your LDL doesn’t go up by 50 dB. If your hearing loss drops by 60 dB from 500 to 3000 Hz, your LDLs won’t change by 60 dB.
- Elberling (1999) estimated that 70% of patients would be okay (within +/- 5 dB) with an output based on average loudness growth. For the remaining 30%, 13% would be “sound sensitive” and 17% would be “sound addicts.”
- The most extensive research on this topic is by Bentler and Cooley, so lets look at that . . .

LDLs (TDs) from >500 ears from individuals with confirmed cochlear hearing losses (no significant age or gender effects) (From Bentler and Cooley, 2001)



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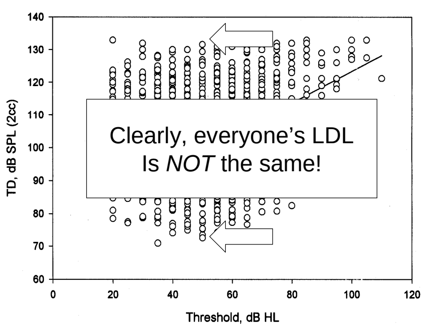
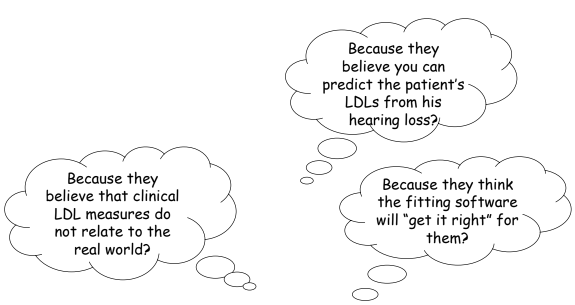
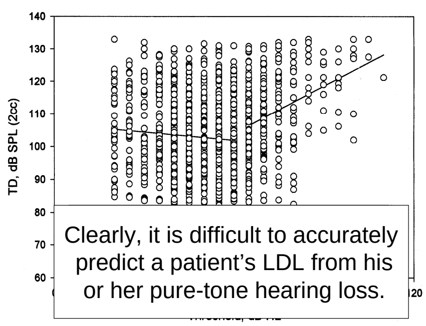




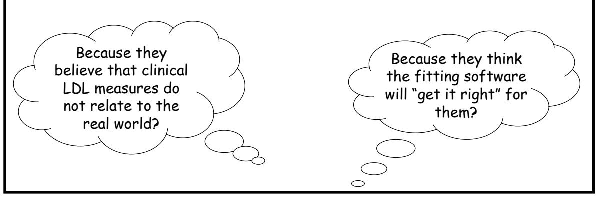
Predicting from the hearing loss:

- We know that there is a relationship between hearing loss and LDLs (e.g., it's unlikely someone with a 40 dB loss would have the same LDLs as someone with an 80 dB loss.
- Predicting would be nice if it worked—would save time. Obviously, it's the only solution for the people who don't have the cognitive function to provide loudness judgments. But how well *does* it work?
- The most common predictive method is that employed by the NAL-NL1. Their research showed that the "predicted" output was in the "acceptable" range for 63% of their subjects.
- Let's go back to the data of Bentler and Cooley.

How big is the "window of acceptance?"
(Match between MPO and the person's LDL)



Clearly, it is difficult to accurately predict a patient's LDL from his or her pure-tone hearing loss.



Clinical tests versus real world Reasons why they might not agree:

- Even if you use LDL measures to program the hearing aid, these are pure-tone signals—not what you hear in the real world.
- The clinic is a more sterile, controlled environment—usually no reverberation, distracting noises, etc.
- Various noises experienced in the real world may be annoying simply because of the spectral content, or emotional association.
- When the patient is in the clinic, they are “a patient,” and might give responses that they believe are appropriate for “a patient.” LDLs also are influenced by “mood.”

Speaking of sounds and associations . . .

When someone from your home team hits a home run, how loud does the cheer have to be, before it is “uncomfortable?”

