Nonlinear Frequency Compression for the Busy Clinician

Joshua M. Alexander, Ph.D.
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Course Objectives

1. After this course, participants will be able to identify potential candidates for nonlinear frequency compression.

2. After this course, participants will be able to describe the advantages and disadvantages of nonlinear frequency compression.

3. After this course, participants will be able to describe the goals in selecting the most appropriate nonlinear frequency compression settings and how to verify that these goals have been met.
Nonlinear Frequency Compression for the Busy Clinician

Joshua M. Alexander
Ph.D., CCC-A

www.tinyURL.com/FLassist
Hearing Aid Fitting Process

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

Benefit

(ASHA Ad Hoc Committee on Hearing Aid Selection and Fitting, 1998)

Assessment & Planning

- Type and magnitude of hearing loss
- Candidacy for frequency lowering
- Areas of need and potential benefit
Typical HA Receiver Response

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

Nonlinear Frequency Compression
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

Moderately Severe Losses (or worse)

• Limitations in hearing aid **gain and feedback**
  • Important mid-frequency information is inaudible

• High-frequency **dead regions**
  • May not make as effective use of amplified high-frequency **speech-in-quiet** and may even **perform worse** when made audible
    • E.g., Moore, 2004; Baer *et al.*, 2002; Vickers *et al.*, 2001

• **Possible goals for outcomes**
  1. Provide users with information that is normally available to those with less severe hearing loss (~5kHz)
  2. Avoid dead regions
Precipitous Losses

- Need help that conventional amplification cannot provide
  - Marginal candidates for amplification
  - Limited frequency range with which to amplify speech because of difficulty getting sufficient gain in regions of hearing loss
    - Too normal to amplify and too severe to amplify

- Possible goals for outcomes
  - Help users make better use of a very limited residual bandwidth of audibility (e.g., < 2000 Hz)

Limitations in Candidacy

- Most nonlinear frequency compression algorithms do NOT lower frequencies < 1500 Hz
  - Done intentionally to limit the amount of degradation to sound quality and pitch that results when low-frequency harmonics are altered

- There must be a region of aided audibility above 1500 Hz
  - Someone with severe or profound loss starting at 1500 Hz or lower is NOT a candidate for ‘conventional’ nonlinear frequency compression
Mild to Moderate Losses

- **Rationale for frequency lowering**
  - Provide users with information that is beyond the bandwidth normally achievable with conventional amplification (>5 kHz)
  - Improve perception (and production) of fricatives, especially /s/
  - Possibly reduce listening fatigue and improve sound quality by providing a fuller, richer signal

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)

- Other potential benefits of extending bandwidth
  - Speech recognition, novel word learning by children, speech clarity and music quality, listening effort, localization, spatial unmasking
Candidacy Summary

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

• **Loss ≤ Moderate**
  - Do **not** base hearing aid selection on whether it has NFC
    - There are **other important considerations**: cost, wireless connectivity, etc.
    - If the hearing aid you select has NFC, 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?*
Selection

- Choosing the frequency lowering technology whose electroacoustic characteristics are most likely to address the areas of need and result in benefit

Nonlinear Frequency Compression

(Alexander & Rallapalli 2017)
Nonlinear Frequency Compression (NFC)

- Adjustable start frequency \(f_{\text{min}}\) and CR \(f_{\text{max}}\)
- Key feature is that frequencies below the start are unaltered

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 mathematical relationship on a Hz scale is
    1. Nonlinear (but linear on a log scale) – Phonak/Unitron
    2. Linear – ReSound
    3. Other – Signia

CR is not compatible across manufacturers! Cannot apply same settings when switching brands and expect the same output.
NFC for Mild-Moderate Loss

Before Lowering

After Lowering
NFC for Moderately Severe Loss

**Before Lowering**

*Formant transitions*

NFC for Moderately Severe Loss

**After Lowering**

*Formant transitions (now flattened)*
Potential Side Effects

• While the speech code is relatively ‘scale invariant,’ it is heavily dependent on frequency
  • No hearing aid feature 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

Potential Pros vs. Cons

(a) Wideband
(b) Low Pass Filtered
(c) NFC

(Alexander, 2016)
Side Effects

Formant alteration, vowel reduction with low start ($f_{\text{min}}$)

