The NAL-NL2 prescription method for hearing aids

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Talk structure

The Fitting Process
Measure hearing thresholds (dB HL)

Enter into manufacturer software (hearing aid auto adjusted to approximate prescription)

Verify with real ear measurement

Adjust amplification to better match prescription

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Measure hearing thresholds (dB HL or dB SPL)

Measure individual RECD (or estimate from age)

Enter into manufacturer software (hearing aid auto adjusted to approximate prescription)

Adjust hearing aid in coupler via computer to better match prescribed coupler gain

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Prescription goals

Prescribe hearing aids to:

- Make speech intelligible
- Make loudness comfortable

Prescription affected by other things
- localization,
- tonal quality,
- detection of environmental sounds,
- naturalness.
How much amplification?

Gain

Frequency

50 dB SPL
65 dB SPL
80 dB SPL

The lolly shop

Deriving NAL-NL2
The rationale for NAL procedures

Maximize calculated speech intelligibility, but
Keep total loudness less than or equal to normal

NAL-NL1 (1999) → empirical studies
→ psychoacoustic studies
→ speech intelligibility models

NAL-NL2

Deriving optimal gains - step 1

Speech spectrum & level → Loudness model → Normal loudness

Gain-frequency response → Compare

Intelligibility achieved

Intelligibility model → Amplified speech spectrum → Loudness model

Loudness (hearing impaired)

Audiogram

The audiograms

Rejection criterion:

-30 ≤ G ≤ 60, where G is the slope
\[ \frac{\sum(H(f))}{3} \leq 100 \], where f is in the set \{0.5, 1, 2\} kHz
The audiograms, continued

**Deriving optimal gains - step 1**

<table>
<thead>
<tr>
<th>Audigram 1</th>
<th>Speech level 1</th>
<th>Optimal gain frequency response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audigram 1</td>
<td>Speech level 2</td>
<td>Optimal gain frequency response</td>
</tr>
<tr>
<td>Audigram 1</td>
<td>Speech level 3</td>
<td>Optimal gain frequency response</td>
</tr>
<tr>
<td>Audigram 2</td>
<td>Speech level 1</td>
<td>Optimal gain frequency response</td>
</tr>
</tbody>
</table>

200 audiograms x 6 speech levels → 1200 gain-frequency responses, each at 20 frequencies from 125 Hz to 10 kHz

**Overall prescription approach**

- Psychoacoustics
- Assumptions, rationale
- Theoretical predictions
- Adjust
- Final formula
- Compare
- Empirical observations
- Speech science
Multi-dimensional equation:

A neural network

The two key ingredients

1. A loudness model
2. An intelligibility model

Calculating loudness

Loudness model of Moore and Glasberg (2004)
Allowance for hearing loss

External & middle ear
Free field speech level

Input to cochlea

Input to auditory bands

Excitation level

Loudness per band

Total loudness

Filtering into auditory bands

Calculate loudness per band

Sum across bands

Gain-frequency response

Intelligibility achieved
Speech intelligibility

![Graph showing 1/3 octave SPL with frequency, audibility, and importance values.](image)

But intelligibility gets worse if we make speech too loud!
Speech intelligibility also depends on ...

**Level distortion**

- Normal hearing people perform poorer at high speech levels

The transfer function

\[ SII = \sum A_i I_i L_i \]
Subjects

- 20 adults with normal hearing
- 55 adults with sensorineural hearing loss
  - mild to profound
  - Experienced hearing aid users

Speech perception

- Stimuli: Filtered speech
  - CUNY sentences
  - VCV syllables
- Shaping:
  - POGO prescription
- Conditions:
  - Quiet at high and low sensation levels
  - Babble Noise
- Headphones: Sennheiser HD25
Audibility and Speech intelligibility - H.I.

Deficit = S_{ansi} - S_{I eff}

VCV deficit vs CUNY deficit
Desensitisation for hearing loss

Psychoacoustics

Why measure only pure tone thresholds?

Other measurements

- Outer hair cell function
  - click-evoked otoacoustic emissions
- Frequency resolution
  - psychophysical tuning curves
  - cochlear dead regions – TEN test
- Cognitive ability
- Age
Healthy PTC - no dead region

Poor PTC: Dead region at 4 kHz

Dead regions

NAL-NL1 only allows for hearing loss desensitization on average
Off-frequency listening: TEN test

Based on Moore (2004)

TEN and PTC (non) agreement

2 kHz

<table>
<thead>
<tr>
<th></th>
<th>TEN: Alive</th>
<th>TEN: Dead</th>
<th>TEN uncertain</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTC:</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Tip in place</td>
<td>60</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>PTC:</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Tip shifted</td>
<td>4</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>PTC uncertain</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Psychoacoustic correlations - 4 kHz

Matrix Plot (Prof and Psy 11 March 09; sta 659v*75c)
Can we better predict intelligibility if we use psychoacoustic results?
Yes, a little - speech deficit increases as frequency selectivity gets broader

