Fitting Methods

Ted Venema PhD
Conestoga College
Fitting the Eye versus Fitting the Ear

Hair Cells of the Cochlea are the “Retina” of the Ear

Hearing Aids Do Not Grow New Haircells

A hearing aid is not a new ear.
"Mirror" the Audiogram with Full Gain?

For 0 dBHL input sounds, add about...
- 30 here
- 70 here

But for speech input, what would the Output be?
- Add 30 here, add 70 here

Loudness Growth:
Normal Hearing vs Sensorineural Hearing Loss

With Sensorineural HL:
“Ceiling” is the same
“Floor” is raised

Typical SN HL
Loud

Normal Dynamic Range

Average

Reduced Dynamic Range

Soft
Linear Hearing Aids

- Same gain at all inputs
- Speech often 70 dB SPL
- LDL often 120 dB SPL
- Speech + gain must be < UCL

If output > 120 dB SPL, clip the peaks
SNHL with its Reduced Dynamic Range + Linear Hearing Aids = Half Gain Fitting Method
Linear Fitting Methods
Based on 1/2 Gain Rule (Lybarger, 1944)

Linear circuits were “state of the art”
- same gain for all input levels

Cannot “mirror” audiogram with full linear gain
- linear gain gives too much output at high inputs

Lybarger found people preferred 1/2 gain
- used trial & error with SNHL

1/2 Gain Rule still in use
- the basis of many threshold-based methods

No method has been proven to be the best
- for speech intelligibility in noise
A) Functional gain:
- Aided vs unaided behavioral thresholds
- Aided HL is about ½ the HL
- Note <1/2 gain for lows

B) Insertion gain:
- Aided vs unaided SPL at TM
- Shows identical amounts of gain
- Note <1/2 gain for lows
Whole idea is match target as closely as possible

Valente, M. (1994) fig 1.2
Strategies for selecting & verifying HA fittings

Choose hearing aid, then set trimmers to approximate target

Note how insertion gain here did not meet target for high Hz’s
Audioscan: a DSL-friendly” real ear system

Note: even though fitting method here is NAL-R, the REUR & REAR read in terms of output, not gain
Comparison of 4 prescriptive methods for mild-moderate HL

Note the different gain prescribed across the Hz’s

Berger: most gain at 2000Hz
POGO: lots of gain at 4000Hz, but less at mids
NAL-R: less gain for high Hz’s
Libby: least gain of all

Figure 1.5
Strategies for selecting & verifying HA fittings
Comparison of 4 prescriptive methods for steep-sloped HL

Note the different gain prescribed across the Hz’s

Berger: again, most gain at 2000Hz
POGO: again, lots of gain at 4000Hz, but less at mids
NAL-R: again, less gain for high Hz’s
Libby: again, least gain of all

Figure 1.6
A Comparison of Threshold Methods

Figure 3.5

DSL FOR DUMMIES

A Reference for the Rest of Us!

by David Angell

The Fun and Easy Way to Get Up to Speed on a Digital Subscriber Line

IDG BOOK EDITION

50 MILLION

NEW!
Desired Sensation Level (DSL)

- Main focus: audibility & comfort of speech
- Originated in 1982 began as a pediatric fitting method
- DSL software: 1997 DSL[i/o] (v4.1) for compression HAs
- University of Western Ontario got registered trademark for DSL in 1995
Special DSL Stuff

1. DSL reads in $SPL$, not HL
2. DSL reads in $output$, not gain
3. DSL insists on $RECD, REDD, MLE$
4. DSL has $more$ than one target
1. DSL Reads in **SPL**, not HL

Audiogram flipped upside-down
  - as dB’s increase, SPL goes up
  - hearing loss & hearing aids on same graph

See “Ceiling” & “floor” of hearing (dynamic range)
  - audiogram above normal HL & below UCLs
2. DSL Reads in \textbf{Output}, not Gain

Output is the final goods (groceries) delivered to the ear
  \begin{itemize}
  \item input + gain = output
  \end{itemize}

DSL targets are shown as amplified speech output
  \begin{itemize}
  \item should sit nicely within dynamic range
  \end{itemize}

HA electroacoustics mapped to client’s hearing (insitu gain)
  \begin{itemize}
  \item this is why DSL “hates” insertion gain
  \end{itemize}
Figure 4.4

The “SPL-o-gram”