Settings vary Potential Pros vs. Cons

(Rallapalli & Alexander, 2016)
/ʃ/ for /s/ Confusions

Verification

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

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

“I stopped taking the medicine because I prefer the original disease to the side effects.”
Primary Goals for Probe Mic Measures

1. The audible bandwidth after NFC is activated should not be less than it was before it was activated
   • Do not unnecessarily restrict the audible bandwidth

2. The lowered information should be audible

3. The ‘weakest’ NFC setting should be used to accomplish your objective
   • Frequency Lowering Fitting Assistants: www.tinyURL.com/FLassist

Protocol for Fitting NFC Hearing Aids

1. Deactivate frequency lowering and fit hearing aid to targets using probe mic as for a conventional aid

2. Find maximum audible output frequency, MAOF
   • The highest frequency at which output exceeds threshold on the SPL-o-gram (Speechmap)
   • Activate NFC and position the lowered speech in the audible bandwidth (MAOF) 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

3. Verify that the MAOF is reasonably close to what it was when it was deactivated
1. Deactivate NFC and Fit to Targets
2. Find the maximum audible frequency

3. Activate NFC, adjust settings

www.tinyURL.com/FLassist
3. Verify Bandwidth of Chosen Setting

Steps 1 & 2 (Signia NFC)

Deactivate NFC

Fit to targets and find the maximum audible frequency
Step 3 (Signia NFC)

\[ f_{\text{min}} = 2.0 \text{ kHz} \]
\[ f_{\text{max}} = 3.5 \text{ kHz} \]
**Step 3 (Signia NFC)**

Output Frequency, kHz

Input Frequency, kHz

\[ f_{\text{min}} = 2.0 \text{ kHz} \]
\[ f_{\text{max}} = 3.75 \text{ kHz} \]

**Step 3 (Signia NFC)**

Output Frequency, kHz

Input Frequency, kHz

\[ f_{\text{min}} = 2.0 \text{ kHz} \]
\[ f_{\text{max}} = 4.0 \text{ kHz} \]
Step 3 (Signia NFC)

Activate NFC, adjust settings

Verify bandwidth of chosen setting

NFC off (Speech)
NFC off (MPO)
NFC On (Speech)
NFC On (MPO)
**Alexander’s Priorities** for Signia NFC

1. $f_{\text{max}} \geq$ maximum audible output frequency (MAOF)
   - Do **NOT** restrict the aided bandwidth
   - Watch the CRs, don’t be afraid to set $f_{\text{max}}$ beyond MAOF (e.g., 0.5 kHz), especially as audibility becomes more restricted
     - **Tradeoff:** less high-freq. energy is lowered into audible region

2. If possible, keep $f_{\text{min}} \geq 2.25$ kHz (Alexander, 2016)

3. **Audible** target region (MAOF − $f_{\text{min}}$) = 1.25-2.0 kHz
   - Connexx 8 will not allow target region to be < 0.75 kHz
   - If $f_{\text{min}} \geq 2.25$ kHz, might still benefit with 1 kHz (Alexander, 2016)

**/s/-/ʃ/ Verification**

- Calibrated /s/ and /ʃ/ test stimuli provided by the Western University (UWO)
  - Evaluate audibility for /s/ and amount of overlap with /ʃ/
Orientation

• Counsel on use of the technology and foster realistic expectations

Validation

• Evaluate impact of the technology on areas of need and overall benefit

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Speech Tests

• **UWO Plurals Test**: Glista & Scollie (2012)
• **Phoneme Perception Test (PPT)**: Schmitt *et al.* (2015)
• **ORCA Nonsense Syllable Test**: Kuk *et al.* (2010)
• **Purdue s-sh Test (PUSSH)**: Alexander (201X)

More on [AudiologyOnline.com](http://www.AudiologyOnline.com)

• **20Q: Frequency Lowering Ten Years Later - New Technology Innovations** (Article #18040) by J. Alexander

• **An Update on Modified Verification Approaches for Frequency Lowering Devices** (Article #16932) by D. Glista, M. Hawkins, & S. Scollie

• **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
Thank you!!!