How loud does *this* have to be to be “uncomfortable?”

Not too many studies comparing clinic findings to real world—but here’s one I like from Munro and Patel (1998):

- Twenty people (8 new users, 12 experienced) previously fit with monaural amplification were subjects.
- All fitted with similar (maybe identical) linear hearing aids
- Frequency specific LDLs measured; RESR predicted by adding RECD to OSPL90. But, no adjustment made to maximum output based on these measures.

Clinical measures of LDL related to real-world loudness discomfort (Munro and Patel, 1998)

- Although the output of the hearing aids was similar, because LDLs differed significantly the MPO exceeded the LDL of 12 subjects (by as much as 17 dB, and fell below the LDL of 8 subjects (by as much as 17 dB).
- Subjects completed a questionnaire related to their loudness perceptions in the real world.
- *Results:*
  - *83% of people whose output exceeded their LDL stated that sounds were too loud*
  - *Only 12% of people whose output fell below their LDL had this complaint. This was only true for long duration signals however—no significant relationship for short duration inputs.*

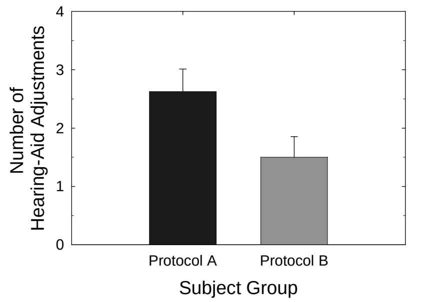
Another paper comparing clinic findings to real-world outcomes (Shi et al, 2007)

- Individuals were fitted according to two different protocols—the primary difference was that in Protocol B the output was adjusted according to their LDLs, in protocol A, it was not.
- Subjects used their hearing aids in the real world for three months, returned for follow-up visits, and completed outcome measures for benefit and satisfaction.

What they found . . .

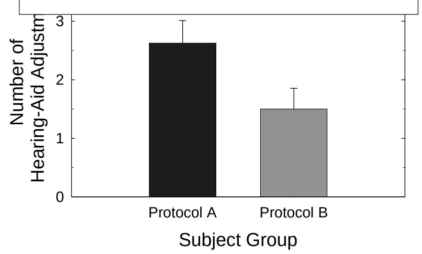
- Those who had received LDLs, and resulting hearing aid fitting adjustments, had the same APHAB benefit as those who did not.
- Those who had received LDLs had a significantly better score for the “negative features” subscale of the SADL. Other subscales were the same.
- AND . . .

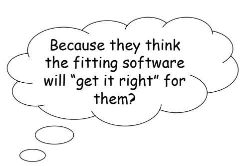
Average required adjustments/person based on users' comments



Average required adjustments/person based on users' comments

SO . . . It seems pretty clear that there *IS* a relationship between clinical measures and real world hearing aid use.

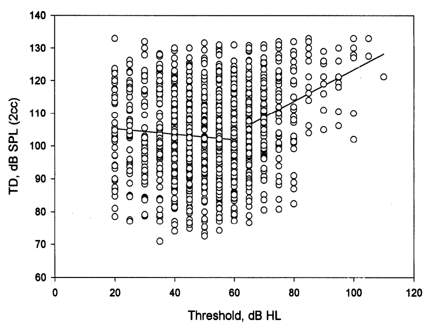




Okay—this will be fun!

- You have just been hired to write the software code for setting the AGCo kneepoint for your favorite company (big bucks!).
- Your company's top customer is ordering hearing aids for her mother (of course, she will take her business elsewhere if you mess up!)
- Her mother's hearing loss at 2000 Hz is 50 dB(HL)
- At what 2-cc coupler value will you set the AGCo kneepoint?

Does this help?