Speech Sounds on an Audiogram

Figure 4.3

Long Term Average Speech Spectrum

Speech Sounds in dB SPL

---

Cox & Moore

Ear Level: child

UWO (child) LTASS

Frequency (kHz)
DSL Goal: Make All Speech Sounds Audible

Speech Sounds in HL
DSL goal cont’d

Speech Spectra for Children vs Adults

Cox & Moore

- used mic in front of person to get speech levels
- most applicable to adults

Mic at Ear Level

- done because kids produce speech themselves
- they need to monitor speech to learn speech
- gives slightly more lows & less highs

UWO Child

- a compromise between both of the above
- kids listen to themselves & to others (hopefully)
If adult choose Cox & Moore
DSL goal cont’d
Raise Speech into Auditory Area

Long term average speech spectrum (LTASS)
• basically refers to unaided speech
• audibility of unaided speech is main DSL focus

SPL-o-gram shows unaided speech & unaided thresholds
• can also see aided speech
• great counseling tool for parents/teachers

Unaided speech has a 30 dB range
• 12 dB above mean; 18 dB below mean
• speech intensity is very unevenly distributed over time
Figure 4.5

Unaided Speech (dotted lines)

SSPL target (based on UCLs)

Hearing loss

Normal HL (dB SPL)

Figure 4.6

Aided Speech (dotted lines)

SPL-o-gram: Label the following:

- 0 dB SPL
- 10 dB SPL
- 20 dB SPL
- 30 dB SPL
- 40 dB SPL
- 50 dB SPL
- 60 dB SPL
- 70 dB SPL
- 80 dB SPL
- 90 dB SPL
- 100 dB SPL
- 110 dB SPL
- 120 dB SPL
- 130 dB SPL

Frequency (Hz):
- 250 Hz
- 500 Hz
- 1000 Hz
- 2000 Hz
- 4000 Hz
- 8000 Hz
3. Real Ear to Coupler Difference (RECD)

RECD = 2cc coupler response - client’s unaided ear response

RECD is “earprint” of client
- once you have it, send client home
- can measure hearing aid response on 2cc coupler
- factor in RECD
- you now know what hearing aid will do in client’s ear

RECD can be done fast on most real ear test equipment
3. Cont’d
Real Ear to Dial Difference (REDD)

REDD = audiometer dial reading vs actual SPL at eardrum

REDD applies to **circumaural** headphones
- these are measured on 6cc coupler
- allows lots of room for error when testing

REDD not necessary for insert headphones
- 2cc coupler used for insert headphones & HAs
- DSL likes inserts: less room for error when testing
MLE: different mic locations for BTE, ITE, ITC, CIC
  • mic location affects aided output at eardrum

MLE for BTEs
  • mic above the helix of ear
  • concha plugged up by mold

MLE for CICs
  • mic is deep inside conch bowl
  • allows for more natural concha resonance
3. e.g. DSL on old fitting software

RECD

MLE

REDD
3. DSL Uses Predicted or Measured Values

UCLs:
- can measure UCLs yourself at each Hz
- *or use DSL norms (almost everyone does this)*

REDD:
- can measure REDDs yourself at each Hz
- to do this, compare dial reading to probe tube measures
- *or use DSL norms (almost everyone does this)*

RECD:
- on software, you must enter client’s birthdate
- can measure yourself (easy on Audioscan™)
- *or use DSL norms, which are based on months of age*
4. DSL Has More Than One Target

Soft inputs: 50 dB SPL
• to imitate soft speech levels

Medium inputs: 70 dB SPL
• about 1/2 way between thresholds & UCLs
• amplified speech should be close to MCLs

Loud inputs: 90 dB SPL
• to approximate maximum comfort levels
4. e.g. More than one target means Compression.
Question: What is the gain at 1000Hz for each of the 3 inputs here?

