Lessons Learned From Over 4 Years of Frequency Transposition
Why Lower Frequency?

- Allows audibility of previously “inaudible” sounds
  - Information in the high frequencies moved/lowered to lower frequencies that are aidable
  - High frequency sounds are heard as low frequency sounds
- May be an unfamiliar percept
  - Avoid comparison to normal perception
  - It’s natural to be “unnatural”
- Do not lower if it can be amplified!
  - Not for mild losses
Frequency Transposition vs Frequency Compression - Normal

Low to High Frequencies
Frequency Transposition vs Frequency Compression – Hearing Impaired

- Good resolution
- Moderate resolution
- Poor resolution
- Dead region
Why Transpose?

Good resolution

Moderate resolution

Poor resolution

Dead region
Why Not Compress?

- Good resolution
- Moderate resolution
- Poor resolution
Audibility Extender – Linear Frequency Transposition

- Steps in linear frequency transposition
  - Analyse spectrum
  - Find sound
  - Set target
  - Transpose sound
  - Filter sound
  - Overlay sound
Studies We Have Conducted

- Normal hearing young adults with simulated high frequency hearing loss above 1600 Hz
  - To identify the efficacy of transposition without the potential confounding issues of hearing loss, cognitive differences, and “cortical reorganization”
- Adults with high frequency hearing loss (normal lows and mild loss in mids) using IN-9e thin-tube open-ear fitting (n =13)
  - To document the efficacy of AE
  - To understand potential issues when evaluating AE
- Children (6 ½ to 13 yrs, n = 10) with moderate loss in the lows and mids and severe-to-profound loss in the highs using IN-19
  - To document efficacy of AE in children with severe hearing losses
  - To examine the potential impact of AE on speech production
- Adults with moderate loss in the lows and mids and severe-to-profound loss in the highs using mind440 (n=8) evaluated on ORCA test
  - To evaluate efficacy in noise
  - To examine phonemic errors over time
- Adults with moderate loss in the lows and mids and severe-to-profound loss in the highs using mind440 (n=9) evaluated on ORCA test with lip-reading
  - To evaluate the impact of lip-reading on potential AE confusion


What We Have Learned So Far -
Frequency Lowering is “Distortion”

- Frequency lowering is a form of “constructive distortion”
How Could That Benefit You?

- Do not use frequency lowering unless you have to
- May degrade performance for those who do not need it
- When may you have to lower frequency?
  - Unaidable frequencies – dead region
  - Unreachable frequencies – insufficient gain
  - Consistency in amplification/audibility
What We Have Learned So Far – Transposition Means No Amplification
How Could That Benefit You?

• Choice of optimal start frequency (or when to start frequency lowering) is important

• Verification of fitting is important
Fitting of the Audibility Extender

- Start Frequency Rule (based on audibility):
  - intersection b/w the sensogram and average level of the aided speech spectrum
  - SF - 1.6 K to 6K Hz
    - higher of the two SF is chosen for both ears.
  - Check Speech Spectrum to ensure optimal SF – use individual SF if asymmetry ≥3 intervals
  - Use “Basic” if start frequency is 3200 Hz or higher
  - Use “Expanded” if start frequency is 2500 Hz or lower
  - Use AE as the first program
  - Use /s/ to estimate SF and AE gain
Verification of AE: SoundTracker

Original amplified – No need to transpose

Transposed, insufficient gain

Transposed - Sufficient gain

Original amplified – May need to transpose
Verification Using Verifit

**Master**

- Speech 3150
- Speech 4000
- Speech 5000
- Speech 6300

**AE SF = 4K Hz**
Comparing ST and Verifit: SF=4 KHz

Filtered male speech at 4000 Hz
What We Have Learned So Far - Differential Effectiveness

- The simpler the stimuli, the stronger and the earlier the preference
- Rate of acclimatization varies among individuals and tasks

![Graph showing preference for different listening materials (Birds, Music, Speech) across visits (Visit 2, Visit 3) for AE On and AE Off conditions.]

