Fitting Methods & Real Ear Measurement

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Agenda

Here’s what we’ll learn about:
- Linear-Based Fitting Methods 30 min
- Early Real Ear Measures (REM) 20 min
- Today’s REM 20 min
- Compression-Based Fitting Methods 20 min
- Fitting Software Talks; REM Walks 20 min
- Q&A 10 min
- Total Time (if you’re good) 120 min
Learning Objectives:

- Learning Objective 1
  Describe the purpose of early fitting method targets as measured by functional gain

- Learning Objective 2
  Compare the early method of doing REM to the speech mapping method of REM used today

- Learning Objective 3
  Explain how today’s REM is a counseling tool whereby to visualize the goals of fitting methods
I. Linear-Based Fitting Methods
Fitting the Eye vs 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 5 dB HL input sounds:
- add 30 here, add 60 here

But for louder speech input
what would the output be?

But for louder speech input
what would the output be?

For 5 dB HL input sounds:
- add 30 here, add 60 here

250 500 1000 2000 4000 8000 Hz
0 10 20 30 40 50 60 70 80 90 100 110

250 500 1000 2000 4000 8000 Hz
0 10 20 30 40 50 60 70 80 90 100 110
With Sensorineural HL:
“Ceiling” is the same
“Floor” is raised
The Audiogram: Hearing Loss Reduces Dynamic Range

The “decibel distance” b/w the softest one can hear & the loudest one can tolerate

**Normal**

- Most Comfortable Loudness level
- Dynamic Range
- Uncomfortable Loudness level

**Moderate HL**

- Most Comfortable Loudness level
- Dynamic Range
- Uncomfortable Loudness level
Reduced Dynamic Range Requires:
Different Amounts of Gain for Different Input Levels

- Soft inputs by \textit{full degree of HL}
- Average inputs by \(\frac{1}{2}\) \textit{degree of HL}
- Loud inputs by \textit{little or nothing at all}
Figure 4.1

Loudness Growth: Normal Hearing vs Sensorineural Hearing Loss

Carhart (1946): comparison fitting method

• Try several hearing aids on same person see which one is best for speech recognition also, which HA person “likes” the best

• No “prescription targets” per se largely relies on individual skill of clinician

• But hard to transmit or convey fitting methods from clinic to clinic
Linear Fitting Methods

Based on 1/2 Gain Rule (Lybarger, 1963)

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
Two Factors Here:

1. 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
2. Reduced Dynamic Range for SNHL

Fig 4.1, Venema, T. Compression for Clinicians 2nd edition, Cengage 2006
1. Linear Hearing Aids

+ 

2. Reduced Dynamic Range for SNHL

= 

3. Half Gain Fitting Method
Functional Gain & ½ Gain Rule

Frequency (Hz): 250, 500, 1000, 2000, 4000, 8000

Gain (dB): 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120

Graph showing functional gain and ½ gain rule with specific frequencies and gains marked.
The Idea Was To Place Speech into Dynamic Range

Aided Speech Output

LDL for Speech
Four “children” of the $\frac{1}{2}$ gain fitting method

Different targets for same HL:

*all based on variations of 1/2 gain rule*


*asks for lots of gain at 1 and 2kHz*

- 250 Hz X .45
- 500 Hz X .5
- 1000 Hz X .625
- 2000 Hz X .667
- 3000 Hz X .588
- 4000 Hz X .5

*also, reserve gain of 10 dB*

These #’s based on optimal speech intelligibility

*AKA: articulation index*
2. POGO (McCandless Lyregaard 1983)

prescription of gain & output

- Lots of high-Hz gain
  
  less mid & low-Hz gain

- Less than half gain for lows
  
  to prevent upward spread of masking

- ½ gain at all Hz’s...
  
  10 dB < than ½ gain at 250 Hz
  5 dB < than ½ gain at 500 Hz

- Reserve gain of 10 dB
3. Libby (1986): 1/3 to 2/3 Gain Procedure

- Similar to POGO except that: for mild to moderately-severe HL multiply each Hz by 1/3, not ½
  *clients don’t prefer ½ gain; too loud*

- 5 dB < 1/3 gain at 250 Hz
  *3 dB < 1/3 gain at 500 Hz*

- For severe-profound HL: 2/3 gain
  *these clients prefer more gain*
4. Original NAL (Byrne & Tonnison, 1976)

NAL does *not* try to preserve loudness relationships among speech Hz’s...