Notice how with output, top line represents greatest input? This is opposite to how gain is read.
Case #1: DSL on Audioscan™ with Three Stimuli

Dotted line: 70dB SP sweep tone average speech
Light vertical lines: 50dB SPL dynamic stimulus loud speech
Dark vertical lines: 85dB SPL dynamic stimulus soft speech

Figure 4.7

Case #2: DSL on Audioscan™ with Three Stimuli

Dotted line: 70dB SP sweep tone
Lower vertical lines: 50dB SPL dynamic stimulus
Upper vertical lines: 85dB SPL dynamic stimulus

average speech
loud speech
soft speech

Figure 4.8

Often difficult to meet DSL targets for High-Hz HL

Many clinicians think DSL prescribes excessive high-Hz gain

But actually, DSL prescribes more low-Hz gain than most other fitting methods.
The Desired Sensation Level (DSL) method is a systematic eardrum sound pressure level (SPLogram) approach to hearing instrument fitting that seeks to ensure amplified speech will be audible and comfortable while loud sounds will not be uncomfortable. It takes into account individual acoustic factors in audiometric and electroacoustic data. DSL was developed by the National Centre for Audiology (NCA), London, Ontario. Audioscan has implemented DSL within its Speechmap fitting system since 1994.

In 2005, DSL underwent an extensive revision resulting in DSL 5.0. It was further revised in 2007 to version 5.0a. See 17.4: DSL 5.0 changes for details of the changes.

The Audioscan version of DSL 5.0 may differ from others in the following ways:

1) DSL 5.0 uses RECD values for ages > 119 months from a different source than for ages ≤ 119 months; Audioscan has used the RECD values for a 119 month old for ages > 119 months so all values come from the same study.

2) Input-output curve targets and compression threshold targets are not provided. Such steady-state parameters are of little value in estimating amplified speech levels. Matching amplified speech to the LTASS targets at levels from 50 to 75 dB SPL provides much better assurance that fitting goals are being met.

3) There is no provision to input the number of compression channels. This may be useful when the signal used for verification is not the signal for which the targets were developed. It is irrelevant when using real-speech signals to match speech targets and when using narrow-band signals to match narrow-band maximum output targets.

4) The term Uncomfortable Level (UCL) is used rather than Upper Limit of Comfort (ULC) in referring to the ear canal SPL that should never be exceeded.

5) Broadband output limiting targets are not provided.
The Audioscan version of DSL 5.0 includes provision for bone conduction and ABR threshold, binaural targets, targets for speech levels from 50 to 75 dB SPL, new targets for children, targets for adults and new RECD default values for children (1 month to 10 years) and adults. The UWO child’s spectrum has been removed and an “own voice” spectrum has been added. As a result of a re-analysis of published data, the vocal effort effects for Soft and Average speech levels have been made the same. In addition, the target symbol has been elongated to indicate that the fit-to target is a range, not a point.

The children’s LTASSa targets for 70 dB speech are lower than those in previous versions of DSL. These differences are functions of the hearing loss and age (where average RECDs are used). Revisions made in version 5.0a reduce these differences at 250 Hz and for more severe losses. The differences will be more significant when the individual RECD values have not been measured for the child being fitted.

Audioscan assumes no responsibility for the validity of these changes; that responsibility rests with the National Centre for Audiology.
Fitting Methods
(Theory vs Reality)
NAL-NL1 v1.01

National Acoustics Labs - Sydney Australia
• a bunker in a suburb (Chatsworth)
• NAL-NL1 website: www.hearing.com.au

Originated in 1997
• developed from NAL-R (1986) & NAL-RP (1990)

Main focus of all NAL methods, including NAL-NL1:
• amplify unaided speech Hz’s so they are equally loud
The NAL-NL1 procedure seeks to amplify speech such that all bands of speech are perceived with equal loudness while maximizing speech intelligibility and ensuring that the wearer perceives speech to be no louder than that which a normal hearing person would perceive. Although NAL-NL1 states its goals for speech, it derives insertion gain targets assuming noise as a verification signal. Because it is more accurate to verify a non-linear fitting using the signal for which the procedure was developed, Audioscan converts the NAL-NL1 insertion gain targets to LTASS targets for amplified speech in the Speechmap environment, resulting in Speechmap/NAL-NL1. The conversions use the same adult average RECD and REUG as used in DSL. The RESR targets are from Hearing Aids (Dillon, Thieme Publishing, 2001, p274).