**Adult data**

**Children data**
How Could That Benefit You?

- Some measures are more sensitive than others to reflect AE benefits
- Use of a range of measures to document benefits
- Use of checklist to evaluate situations
Hierarchy of AE Benefits

- Detection of sounds - presence/absence
- Discrimination of sounds - same/different
- Identification of speech sounds
- Identification of simple sounds
- Production of speech sounds

- Hear sounds that have not heard awhile
- Words are clearer more distinct, less confused
- Improve speech under-standing, especially soft
- Improve articulation
- Improve voice quality
- Increase awareness, less fatigue, comfort
# Checklist of Everyday Sounds

## Sounds at home
### Kitchen:
1. Dripping faucet
2. Gas stove ignition
3. Microwave buttons
4. Microwave alarm
5. Cracking ice
6. Aluminum foil
7. Candy wrappers
8. Whistling tea kettle
9. Plastic bag/wrap
10. Dripping faucet

### Dining:
11. Silverware
12. Spoon stirring a drink
13. Ice clinking in a glass
14. Glasses clinking for a toast
15. Tapping glass with a spoon
16. Hitting chopsticks together
17. Soda fizzing
18. Other people eating
19. Chair scraping the floor

### Office:
20. Keyboard buttons
21. Rustling paper
22. Paperclips on hard surface
23. Clicking a pen
24. Scissors
25. Stapler
26. Computer sounds
27. Computer mouse click
28. Phone ring (in same room)
29. Phone ring (in other room)
30. Phone button tones

## Family Room:
31. Squeaky furniture
32. Door hinge
33. Ticking clock
34. Coo-coo clock
35. Adjusting window blinds
36. Fire crackling in fireplace
37. Door bell
38. Door locking
39. Rain on the roof
40. Various light switches
   a. Pull chain
   b. Standard flip switch

## Children:
41. Child’s squeaky toy
42. Child’s toy that plays music or beeps

## Pets:
43. Pet toe nails on tile
44. Pet collar tags
45. Whining dog
46. Meowing cat
47. Pet toys with bell or squeak

## Personal:
48. Clothes rustling
49. Brushing hair
50. Jewelry (ring on hard surface, noisy bracelet, etc.)
51. Watch alarm
52. Tapping fingernails

## Sounds in Public:
53. Hearing aid held in hand
54. Snap closures
55. Elevator bell
56. Coins jingling
57. Wet shoes on tile
58. Shopping carts
59. Instruments (ex: piccolo)
60. Cash register printing receipt
61. Music in stores over intercom (doctor’s office/waiting area)
62. High heel shoes on hard floor

## Sounds outdoors:
63. Cracking ice
64. Rustling leaves
65. Birds
66. Crickets
67. Whistling
68. Wind chimes
69. Bicycle bell

## Car sounds:
70. Car turn signal
71. Left key in ignition with door open (warning ding)
72. Door locking
73. Screeching tires
74. Checking air in tires (hiss)
75. Washing window or mirror
76. Shaking keys
What We Have Learned So Far – Vowels Are Minimally Affected

- It does not improve perception of vowel sounds unless the severity of loss extends to the lower/mid frequencies

Adult data at 30 dB HL

Children data at 30 dB HL
What We Have Learned So Far – Improvement in Speech Perception

- It improves perception of consonant sounds by 5 - 20% in adults and children (depending on input level)

Adult data at 30 dB HL

Children data at 30 dB HL
What We Have Learned So Far – Voiceless Fricatives Benefitted Most

50 dB quiet

68 dB quiet

Phoneme Class

Percent Correct [%]

V1: LFT off pre training  V2: LFT on pre training  V3: LFT on post training  V4: LFT on last visit
What We Have Learned So Far – Benefits Were Seen in Noise Also
What We Have Learned So Far –
Most Benefit in Final Word Position

68 dB Quiet

- Master
- AE - 2 months

Correct (%)

<table>
<thead>
<tr>
<th>Word Position</th>
<th>Master</th>
<th>AE - 2 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
What We Have Learned So Far – Differences in Evaluation Materials

Consonants in full list

- Male speaker
- Female speaker

Correct (%)

Cutoff Frequency (Hz)

0 10 20 30 40 50 60 70 80 90 100

500 1000 1500 2000 4000 Full Band
How Could That Benefit You?