But not once we fully build HL into the SII prediction

Correlations

<table>
<thead>
<tr>
<th>500 Hz</th>
<th>1 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>HL 500 PTC5 Q10 OAE 500 TEN 500 Cognit Age</td>
<td>HL 1k PTC1k Q10 OAE 1k TEN 1k Cognit Age</td>
</tr>
<tr>
<td>HL 500</td>
<td>-0.79</td>
</tr>
<tr>
<td>PTC5 Q10</td>
<td>-0.49</td>
</tr>
<tr>
<td>OAE 500</td>
<td>0.73</td>
</tr>
<tr>
<td>TEN 500</td>
<td>0.36</td>
</tr>
<tr>
<td>Cognit Age</td>
<td>-0.49</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2 kHz</th>
<th>4 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>HL 2k PTC2k Q10 OAE 2k TEN 2k Cognit Age</td>
<td>HL 4k PTC4k Q10 OAE 4k TEN 4k Cognit Age</td>
</tr>
<tr>
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Correlations
**Multiple regression**

Including HL causes:
- Correlations between age and PTC/OAE/TEN to disappear
- Correlations between cognition and PTC/OAE/TEN to disappear

**Likely intermediate effects**

**Why are hearing thresholds so useful?**
Factors affecting prescription

Gain; 187 adults, medium input level

Overall gain reduction of 3 dB
Gender effect
Effect of experience

Source: Keidser et al., 2008

Gain deviation from NAL-NL2 (dB)

-20 -10 0 10

Female Male

NA gain (dB)

N = 16

N = 12

N = 18

N = 18

N = 2

N = 6

N = 12

N = 29

N = 36

N = 15

N = 6

Gain deviation from NAL-NL2 (dB)

-20 -10 0 10

Female Male

NA gain (dB)

N = 16

N = 12

N = 18

N = 18

N = 2

N = 6

N = 12

N = 29

N = 36

N = 15

N = 6

Source: Keidser et al., 2008

Preferred AF gain vs NAL-NL2 (dB)

-20 -10 0 10 20 30 40 50 60

4FA HTL (dB HL)

New hearing aid users

Experienced hearing aid users
Adjustments to prescription to allow for experience

Gain preference over time

Source: Keidser et al. (submitted)
Gain; adults, low and high input levels

Smeds et al. 2006
Zakis et al. 2007

Preferred gain deviation from NAL-NL2 re gain preferred at 65 dB SPL in dB

Input level in dB SPL

Desired gain

Gain and compression; adults vs children

Output level

Children, NL2
NAL-NL1
Adults, NL2

Age dependent gain

Input level

Adults – congenital or acquired?

Preferred gain deviation from NAL-NL2 re gain

Congenital (N=15)
Acquired (N=28)
Compression

Limiting compression for severe/profound hearing loss (Fast compression)

NAL-NL2 prescribes different compression for slow and fast compressors for those with high degrees of hearing loss.

Compression ratio preferences: severe and profound hearing loss

Gain preference by aid configuration (N = 187)

Bilateral loudness correction too large – supported by newer data (e.g. Whilby, 2006; Epstein & Florentine, 2009)
Effect of language

- Gain at each frequency depends on importance of each frequency
- Low frequencies more important in tonal languages
- Two versions of NAL-NL2
  - Tonal languages
  - Non-tonal languages

Tonal versus non-tonal language
New features in NAL-NL2

- Different gain-frequency response shape and higher compression ratios
- Different compression ratios for fast and slow compressors (severe/profound hearing loss)
- Gender dependent gain
- Age dependent gain
- Gain adaptation for new hearing aid users
- Language dependent gain (tonal vs non-tonal)

Examples of prescriptions
Example audiogram: moderate sloping

Example audiogram: flat 60

Example audiogram: steeply sloping
Figure 5. Specific loudness for A-1 through A-4 based on a 65 dB international long-term average speech spectrum input in quiet. Overall loudness is shown to the right of the prescriptive method in the legends (NH designates normal hearing).

Johnson & Dillon, JAAA, 2011
Figure 5. Specific loudness for A-1 through A-4 based on a 65 dB international long-term average speech spectrum input in quiet. Overall loudness is shown to the right of the prescriptive method in the legends (NH designates normal hearing).

Johnson & Dillon, JAAA, 2011

Figure 7. Overall loudness of each prescriptive method averaged across the five sensorineural hearing losses (A-1 through A-5) based on a 65 dB international long-term average speech spectrum input in quiet.

Johnson & Dillon, JAAA, 2011

Figure 8. Average Speech Intelligibility Index (SII) value for speech in quiet across the five sensorineural hearing losses for each prescriptive method along with ANSI S3.5-1997 and National Acoustic Laboratories SII methods. Also shown is the SII transformed into a predicted speech recognition score (% correct) for the Connected Speech Test (Cox et al., 1987) using the transfer function of Humes (2002).

Johnson & Dillon, JAAA, 2011
We measure several times,

NAL & DSL groups have equal language outcomes

We measure several times,

NAL & DSL groups have equal language outcomes

Relationships between variables in NAL-NL2

Blue = User i/p
Grey = Internal variable
Red = effect of saturation
Dash-dot = alternatives
Green = stored data

Taking the pressure off prescription

The trainable hearing aid
Aid user adjusts settings...

Trainable Aid

Zakis et al (2007)

Process repeats for other sounds

Trainable Aid

After training...

...preferred settings are automatically applied
“A challenge for the profession is to devise fitting procedures that are scientifically defensible and the challenge for the individual audiologist is to choose the best procedures from whatever are available”

Denis Byrne, 1998

Acknowledgements

www.hearingcrc.org
www.nal.gov.au

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Thanks for listening