An insertion gain version is available by selecting [Insertion gain] from the test box menu. The pink noise stimulus should be used.
Recall DSL Goal:
Make All Speech Sounds Audible

Speech Sounds in HL
NAL does *not* try to preserve loudness relationships among speech Hz’s...
Other methods try to *normalize* loudness

- for normal hearing, low Hz’s of speech are loudest
- if we preserve loudness relationships among speech Hz’s
- then we **amplify low Hz’s more** than other speech Hz’s

**NAL-NS1** tries to *equalize* loudness

- amplify unaided speech Hz’s to be **equally loud**
- this results in maximized speech intelligibility for HL
NAL says:

Restore normal loudness growth for *whole speech signal*

Not for each Hz band of speech
Theoretical goal:
• make all speech Hz’s contribute equally to its loudness

Subsequent testing showed this goal was not achieved:
• amplified speech Hz’s were not equally loud at MCL

Original NAL also compensated too much for audiogram slope
• too much high-Hz gain for precipitous HL
Revised NAL (NAL-R)
(Byrne & Dillon, 1983)

For a *flat* audiogram, NAL-R suggests:
- about 10 dB more gain at 500Hz
- about 3-4 dB more gain at 3000 & 4000Hz

In general, NAL-R provides:
- slightly < 1/2 gain across frequencies
- a “flatter” gain than other linear fitting methods

NAL-R remains the most popular linear fitting method
- many think it is “kind” to steep, high-Hz HL
NAL vs NAL-R (Byrne & Dillon, 1986)

Frequency responses based on a flat audiogram (0 dBHL)

Relative Gain (dB)

250 500 1k 2k 4k 6k

Frequency (Hz)
NAL-R
(Byrne & Dillon, 1983)

Gain calculations: at each Hz, add three things

1. PTA of .5, 1, 2kHz: multiply it by .05

2. Multiply thresholds by .31

3. Different values at each Hz to make speech equally loud
#3. Lows/highs given less gain than mids

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Gain (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>-17</td>
</tr>
<tr>
<td>500</td>
<td>-8</td>
</tr>
<tr>
<td>750</td>
<td>-3</td>
</tr>
<tr>
<td>1000</td>
<td>+1</td>
</tr>
<tr>
<td>1500</td>
<td>+1</td>
</tr>
<tr>
<td>2000</td>
<td>-2</td>
</tr>
<tr>
<td>4000</td>
<td>-2</td>
</tr>
<tr>
<td>6000</td>
<td>-2</td>
</tr>
</tbody>
</table>

NAL-R
(Byrne & Dillon, 1983)
NAL-RP
(Byrne, Parkinson and Newell, 1990)

The latest, linear version of NAL-R
• addresses unique needs of severe-profound HL

If 500, 1kHz, 2kHz average > 60dB, then:
• give about 10 dB more gain (i.e. > 1/2 gain)

If HL at 2kHz > 90 dB:
• increase low-Hz gain
• reduce high-Hz gain
**For steeper sloped HL:**
- more low Hz gain
- less high-Hz gain

**Dead hair cell regions:**
- receive less gain
- So, less gain for worse HL

---

*Average Audiograms for 2 Groups*

- Prefers **more** high-Hz gain
- Prefers **less** high-Hz gain
- Prefers **more** low-Hz gain
- Prefers **less** low-Hz gain
NAL-NL1
(Dillon, Katsch, Byrne, Ching, Keidser, Brewer, 1997)

Linear fitting methods only show one target
• linear hearing aids give *same* gain for all inputs

Compression show more than one target
• compression gives *different* gain at different inputs

This is mainly how NAL-NL1 differs from NAL-R!
• it concerns compression
NAL-NL1 distinguishes between:

- audibility & “effective audibility”

Audibility:

- can be physically measured if you know thresholds

Effective audibility:

- how much information one can *extract* from speech
NAL-NL1 vs NAL-R
Target Comparison

NAL-RP
(Linear)

NAL-NL1
(Compression)
Fitting Method Comparisons Here

- DSL v4 versus NAL-NL1
- DSL5 adult versus DSL 5 Child
- DSL 5 adult versus NAL-NL1
NAL-NL1 vs older DSL on Audioscan™ System

Solid Line: NAL-NL1
Dotted Line: DSL
NAL-NL1 vs DSL on Audioscan™ System

Solid Line: NAL-NL1
Dotted Line: DSL

**Figure 4.10**

NAL-NL1 vs DSL on Audioscan™ System

Solid Line: NAL-NL1
Dotted Line: DSL

Figure 4.11

NAL-NL1 vs older DSL on Audioscan™ System

Solid Line: NAL-NL1
Dotted Line: DSL

Figure 4.12

Figure 4.13: NAL-NL1 vs older DSL on Audioscan™ System

Solid Line: NAL-NL1
Dotted Line: DSL

• DSL has changed from version 4 to version 5
• Child version 5 is much the same as before
• Adult version 5 has less prescribed gain/output