- Set realistic expectations to counsel patients
  - Magnitude of speech improvement
- Types of speech sounds most benefit from:
  - Fricative
  - Voiceless
  - Final consonant positions
  - Omission
- Test materials to evaluate benefit
  - Female and fricative sounds
How Could That Benefit You – A Simple Validation Test

<table>
<thead>
<tr>
<th>CV (voiced)</th>
<th>CV (unvoiced)</th>
<th>VC (voiced)</th>
<th>VC (unvoiced)</th>
</tr>
</thead>
<tbody>
<tr>
<td>bee</td>
<td>pee</td>
<td>eeb</td>
<td>eep</td>
</tr>
<tr>
<td>dee</td>
<td>tee</td>
<td>eed</td>
<td>eet</td>
</tr>
<tr>
<td>gee</td>
<td>kee</td>
<td>eeg</td>
<td>eek</td>
</tr>
<tr>
<td>vee</td>
<td>fee</td>
<td>eev</td>
<td>eef</td>
</tr>
<tr>
<td>THee (ð)</td>
<td>thee (θ)</td>
<td>eeTH (ð)</td>
<td>eeth (θ)</td>
</tr>
<tr>
<td>zee</td>
<td>see</td>
<td>eez</td>
<td>ees</td>
</tr>
<tr>
<td>zhee (ʒ)</td>
<td>shee (ʃ)</td>
<td>eezh (ʒ)</td>
<td>eesh (ʃ)</td>
</tr>
<tr>
<td>dgee (dʒ)</td>
<td>chee (tʃ)</td>
<td>eedg (dʒ)</td>
<td>eech (tʃ)</td>
</tr>
</tbody>
</table>

- Present one list (order of difficulty: CV – v, VC – v, CV – unv, VC – unv)
- Present at 30 dB HL and/or 50 dB HL
- Randomize order or presentation, record number correct
- Compare master and AE (at various F/U)
What We Have Learned So Far – Initially There May Be Confusions

Only phonemes showing >10% changes are shown; circled phonemes showed decreased performance
What We Have Learned So Far – Confusion Eased Over Time

Initial

One month

Two months
What We Have Learned So Far – Lip-Reading Reduced Confusion

Table 1: Most common confusion pairs for LFT measured at 50dB SPL in quiet in audio only mode sorted in descending order with most common confusions first. Alongside are shown the frequency of occurrence for these confusions in audio-visual mode and the absolute improvement.

<table>
<thead>
<tr>
<th>Stimulus</th>
<th>Response</th>
<th>Confusions in auditory condition [%]</th>
<th>Confusions in audio-visual condition [%]</th>
<th>Improvement [%]</th>
<th>Distinct visemes</th>
</tr>
</thead>
<tbody>
<tr>
<td>η</td>
<td>m</td>
<td>40</td>
<td>0</td>
<td>40</td>
<td>YES</td>
</tr>
<tr>
<td>d₁</td>
<td>d</td>
<td>40</td>
<td>10</td>
<td>30</td>
<td>YES</td>
</tr>
<tr>
<td>g</td>
<td>d</td>
<td>40</td>
<td>40</td>
<td>0</td>
<td>YES</td>
</tr>
<tr>
<td>k</td>
<td>t</td>
<td>40</td>
<td>27</td>
<td>13</td>
<td>YES</td>
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<tr>
<td>δ</td>
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<td>f</td>
<td>34</td>
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<td>t</td>
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<td>2</td>
<td>29</td>
<td>YES</td>
</tr>
<tr>
<td>wh</td>
<td>l</td>
<td>30</td>
<td>50</td>
<td>-20</td>
<td>NO</td>
</tr>
<tr>
<td>n</td>
<td>m</td>
<td>27</td>
<td>0</td>
<td>27</td>
<td>YES</td>
</tr>
<tr>
<td>j</td>
<td>l</td>
<td>25</td>
<td>0</td>
<td>25</td>
<td>YES</td>
</tr>
<tr>
<td>z</td>
<td>v</td>
<td>25</td>
<td>0</td>
<td>25</td>
<td>YES</td>
</tr>
</tbody>
</table>
How Could That Benefit You?

- Set realistic expectation and counseling
- In real-life, initial confusion from auditory input may be reduced because of visual input
- Initial negative reaction may be temporary and transitory
What We Have Learned So Far – Greater High Frequency Loss, Greater Speech Improvement

**Start frequency & phoneme class**

- **<2.5 kHz, consonants**
- **<2.5 kHz vowels**
- **3.2 kHz, consonants**
- **3.2 kHz, vowels**

**Identification score [%]**

- **AE off pre-training**
- **AE on pre-training**
- **AE on post-training**
- **AE on last visit**

50 dB in Quiet
What We Have Learned So Far – Greater High Frequency Loss, Greater Speech Improvement

Adult subjects showing greater loss, more frequent use of AE

Pediatric subjects showing those with poorer speech scores received greater improvement with AE
How Could That Benefit You?