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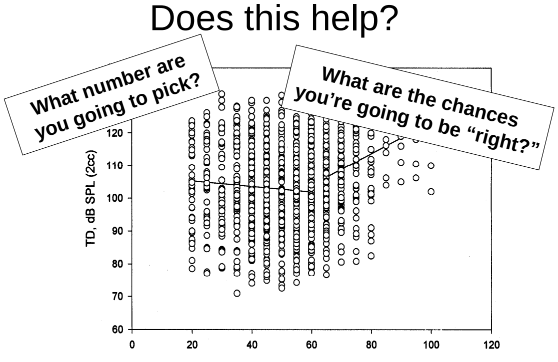
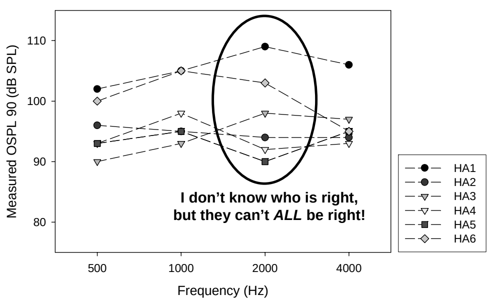
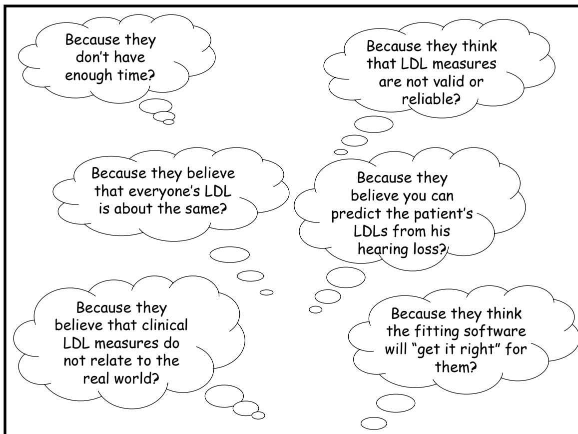


Do you really want your computer software to do your thinking for you?

- Mueller et al (2008) examined differences among the “manufacturer’s” maximum output settings for 6 popular hearing aids, all fitted to the same hearing loss.
- Maximum output levels were measured for when LDLs were not entered, and also when they were.
- Actual measured output values were compared to values shown on the fitting screen

Maximum output selected by fitting software for 50 dB loss when no LDLs were entered





Some questions you might (should) have:

- When do I do the testing?
- What stimuli do I use?
- What psychophysical procedure do I use?
- How do I define the point of "uncomfortable?"
- What instructions do I use?
- What frequencies should I test?

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When to do testing?

- In a busy clinic, it usually makes sense to do as much testing as possible when you have the patient "hooked up."
- It is reasonable then, to do LDL testing at the same time that routine pure-tone testing is conducted, once you see that the patient has a hearing loss that might be aidable.

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Stimuli to use?

- The purpose of obtaining the LDL is the have frequency-specific information for programming the hearing aid (this is why a speech LDL is of little use).
- Pulsed pure-tones work the best, although you'd probably obtain similar results using narrow-band noise.

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Test methods

- The method of presentation *will* influence the results. The recommended method is an ascending approach, using 5-dB steps.
- If the dynamic range is small, it's best to use 2-dB steps.
- Use the Cox Loudness Anchors (more on that in a moment), starting at a point that you predict will be around the patient's MCL.
- Once you reach the rating of #7, drop back down to the #4 region (MCL) and do another run.
- Two or three runs should give you a reliable #7 rating.

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Loudness Anchors

- If you don't have loudness anchors for the patient, you're probably better off to just predict from the hearing loss (or personality).
- You can't simply ask them to raise their hand when it's too loud, is no longer "tolerable", hurts, or whatever.
- The anchors go hand-in-hand with the instructions, but first, the anchors . . .