• See examples for flat & sloping Hearing Losses:
• Comparing DSL 5 versions of Child to Adult
• Also comparing to NAL-NL1
NAL-NL1 vs newer DSL (v5) on VeriFit™ System
NAL-NL1 vs newer DSL (v5) on VeriFit™ System

input: speech 55 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System
input: speech 55 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System

input: speech 55 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System

input: speech 65 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System
input: speech 65 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System
input: speech 65 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System

input: speech 75 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System

Input: speech 75 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System
input: speech 75 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System

input: tones 85 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System
input: tones 85 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System
input: tones 85 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System
input: speech 65 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System
input: speech 65 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System

input: speech 65 dB SPL
NAL-NL1 vs newer DSL (v5) on VeriFit™ System

input: soft speech 55 dB SPL
Probe Tube Measures & Fitting Methods

• Mainly NAL-NL1 or DSL

• Manufacturers also have proprietary fitting methods

• These tend to roll off high Hz’s; Why?

• Software almost always overestimate gain/output

• Real ear almost always shows less than predicted
Verification of Thin Tube BTEs

**Speechmap/Camfit - restoration**

Max TM SPL 120

- Instrument: Open
- Mode: REM
- Presentation: Single view
- Format: Graph
- Scale (dB): SPL

**Audiometry**
- Age: Adult
- Transducer: Headphone
- UCL: Average
- RECD: Average
- BCT: N/A
- Binaural: Yes

**Equalize**
- Equalize sound field with hearing aid turned off or muted. Repeat if client or nearby objects move.

After equalizing, turn hearing aid on and run test.
Thin Tube Open Fit BTEs

• Recall, the job of the reference microphone is to make sure that the sound level at the ear is constant.

Sound coming through the vent
Will be picked up by the reference mic!
Acoustic Effects of Open Fit Thin Tube BTEs

Vent = 2 way street; sound goes in & out
Thin Tube Effect

Smaller diameter reduces high Hz resonance peaks
More electronic gain therefore needed
Amplified sound & Vent Interactions

Open fit *can* give pleasing mixture of in/out sounds

But at similar levels these don’t mix well

Leads to Doubling or Cancelling

“Comb filter” effect

Courtesy Bernafon
Real Ear Leakage into Ref. Microphone

Due to large vent, sound escapes & contaminates inputs
- Reference mic measures increase in SPL...
- Real ear system reduces test stimulus level

Results in Under-estimated HA output...

Can lead to Over amplification

Courtesy Bernafon
Real Ear Leakage into Ref. Microphone

Same here...

- Reference mic measures increase in SPL...
- Real ear system reduces test stimulus level
A Solution on VeriFit

You will note that stimuli become quieter…
  • as client nears head towards VeriFit
  • this is due to “Equalization” on VeriFit

Solution:
  • mute HA during equalization
  • when equalization done, turn HA back on
  • go ahead with real ear measures
  • critical that client does not move during this process
Cannot Do S-REM with Open Fit BTEs

Coupler based measures
- do not account for venting effects
- S-REM cannot therefore be done
Study with Thin Tube Open Fit BTEs

To compare software predictions to real ear verification

14 HAs from 9 manufacturers

Client experience level set to maximum

HAs set to NAL-NL1 & DSL

Feedback manager ran only if recommended by mfr
Study with Thin Tube Open Fit BTEs

Minimum Hearing Loss

Maximum Hearing Loss

Courtesy Bernafon
NAL-NL1 Target Match
Minimum Hearing Loss

NAL-NL1 target right in centre; not bad...

Courtesy Bernafon
DSL[i/o] Target Match
Minimum Hearing Loss

DSL target fairly in centre; not bad either...

Courtesy Bernafon
NAL-NL1 Target Match
Maximum Hearing Loss

NAL-NL1 target above software predictions...
DSL[i/o] Target Match
Maximum Hearing Loss

DSL target way above software predictions…
Target Match Default Formula
Minimum Hearing Loss

Note the manufacturer’s high Hz roll off
Target Match Default Formula
Maximum Hearing Loss

Note the manufacturer’s high Hz roll off