• Benefit expectation
  – Milder loss may show less improvement on speech tests – include other test measures

• Candidate selection
  – People with moderate HL (50-60 dB) at 1000 and 2000 Hz are likely to show most speech improvement
What We Have Learned So Far – Audibility of Soft Sounds

50 dB HL input

30 dB HL input
How Could That Benefit You?

- Expand the fitting range to those with only 60 dB or so loss in the highs with a start frequency at 4000 or 6000 Hz to increase consistency of audibility of such sounds.
What We Have Learned So Far – Improvement in Speech Production
What We Have Learned So Far – Improvement in Speech Production

Articulation Errors (GFTA 2)

![Graph showing articulation errors](image)
Example of Improvement in Speech Production - Baseline
Example of Improvement in Speech Production – 6 Months
How Could That Benefit You?

- Evaluate speech production skills at pre and post sessions, especially for children
- Work closely with speech pathologists
- Counsel and set right expectations
What We Have Learned So Far – AE Training Facilitates Improvements

![Bar chart for adult and children scores with AE Off and AE On conditions.](chart)

- Adult scores: AE Off vs. AE On across visits 1, 2, and 3.
- Children scores: Identification score (%) for Consonants and Vowels across Own aid, Master baseline, Master post AT, AE baseline, AE post AT1, and AE post AT2 conditions.
What We Have Learned So Far – AE Training Facilitates Improvements

- Initial:
  - 14% correct
  - 41% substitutions
  - 45% omissions

- One month w/ training:
  - 11% correct
  - 49% substitutions
  - 40% omissions

- Two months:
  - 7% correct
  - 58% substitutions
  - 35% omissions

- AE program:
  - 33% correct
  - 60% substitutions
  - 7% omissions

- Master program:
  - 37% correct
  - 54% substitutions
  - 9% omissions
What We Have Learned So Far – Stable Improvement Over Time

Pediatric data, 30 dB HL

Pediatric data, 50 dB HL
How Could That Benefit You?

• Sensitization (e.g., training) to AE is needed to realize full speech benefit
• Training alone without AE did not yield as much speech benefit as training with AE (i.e., cues must be available)
• Counseling on immediate benefit and training
• Activities to promote sensitization
• Schedule to examine benefit
The Widex Training CD

- Take-home CD running on MS Windows 2000 and higher, need loudspeaker with VC
- Objective is to increase attention to and identification of targeted sounds in quiet and in noise; for adult use only
  - Directed listening to *voiceless consonant* sounds / p, t, k, s, f, Θ, й, тʃ/ and all vowels
  - Not targeted at specific auditory skills such as auditory closure etc (but hopefully attention, discrimination and memory skills are heightened)
  - Has option to perform training in variable noise backgrounds
  - Appropriate for anyone with a hearing loss, but especially ideal for those with a sloping high frequency loss
  - Each CD (2 - vowel and consonant) is a 10-day, 20-30 min training
- Materials read by three speakers (2 females & one male)
- Not meant to replace commercial materials; NOT VALIDATED
- Clinician demo of use and patient commitment are important
Selected Exercises

- Sound matching - both
- Picture puzzle - both
- Crossword - both
- Count the number - consonant
- Sound matrix - vowel
What We Have Learned So Far: Moderate Losses Also Benefit

- 37 yr old male, Diva CIC
- Patient works for an office security company
- Struggles to hear the beeps of the systems
- Does not want BTE; needs >2 mm vent
- Attempted mind440 CIC w/ 2 mm vent
- Though not typical AE candidate, gave AE in order to hear the beeps of the security systems – SF at 4K Hz
- Patient LOVES the AE – uses a remote with his CICs
- Uses AE at work/during installation
- Revised view on candidacy
  - Primary Group
  - Regions of unaidable or unreachable hearing (>80 dB HL) along with regions of aidable hearing (<70/80 dB HL) – speech focus
  - Secondary Group
  - Mild to moderate loss in highs to provide consistent audibility. SF at 4K or 6 K Hz
What We Have Learned So Far: Insistent on Recommendations

- 6 year old girl fitted with M4-19 for 6 mos
- AE was given as first program
  - start frequency at 2K, expanded
  - AE gain +6 and +8
  - coupled with DAI
  - received AR training with Widex CD
- Reported by speech pathologist –
  - some vowel & consonant confusion/substitution
  - perception and production of /s/ improved
  - vowel/consonant confusion cleared within three weeks
- Why and should something be done to minimize confusion?