Loudness Chart from Cox Contour Test

- #7 Uncomfortably Loud
- #6 Loud, But Okay
- #5 Comfortable, But Slightly Loud
- #4 Comfortable
- #3 Comfortable, But Slightly Soft
- #2 Soft
- #1 Very Soft
- #0 Cannot Hear

This chart needs to be big, and handed to the patient. During the testing, they can simply call out the number of the corresponding loudness category.

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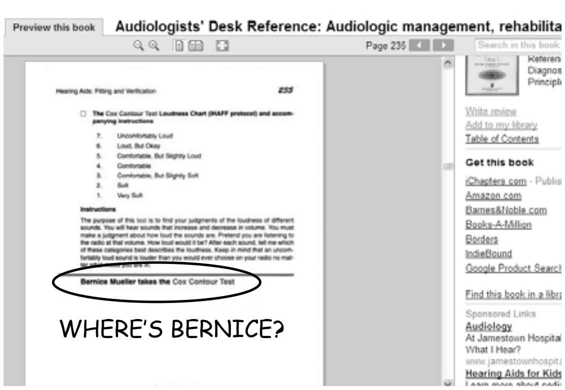

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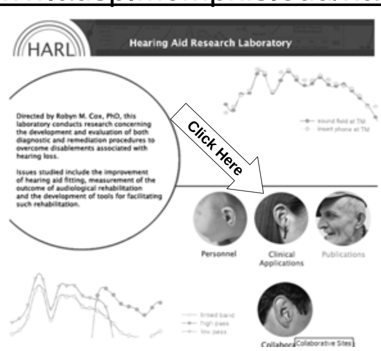
- What instructions do I use?
- What frequencies should I test?

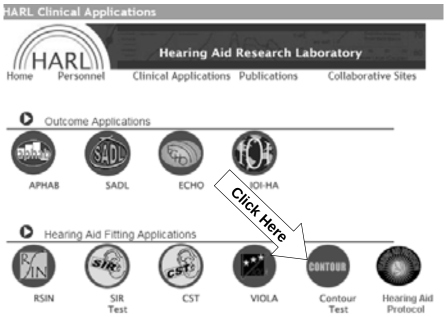
Instructions

- The instructions can change a person's LDL by 20 dB. If you don't get the instructions right, you might as well not do the test.
- Since we're using the Cox Anchors, it's only logical that we use the Cox instructions (this is what all supporting research is based on).

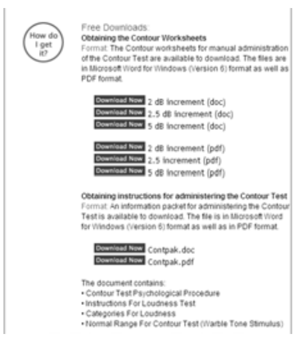
Go to Robyn Cox's lab at: www.ausp.memphis.edu/harl



There is a “treasure chest” of useful stuff here, but for now we’re going to go to the *Contour Test*



You can now download score sheets, the procedures, the loudness categories, instructions, and all sorts of fun things!



INSTRUCTIONS FOR LOUDNESS TEST

THE PURPOSE OF THIS TEST IS TO FIND YOUR JUDGMENTS OF THE LOUDNESS OF DIFFERENT SOUNDS.

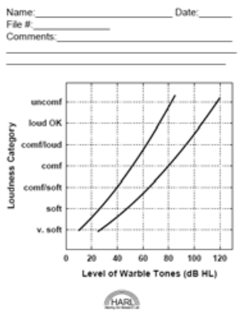
YOU WILL HEAR SOUNDS THAT INCREASE AND DECREASE IN VOLUME. YOU MUST MAKE A JUDGMENT ABOUT HOW LOUD THE SOUNDS ARE. PRETEND YOU ARE LISTENING TO THE RADIO AT THAT VOLUME. HOW LOUD WOULD IT BE?

AFTER EACH SOUND, TELL ME WHICH OF THESE CATEGORIES BEST DESCRIBES THE LOUDNESS.