Instead, it tries to make all speech Hz’s contribute equally to it’s *overall* 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*

For a *flat* audiogram, NAL-R (revised) suggests: *a few dB more gain at 500Hz & at 3-4kHz*

NAL-R remained by far the most popular fitting method *many thought it “kind” to high-Hz SNHL*
NAL vs NAL-R (Byrne & Dillon, 1986)

Frequency responses based on a flat audiogram (0 dBHL)

Relative Gain (dB)

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>250</th>
<th>500</th>
<th>1k</th>
<th>2k</th>
<th>4k</th>
<th>6k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original NAL</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NAL-R</td>
<td></td>
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<td>*</td>
<td>*</td>
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</tr>
</tbody>
</table>
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

250Hz  -17 dB  
500Hz  -8 dB   
750Hz  -3 dB   
1000Hz +1 dB   
1500Hz +1 dB   
2000Hz -2 dB   
4000Hz -2 dB   
6000Hz -2 dB   

NAL-R  
(Byrne & Dillon, 1986)
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
Strategies for selecting & verifying HA fittings
A Comparison of Threshold Methods

II. Early Real Ear Measures

Meanwhile, Behind the Fitting Method Scene...

Real Ear Measures Emerged...in 1988

Imperative to keep in mind...

Fitting method *targets* didn’t change

Just the *measurement method* changed
Instead of Behavioral Functional Gain...
Real Ear Measures Used *Insertion Gain*

*Insertion Gain*: Aided vs Unaided SPL at TM

*Fitting Methods did not change*

Note target values are same as previous slide!
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

Valente, M. (1994) fig 1.1
Strategies for selecting & verifying HA fittings
Because all hearing aids were linear!

They gave same gain at all input levels

Target was that for average conversational speech
65 dB SPL or 50-60 dB HL

Note only 1 target
Whole idea was match target as closely as possible

Choose hearing aid, then set trimmers to approximate target

Note how insertion gain here did not meet target for high Hz’s

Valente, M. (1994) fig 1.2
Strategies for selecting & verifying HA fittings
In early days of REM
We looked lots at Outer Ear Canal Resonance

- Natural amplification of soft high-pitched consonants
- Varies lots among individuals
You say you want more detail? Here’s more then.
Job of Reference mic is to make sure sound level at ear is constant and at setting.
Length of Mic Assembly Box

29mm from tragus ensures probe tube tip is about 5 mm from TM

Tragus Ring
Reference Microphone
Probe Microphone
Probe Tube Placement

- Tragus Ring
- Probe Microphone
- Reference Microphone

Distance:
- 29 mm
Example of probe tube placement

Real Ear Unaided Response (REUR)

measurement on the Audioscan RM500

Real-Ear Measurement: Basic Terminology and Procedures
Pumford, J., & Sinclair, S. Audiology Online article
Note as distance from TM increased, high-Hz’s drop

Hardly any dB loss for 1000Hz as probe distance increased.
REM Calibration

- Reference Microphone
- Probe Microphone
- Tragus Ring: 29 mm
Calibration done to remove effects of tube in EAM
Terms Encountered in Real Ear

• Real ear unaided response (REUR)

• Real ear aided response (REAR)

• Real ear insertion gain (REIG)

• Real ear to coupler difference (RECD)

• Real ear to dial difference (REDD)

*Ending in “R” is always output dB SPL*
*Ending in “G” is always gain in dB*
Difference between aided & unaided SPL at TM
Yesterday’s Real Ear Measures

Insertion Gain: Aided vs Unaided SPL at TM
Real Ear Occluded Response

REOR: Always Sits Below REUR
REIG: Try to Match Fitting Method Target

Find out whether you have indeed hit fitting method target
• with hearing aid settings you have chosen

Always try to get as close to target as possible
• this is not always possible

REIG does at least *quantify* what you were getting
• always keep in client’s file!!