- Vowel confusion possible with SF < 2.5 K Hz
  - increase SF reduces confusion –
    but may compromise AE benefit
- Consonant confusion because transposed sounds similar in frequency as original ones
- But use of AE will resolve problems – be firm in recommendations
What We Have Learned So Far: Consider Acceptance in Adults

- Male 84 yr
- Speech in quiet 48% at 70 dB HL
- Wears Mind440-19 AU; vent – 2 mm
- AE start frequency at 2500 Hz, gain +4
- What would SF be if audibility criterion?

- After 2-weeks use,
- Heard much clearer, understood speech
  - master program – 80%
  - AE – 88%
- Family noticed improvement; but patient expects normal hearing – need counseling
- A lower SF may further improve performance – but at expense of acceptance
What We Have Learned So Far: Consider Acceptance in Adults

• Male 56yr accountant
• Loss from car accident; disc 32%
• Speech (own) deteriorating
• Wore ReSound and AVR w/o success
• What can be done?
  • Wears IN-9, élan flex, 3 mm vent
  • AE start frequency at 3200 Hz, AE gain +4
    • heard things hasn’t heard for a while
    • two programs – master and AE
  • After 3 weeks, wants AE to be first and only
    • start frequency at 2500 Hz, AE gain +2
    • (an audibility change)
  • After 2 months, disc 42-48%,
  • Can monitor own voice
  • There may be more undetected improvement
How Could That Benefit You?

- The criteria to fitting the AE in adults and children may be different
- For children, AE should always be used for the purpose of improving audibility
  - Use default (or individual /s/) start frequency and use as first program and on 24/7 basis
  - Accept a milder loss (60 dB HL at 4000 Hz)
- For adults, may consider a multi-stage approach
  - Accept occasional use of AE
  - Accept use of a higher than needed (default) start frequency – with gradual adjustment of SF over time
  - Provide 2 AE programs with 2 SF
A Recap on Frequency Transposition

- Decision to use frequency lowering
  - Do not use frequency lowering unless you have to
    - Unaidable frequencies – dead region
    - Unreachable frequencies – insufficient gain
    - Consistency in amplification/audibility
Candidate selection

- People with moderate HL (50-60 dB) at 1000 and 2000 Hz and severe to profound loss at higher frequencies are likely to show the most speech improvement.
- Those with only 60 dB or so loss at 4000 Hz or higher may use SF at 6000 Hz to increase consistency of audibility.
A Recap on Frequency Transposition

• Fitting to ensure optimal settings
  – Choice of optimal start frequency (or when to start frequency lowering) is important
    • /s/ approach or default
  – Verification of fitting is important
    • SoundTracker
• Expected benefits
  – Simpler sounds showed more immediate benefits
  – Milder loss may show less improvement on speech tests
  – Speech sounds that benefit most
    • Fricative
    • Voiceless
    • Final consonant position
    • Omission errors
  – Benefits reported in quiet and in noise
A Recap on Frequency Transposition

- Potential confusion
  - Stop (and some fricative) consonants depending on SF
  - Vowels if SF < 2500 Hz
  - Confusion temporary/transitory because
    - Visual input (from facial and lip reading)
    - Learning / training/acclimatization
A Recap on Frequency Transposition

• Counseling
  – Set appropriate expectations
    • Hierarchical benefits
    • Magnitude of speech improvement
    • Time course of benefit
  – Insistent in patient compliance
    • The criterion of audibility is critical in children
    • May consider the use of multi-stage SF in adults
A Recap on Frequency Transposition

- Validation measures
  - Some measures are more sensitive than others to reflect AE benefits
    - Female speech with fricatives and stops would be most sensitive
  - Use of a range of measures to document benefits
    - Include speech production assessment in children
    - Use of checklist to evaluate situations
• Importance of training/acclimatization
  – Sensitization to AE is needed to realize full speech benefit
  – Consistent use of AE to facilitate habituation
  – Activities to promote sensitization
  – Schedule to examine benefit