KEEP IN MIND THAT AN UNCOMFORTABLY LOUD SOUND IS LOUDER THAN YOU WOULD EVER CHOOSE ON YOUR RADIO NO MATTER WHAT MOOD YOU ARE IN.

It is okay to skip a category, or to repeat a category

In case you're ambitious and want to do a complete "contour," there is even a score sheet for that!



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Frequencies to test?

- Fortunately, LDLs nearly always follow a fairly predictable pattern—e.g., if 500 Hz is 90 dB, and 3000 Hz is 110 dB, 1000 and 2000 will usually be at or in between these numbers.
- The most important frequency to test, especially for a single channel AGCo, is around the region of the real-ear peak of the hearing aid output: usually 2000-3000 Hz. For a relatively flat loss, LDLs at 500 and 3000 Hz should work just fine.
- But common sense needs to be applied: You don't need an LDL for a region where there is normal hearing (often true for 500 Hz) and you don't need an LDL for a region where there are probably cochlear dead regions, where you're not going to chase audibility (sometimes true for 3000 Hz).

Okay—I think we covered all the topics!

- When do I do the testing?
- What stimuli do I use?
- What psychophysical procedure do I use?
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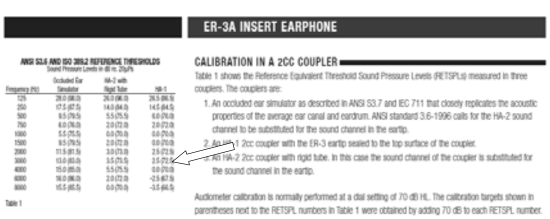
This is one of our topics for Part II, but just to get you started:

- Let's say your patient has an LDL of 100 dB at 2000 Hz.
- You think it would be a good idea to limit sounds at or just below this point—good thinking!
- You know that AGCo will do just that, so you know that your AGCo kneepoint needs to be set at or below 100 dB (in 2-cc coupler talk!).
- So . . . You simply need to convert that 100 dB HL value to a 2-cc value so you can talk to your fitting software. HL to 2-cc is the RETSPL—we talked about that 45 minutes ago, right?
- Insert earphones are calibrated in a 2-cc coupler, so this is going to be easy. Simply add the calibration value (the RETSPL) to 100, and you've got it!

Let's assume your audiometer is calibrated correctly:



ER-3A INSERT EARPHONE

ANSI S3.6 AND ISO 389.2 REFERENCE THRESHOLDS
Sound Pressure Levels in dB re. 20µPa

Frequency (Hz)	Occluded Ear Simulator	HA-2 with Rigid Tube	HA-1
125	28.0 (98.0)	26.0 (96.0)	26.5 (96.5)
250	17.5 (87.5)	14.0 (84.0)	14.5 (84.5)
500	9.5 (79.5)	5.5 (75.5)	6.0 (76.0)
750	6.0 (76.0)	2.0 (72.0)	2.0 (72.0)
1000	5.5 (75.5)	0.0 (70.0)	0.0 (70.0)
1500	9.5 (79.5)	2.0 (72.0)	0.0 (70.0)
2000	11.5 (81.5)	3.0 (73.0)	2.5 (72.5)
3000	13.0 (83.0)	3.5 (73.5)	2.5 (72.5)
4000	15.0 (85.0)	5.5 (75.5)	0.0 (70.0)
6000	16.0 (86.0)	2.0 (72.0)	-2.5 (67.5)
8000	15.5 (85.5)	0.0 (70.0)	-3.5 (66.5)

Table 1

CALIBRATION IN A 2CC COUPLER

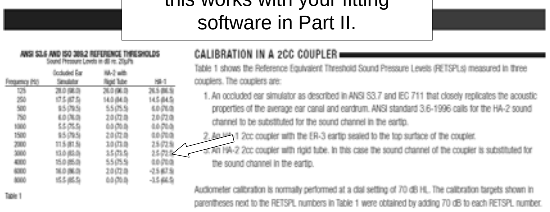
Table 1 shows the Reference Equivalent Threshold Sound Pressure Levels (RETSPLs) measured in three couplers. The couplers are:

1. An occluded ear simulator as described in ANSI S3.7 and IEC 711 that closely replicates the acoustic properties of the average ear canal and eardrum. ANSI standard 3.6-1996 calls for the HA-2 sound channel to be substituted for the sound channel in the eartip.
2. An HA-1 2cc coupler with the ER-3 eartip sealed to the top surface of the coupler.
3. An HA-2 2cc coupler with rigid tube. In this case the sound channel of the coupler is substituted for the sound channel in the eartip.

