The Hearing Aid Fitting Process for Frequency Lowering Amplification

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Hearing Aid Fitting Process

• Rehabilitation Plan – 6 stages
  1. Assessment
  2. Planning
  3. Selection
  4. Verification
  5. Orientation
  6. Validation

• Evidence-Based Practice
  – “Guidelines for Hearing Aid Fitting for Adults”
  • 1998 ASHA Ad Hoc Committee, Am. J. Audiol. 7, 5-13

Assessment & Planning

• Type and magnitude of hearing loss
• Candidacy for frequency lowering
• Areas of need and potential benefit

Typical High Frequency Hearing Loss

Frequency, Hertz

Hearing Level, dB HL
Limits of Conventional Amplification

Typical HA Receiver Response

Triple Whammy
- Gain is least where speech energy is least & hearing loss is greatest

Nonlinear Frequency Compression

Frequency Transposition
**Candidacy**

- **Expected outcomes** vary depending on severity of loss
  - Moderately severe or greater loss
  - Precipitous high-frequency loss
  - Mild to moderate loss

- Influenced by the information we hope to ‘recover’ from the speech spectrum
  - **Different needs/goals** for different hearing losses

**Importance of High Frequencies**

- High occurrence of fricatives/affricates that carry significant morphological importance in English

- Developmental delays
  - **Fricative/affricate production** in toddlers, despite early amplification (Moeller et al., 2007)
  - **Morpho-syntax** in 5-7 year-olds identified late, especially for the morpheme /s/ (Moeller et al., 2010)

- Even **NH adults listening in quiet** can benefit
  - Relative importance increases in challenging listening conditions and with **decreased linguistic context**

**Benefits of Extending Bandwidth**

**Increasing bandwidth >5 kHz in the laboratory (no lowering)**

1. **Improved speech recognition** (Stelmachowicz & colleagues; Hornsby & Ricketts, 2006; Hornsby, 2007)
2. **Improved novel word learning by children** (Pittman 2008)
3. **Improved speech clarity and music quality** (Moore & Tan, 2003; Ricketts et al., 2008; Sjolander & Holmberg, 2009; Füllgrabe et al., 2010; Moore et al., 2011)
4. **Less effortful listening** (Karlsen et al., 2006)
5. **Improved localization** (Best et al., 2005; Brungart & Simpson, 2009)
6. **Improved spatial unmasking** (Hamacher et al., 2005; Moore et al., 2010)

**Frequency Lowering Evidence**

- **Alexander (2013)**
  - Review of modern techniques

- **McCreery et al. (2012)**
  - Evidence-based review focusing explicitly on children

- **Simpson (2009)**
  - *Trends in Amplification*, 13(2), 87-106.
  - Review of early techniques
Frequency Lowering Evidence
- There is not a lot of *good* evidence
  - Double-blinded, randomized control experiments
  - Many *uncontrolled variables* within and between studies, especially how settings are chosen for FL
- The evidence so far indicates that, when *properly set*, frequency lowering *does not do harm*
  - Estimate that about $\frac{1}{3}$ of *research subjects* fail to show a difference in outcomes with FL
- *Depends on how outcomes are measured*
  - Plural detection in quiet vs. sentence recognition in noise

Effectiveness - Points to Consider
- Results might be highly *individualized*
  - Perhaps the focus should be on *individuals*, in addition to group means — *do they form a subpopulation along one or more predictive factors?*
- *Interactions* with audiometric configuration, peripheral integrity, cognitive status, *FL settings*, etc. are expected
- Benefit may not always manifest as improvement in speech intelligibility, but perhaps, *ease of listening and effort* (like noise reduction), production accuracy, etc.

Modeling *Individual* Outcomes

Extrinsic Factors
- A. *Which sounds?*
  - Usually, most improvement for *fricative consonants*, especially /s/ (e.g., Alexander et al., 2012; 2014)
- B. *Which technique and settings?*
  - Likely depends on the sounds one is trying to restore (A) and the individual loss (C)
- C. *Which losses?*
  - As severity increases, so do potential benefits (Glista et al., 2009; Souza et al., 2013), but unfortunately, so do the challenges (e.g., Hopkins et al., 2014)

Extrinsic Factors

Intrinsic Factors

Alexander (2013)
Intrinsic Factors

A. Adults vs. children
   - No differences observed when both groups have the same treatment (McCreery et al., 2014; Brennan et al., 2014)

B. Age of hearing loss onset
   - Pre/post linguistic differences and etiology may relate to the amount of deficit, hence amount of benefit – no data