Something visually “clean” about “good old gain”
• easy to compare things with REUR/REAR/REIG
Insertion Gain: Its Critical Woes

The devil is in what it does not tell:

Audibility of Speech!

In this way, it is even worse than Functional Gain
III. Today’s Real Ear Measures

To Move From Yesterday’s REM
To
Today’s REM...

We Must Move From Gain in dB
To
Output in dB SPL
“Gain” is a *difference* measure; a relative value
  • difference b/w input & output (output – input = gain)
  • specified in terms of simple “dB”

“Response” is an *absolute* measure of output SPL
  • that is, referenced to some absolute fixed value
  • for example, .0002 dynes/cm\(^2\)
  • always specified in terms of “dB SPL”

This is why on specs sheet graphs
  • gain is seen on vertical axis as “dB”
  • output is seen on vertical axis as “dB SPL”
You *cannot* add dBs if:

- adding 2 absolute values together
- eg. 1 machine making 80dB SPL...
- added to another making 80dB SPL...
- total 83 dB SPL

You *can* dBs if:

- adding a relative dB value to an absolute value
  - eg. input (dB SPL) + gain (dB) = output (dB SPL)
Gain vs Output for Input Intensity Changes

Gain decreases as inputs increase

Output increases as Inputs increase

Gain decreases as inputs increase

Output increases as Inputs increase
If vertical intensity axes have same increments
eg 10 dB

Smaller gain changes
Give larger output changes

WDRC & Gain

Larger gain changes
Give smaller output changes

WDRC & Output

Frequency

Frequency

dB

dB SPL

10

20

30

40

50

60

70

80

90

100

40

60

80
The Basic Layout for Today’s REM

Outputs for inputs of:
- 80
- 65
- 50

Gain at 1000 Hz is:
- 15
- 20
- 25
The Game-Changer: DSL

Desired Sensation Level Fitting Method

By Richard Seewald PhD, Western University, Ontario

DSL took a dim view of Gain, REUR & REIG b/c:
thresholds are obtained with TDH39’s or ER-3A’s...
and REUR is bypassed when testing with headphones!

Therefore, REIG targets are based on thresholds
that did not incorporate one’s REUR in 1st place

If REIG is to be used, then:
unaided thresholds should be obtained in sound field
because this does indeed incorporate one’s REUR
DSL Totally Changed Real Ear Measures

• Gain (in dB) is just a means to an end
  • output (in dB SPL) rules
  • input & output read in dB SPL, not dB
  • output is the “groceries” delivered to TM!

• SPL-o-Gram
  • *In Situ Output* (REAR)
  • no more REAR - REAR
  • actually easier than the old REAR – REUR!
  • just one measure: aided output
Hearing Loss on Typical Audiogram

Same Hearing Loss On SPL-o-Gram

Frequency in Hertz (Hz)

UCL

Normal hearing

0dBA HL
Unaided Speech
Only the Vowels
Are Audible

Aided Speech
All Parts
Are Audible

Unaided Speech

Aided Speech

Graph 1: Unaided Speech
- Normal hearing
- 0dB HL

Graph 2: Aided Speech
- Normal hearing
- 0dB HL

Frequency (Hz)
- 250, 500, 1000, 2000, 4000, 8000

Intensity (dB HL)
- 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120
But how do we get from dB HL to dB SPL?
Let’s look closer at the bottom line. It can be called MAP or average REDD... Either way, it is 0dB HL.
The resonances of the Outer and Middle ears together create an equal loudness curve that shows our best hearing sensitivity is between 1000 to 4000 Hz.
Minimal audible field (MAF)
softest it takes to just barely hear all the Hz’s
at 1 meter distance from speaker with both ears

Minimal audible pressure (MAP)
softest it takes to hear all the Hz’s
with 1 ear under a headphone

MAP bump caused by loss of REUR
When plugging ear with headphone
MAP is the Same for Any Headphone

Look at the bump on REDD (or MAP)

Insert Or Circum-aural

Normal hearing 0dB HL
MAP or REDD is added to dB HL thresholds to convert them to dB SPL.
REDD = RETSPL + RECD

REDD: *Real ear to dial difference*
difference b/w audiometer dial reading vs actual intensity in dB SPL measured near TM