Audiometer calibration is normally performed at a dial setting of 70 dB HL. The calibration targets shown in parentheses next to the RETSPL numbers in Table 1 were obtained by adding 70 dB to each RETSPL number.

Let's assume your audiometer is calibrated correctly:

Never fear: We'll show you how this works with your fitting software in Part II.



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1000	5.5 (75.5)	0.0 (70.0)	0.0 (70.0)
1500	9.5 (79.5)	2.0 (72.0)	0.0 (70.0)
2000	11.5 (81.5)	3.0 (73.0)	2.5 (72.5)
3000	13.0 (83.0)	3.5 (73.5)	2.5 (72.5)
4000	15.0 (85.0)	5.5 (75.5)	0.0 (70.0)
6000	16.0 (86.0)	2.0 (72.0)	-2.5 (67.5)
8000	15.5 (85.5)	0.0 (70.0)	-3.5 (66.5)

Table 1

CALIBRATION IN A 2CC COUPLER

Table 1 shows the Reference Equivalent Threshold Sound Pressure Levels (RETSPLs) measured in three couplers. The couplers are:

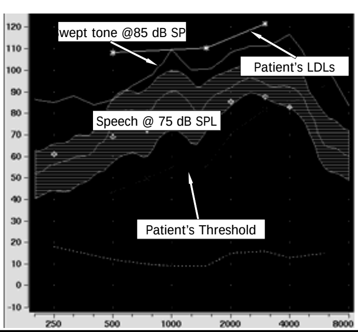
1. An occluded ear simulator as described in ANSI S3.7 and IEC 711 that closely replicates the acoustic properties of the average ear canal and eardrum. ANSI standard 3.6-1996 calls for the HA-2 sound channel to be substituted for the sound channel in the eartip.
2. An HA-1 2cc coupler with the ER-3 eartip sealed to the top surface of the coupler.
3. An HA-2 2cc coupler with rigid tube. In this case the sound channel of the coupler is substituted for the sound channel in the eartip.

Audiometer calibration is normally performed at a dial setting of 70 dB HL. The calibration targets shown in parentheses next to the RETSPL numbers in Table 1 were obtained by adding 70 dB to each RETSPL number.

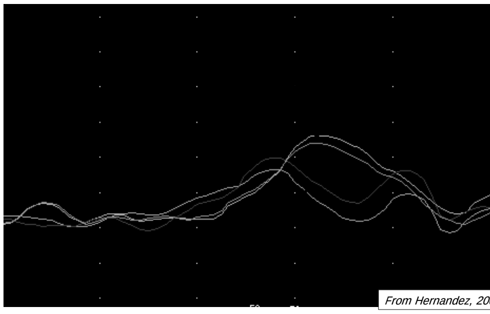
Here's a few exciting things we'll be talking about:

- Using LDLs to set the AGCo kneepoint
- How measured LDLs interact with the fitting software (or *not*)
- AGCo versus AGCi: Which one to tweak when?
- Aided loudness: What hearing aid properties and psychoacoustic factors could mess with all your hard work?
- Verification of pre-fitting settings using probe-mic measures.

Here's a sample: Using both speech mapping and a swept tone to assess hearing aid output.



Examples of “openness” using different fitting tips



From Hernandez, 2009

Typical finding for open versus closed RESR: Note again, that difference is around residual earcanal resonance.