C. Acclimatization
   - Maybe some improvement in children over 6 weeks to 6 months (Wolfe et al., 2011; Glista et al., 2012); maybe no improvement in adults (Hopkins et al., 2014)

D. Role of cognition
   - Amount of relearning needed may mediate this factor
     - (YES: Arehart et al. 2013; NO: Ellis & Munro, 2013)

Potential Side Effects

- While the speech code is relatively ‘scale invariant,’ it is heavily dependent on frequency
  - No currently implemented strategy has as much potential to change the identity of individual speech sounds
  - Potential to make speech understanding worse because low-frequency information has to be altered to accommodate displaced high-frequency information

- Re-coded information must go somewhere
  - Regions that otherwise would be amplified normally
  - Concern is not so much fidelity of re-coded information as it is newly introduced distortion and sound quality

Information-Theoretic Model

A successful fitting requires giving the patient more than is taken away

DO NO HARM
Depends on interaction b/w hearing loss & re-coding technique
less can equal more

Potential Pros vs. Cons

- (a) Wideband
- (b) Low Pass Filtered
- (c) NFC
**Settings vary Potential Pros vs. Cons**

![Graphs showing amplitude over time for different frequency bands]

(Rallapalli & Alexander, 20XX)

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**Candidacy Summary**

- **Loss ≥ Moderately-severe**
  - Go ahead, but be careful of distorting low frequencies
  - **WARNING!** If the hearing aid has FL, it might default to “ON” for certain audiometric configurations

- **Loss ≤ Moderate**
  - Do not base hearing aid selection on whether it has FL
  - There are **other important considerations**: cost, wireless connectivity, etc.
  - If the hearing aid you select has FL, it might be worth trying *(i.e., experimenting)*

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**To Fit or Not to Fit**

- Ultimately, a decision has to be made whether the **potential pros** outweigh the **cons**
  - *Does the patient experience speech perception deficits with conventional amplification, despite your best efforts to achieve high-frequency audibility?*

- If the decision is to fit, there are a few things to ask:
  1. How does the technology of choice work?
     - **Fundamental differences between manufacturers**: techniques, terminology, adjustments, etc.
  2. How much of the lowered information is **audible**?
  3. Can the patient **use** the lowered information?

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**Selection**

- *Choosing the frequency lowering technology whose electroacoustic characteristics are most likely to address the areas of need and result in benefit*
Techniques in Today’s Hearing Aids

- **Dynamic Linear Frequency Compression (DLFC)**

- **Frequency Transposition (FT)**
  - Widex: “Audibility Extender” (AE) – Introduced in 2006

- **Nonlinear Frequency Compression (NFC)**
  - Phonak: “SoundRecover” (SR) – Introduced in 2008
  - Unitron: same as Phonak – Adopted 2012
  - Siemens: “Frequency Compression” (FCo) – Introduced in 2012
  - ReSound: “Sound Shaper”– Introduced in 2014

- **Spectral Envelope Warping**
  - Starkey/Microtech: “Spectral iQ” – Introduced in 2011

- **Frequency Composition**
  - Bernafon: Introduced in 2012

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**Linear Frequency Transposition**

- **Start frequency** is start of inaudibility
- **Basic AE**: dominant peak shifted **down by 1/2** (octave), source region begins ½ octave **below** start frequency
- **Expanded AE**: dominant peak shifted **down by 1/3**, source region begins ⅔ octave **above** frequency start; peak shift from basic AE remains

Adapted from: Widex (9502088001 #01)
**Linear Frequency Transposition**

6 kHz 'start'

Source

Output

Actual start

Input

Target

Source content mixes with content in target region

**Nonlinear Frequency Compression**

Source Region ≈ 4500 Hz wide

Input BW

CR=2:1

Target Region ≈ 1800 Hz wide

**NFC for Moderately Severe Loss**

Source

Target

Flattened formant transitions

**Side Effects - Revisited**

Formant alteration, vowel reduction with low start freq.
**NFC for Mild-Moderate Loss**

![Diagram showing frequency bands for childen and like](image)

**NFC Differs between Manufacturers**

- What does “nonlinear” mean anyway???