= RETSPL: *Reference equivalent sound pressure level*
difference b/w audiometer dial setting vs output in a coupler (calibration)

+ RECD: *Real ear to coupler difference*
difference b/w headphone output in a coupler vs output in a real ear near TM
REDD for Headphones

Insert headphones:

\[
\text{REDD} = \text{dB HL threshold} + \text{insert headphone RETSPL} + \text{RECD in 2cc coupler threshold in dB SPL}
\]

Circum-aural headphones:

\[
\text{REDD} = \text{dB HL threshold} + \text{circum-aural headphone RETSPL} + \text{RECD in 6cc coupler threshold in dB SPL}
\]
RETSPLs take you from audiometer to coupler

Published all over the place
eg F. Martin, Introduction to Audiology

They exist for insert & circum-aural headphones
inserts calibrated in 2cc coupler
circum-aurals calibrated in 6cc coupler

RETSPLs are a calibration thing
a list of Hz’s and corresponding dB SPLs
for specific headphone & specific coupler
RECDs take you from coupler to real ear

Circum-aural headphones
average 6cc coupler RECD (Bentler & Pavlovic 1989) does exist; not often used
large variability among subjects
not used in REM

Insert headphones
average 2cc coupler RECD
well established, well known
commonly used in REM
Changing Thresholds in dB HL into dB SPL

With Circum-aural Headphones:

- Average REDD used by REM system as transform
- Can measure REDD, takes way more time than RECD
- Almost no one measures REDD

Gotta use REDD because REM systems don’t use 6cc coupler values

Real-Ear Measurement: Basic Terminology and Procedures
Pumford, J., & Sinclair, S. Audiology Online article
Here’s Why...

- Probe tube in ear canal (close to TM), then place headphone over client’s ear
- Set dial setting to 70dB HL at some Hz, present pure tone, then measure output in ear canal
- Do at other Hz’s; **REDD = real ear measurement – dial reading**

Real-Ear Measurement: Basic Terminology and Procedures
Pumford, J., & Sinclair, S. Audiology Online article
Changing Thresholds in dB HL into dB SPL

*With Insert Headphones:*

- If ER-3A used, *average* RECD used by REM system as transform
- can use average or measured; either way is easy
- RECD simply *adjusts 2cc coupler calibration values* of inserts

![Graph showing Real Ear Response, Coupler Response, Measured RECD, and Average RECD across different frequencies]
2cc Coupler vs RECD

2cc coupler contains 2cc volume air
- meant to imitate that in closed ear canal

2cc coupler standard adopted 1959
- gives rough approximation to ear canal but too large

Typical ear canal has < 2cc volume
- so, > SPL in ear canal than in 2cc coupler

RECD values are generally about 5 dB below 1000Hz
- about 10 dB above 1000Hz
Real Ear to Coupler Difference

Closed Ear canal

Closed 2 cc coupler
RECD done to show how sound in closed 2cc coupler...

Figure 3–5. 2-cc coupler for behind-the-ear hearing instrument measurements.
Compares to the same in a closed EAM
First measure coupler response...

Measuring the coupler response of the insert earphone

COUPLER MICROPHONE

BTE COUPLER

RE770 TRANSDUCER

[Graph showing frequency response]
Then measure real-ear response with insert earphone.
The genius of RECD is it allows S-REM: Simulated Real Ear Measurement

- Once you have client’s RECD, send client home
- Measure hearing aid response on 2cc coupler
- Then factor in RECD
- You can then predict what hearing aid will do in client’s ear!
- RECD can be done fast on most real ear test equipment
Probe Tube Measures Today Follow DSL’s Lead
Use only insitu REAR!

• Actually easier than the old REAR – REUR
  REUR only measured to ensure good probe placement

• Outputs measured for soft, average, loud inputs
  gain is yesterday’s news; just a means to an end
  output rules; it is the “groceries” delivered to TM!

• Output is final goods (groceries) delivered to doorstep of TM
  Input + gain = output

• Unaided speech can be laid across unaided thresholds
  can then compare aided vs unaided speech
This is How We Got to Today’s Real Ear

Target outputs for these inputs:

Soft
Average
Loud

Map Soft, Average, Loud Speech Into Remaining Dynamic Range