- From the start frequency, the input-output frequency relationship is **defined by the compression ratio** (CR)
  - Higher CRs = greater reduction of source bandwidth
  - The relationship on a Hz scale is
    1. **Nonlinear** (but linear on a log scale) – Phonak/Unitron
    2. **Linear** – ReSound
    3. **Indeterminate** (by me!) – Siemens

**Spectral Feature Translation**

**Before**

![Spectral Envelope Warping Before](image)

**After**

![Spectral Envelope Warping After](image)
**Spectral Feature Translation**

*Figures showing spectral features of speech.*

**Frequency Composition**

*Figures showing frequency composition of speech.*

**Summary of Strategies**

<table>
<thead>
<tr>
<th>Activation</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Dependent</td>
<td>Compression</td>
</tr>
<tr>
<td>Always Active</td>
<td>Transposition</td>
</tr>
<tr>
<td>AVR (linear @ 0 Hz)</td>
<td>Starkey (feature lowering)</td>
</tr>
<tr>
<td>Phonak/Unitron</td>
<td>Widex (peak lowering)</td>
</tr>
<tr>
<td>Siemens</td>
<td>Bernafon (frequency composition)</td>
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</tbody>
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*(Angelo, Alexander, et al., 2015)*
Frequency Lowering Taxonomy

- **Technique**
  - Compression (AVR, Phonak, Siemens, ReSound, Bernafon)
  - Transposition (Widex, Starkey, Bernafon)

- **Activation**
  - Input dependent (AVR, Starkey)
  - Always active (Phonak, Siemens, ReSound, Widex, Bernafon)

- **Bandwidth** (not an issue if use probe mics)
  - Source region preserved (Starkey, Bernafon)
  - Source region rolled off (AVR, Phonak, Siemens, ReSound, Widex)

- **Additional gain for lowered signal**
  - No (Phonak, Siemens, ReSound)
  - Yes (AVR, Widex, Starkey, Bernafon)

Potential side effects

- Masking (Widex, Starkey, Bernafon)
- Formant alteration (AVR, Widex, Phonak, Siemens, ReSound)

Methods for preserving low frequencies

1. **How**: maintain harmonics (Widex, Starkey, Bernafon)
2. **Where**: > 1.5 kHz only (Phonak, Siemens, Bernafon)
   > 2.5 kHz only (ReSound)
3. **When**: ‘feature detector’ (AVR, Starkey)

Verification

- Probe microphone measurements to guide programming of different frequency lowering techniques for individuals

To Fit or Not to Fit

- Ultimately, a decision has to be made whether the potential pros outweigh the cons
  - Does the patient experience speech perception deficits with conventional amplification, despite your best efforts to achieve high-frequency audibility?
- If the decision is to fit, there are a few things to ask:
  1. How does the technology of choice work?
     - Fundamental differences between manufacturers: techniques, terminology, adjustments, etc.
  2. How much of the lowered information is audible?
  3. Can the patient use the lowered information?
Importance of Probe Mic Measures

With the possibility of side effects causing ‘harm,’ if you plan to fit a hearing aid with FL, you must know what you are delivering to the patient

Primary Goals for Probe Mic Measures

1. The audible bandwidth after FL is activated should not be less than it was before it was activated
   - FL should not unnecessarily restrict the audible bandwidth
2. The lowered information should be audible
3. The ‘weakest’ FL setting should be used to accomplish your objective
   - Frequency Lowering Fitting Assistants: www.tinyURL.com/Flassist

Protocol for Fitting FL Hearing Aids

1. Deactivate frequency lowering and fit the hearing aid to targets using probe mic as for a conventional aid
2. Find the maximum audible frequency, MAF
   - The highest frequency at which output exceeds threshold on the SPL-o-gram (Speechmap)
3. Activate FL and position the lowered speech in the audible bandwidth (MAF) while not reducing it further
   - Most of the target region should be audible
   - Avoid too much lowering, which will unnecessarily restrict the bandwidth you had to start with and reduce intelligibility
1. Deactivate NFC and Fit to Targets

2. Find the maximum audible frequency

3. Activate NFC, adjust settings

3. Verify Bandwidth of Chosen Setting

Special Caveat with Transposition

- With frequency compression, the levels of the input speech spectrum can be inferred by from the amplified output and the Fitting Assistants.

- However, because transposition mixes the signals, you cannot tell what the contribution of each is to the overall amplified levels.

  While the Fitting Assistants can indicate whether the transposed speech has been moved to a region where aided audibility is possible, they cannot specifically verify that the transposed signal is audible.
Special Verifit Test Signals

Orientation
- Counsel on use of the technology and foster realistic expectations

Validation
- Evaluation impact of the technology on areas of need and overall benefit

More on AudiologyOnline.com
- 20Q: The Highs and Lows of Frequency Lowering Amplification (Article # 11772) by J. Alexander
- 20Q: The Ins and Outs of Frequency Lowering Amplification (Article # 11863) by S. Scollie
- 20Q: Frequency Lowering - The Whole Shebang (Article # 11913) by G. Mueller, J. Alexander, & S. Scollie
- Frequency Compression - Understanding the Clinical Application (Webinar # 23078) by S. Scollie

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