HEARING AID FEATURES ACROSS MANUFACTURERS: WHAT REALLY WORKS AND CLINICAL IMPLICATIONS

Todd A. Ricketts, PhD
Associate Professor and Director of Graduate Studies
Department of Hearing and Speech Sciences
Director, Dan Maddox Memorial Hearing Aid Research Laboratory
Vanderbilt University Medical Center
Nashville, TN

Financial Disclosures
- Financial support for this presentation was provided by the MSHA
- I have the following financially relevant relationships in the service and/or product communicated, compared, evaluated and/or reviewed in this presentation.
- Some of the data presented was supported by investigator initiated research grants provided by the Dan Maddox Foundation, Phonak AG, GN Resound, Siemens, Starkey, Oticon, Widex, Persona Medical, Frye Electronics, the Department of Veterans Affairs, and the US National Institute of Disabilities and Rehabilitative Research (NIDRR - DOE)

Did You Know #1 . . .
About 85% of hearing health care providers have a “favorite” manufacturer (Johnson & Ricketts, 2011)

Did You Know #2 . . .
Hearing health care providers who have a favorite manufacturer, fit that product to about 80% of their patients.

Did You Know #3 . . .
Regardless of what company of the “Big Six” they all reported they picked the company because it had the best technology. THEY CAN’T ALL BE RIGHT!

How to try to ensure satisfied patients?
- Examine the Patient’s communication and listening needs and based on the evidence select and adjust features and processing to best address those needs.
- Counsel regarding use and benefit from technologies to make sure the patients expectations are met.
- Satisfaction = Expectations Met!
Why is Evidence Based Research Particularly Important in Modern Hearing Aids?

- 16 Participants compared two devices that were acoustically identical, except one was described as “new” and the other as “conventional”. Participants completed a speech-in-noise test, sound quality ratings, and rated overall personal preference for both hearing aids.
- Significantly better mean speech-in-noise performance (70.9% versus 66.8%), and sound quality ratings for the “new” hearing aid
- 75% expressed an overall preference for the “new” hearing aid - double-blind methodology is optimal.

Finally, we’ll grade each feature in 3 different areas...

- What is the true patient benefit in the real world (our best guess if limited studies available)?
  - A = Real and valid benefit, F = No benefit expected even theoretically.
- If benefit is present, would it apply to a wide range of patients?
  - A = Nearly all patients; F = you may stumble across a couple of patients that benefit during your career.
- Would you expect the same benefit from the products from different manufacturers?

The 4 features we’ll discuss

- Sophisticated Gain Processing
  - Complex amplitude compression
  - Sliding gain windows, etc.
- Directional Technology
- Advanced Microphone Array Technologies
  - Adaptive Directional Lobe
  - Steering, Bilateral Beamforming
- Digital Noise Reduction
  - Frequency Lowering
  - Frequency Compression, Frequency Transposition, Frequency Duplication, and Frequency Duplication
- Trainable Algorithms
- Learning VU Acclimatization Managers
- Wireless Routing Applications (not sound sharing)
- Rechargeable, advanced remote controls (or other cool features?)

What we’re going to do...

- Review X different hearing aid features.
  - Selected based on features for which either the manufacturer or the specific patient, or the listening environment is likely to matter significantly based on the data (or all three).
- Limit our discussion of patient benefit primarily to adults.
- Review some of our recent research and pull in some studies from the recent literature.
- Provide a few clinical tips and techniques along the way.

Interpreting the grades for the third category

- Small or No Difference (SD): Few patients would notice a difference for that feature among products from different manufacturers.
- Medium Difference (MD): Many patients would notice a difference for that feature among products from different manufacturers.
- Large Difference (LD): Most patients would notice a difference for that feature among products from different manufacturers. Or differences are so large that the feature is aimed at different populations based on the specific design.

Take Home Points for The 8 Features That Didn’t Make the Cut

- Sophisticated Gain Processing
  - Modern versions work pretty well and generally fairly equally when looking at group data. Individual differences are present and generally complicated.
  - Some emerging data in the youngest kids
- Digital Noise Reduction
  - Improved comfort and preference, still hoping for more
- Tinnitus Masking
  - We know a lot about it when not in hearing aids, new versions are too new to know if there are other advantages other than packaged in a hearing aid.
- Bilateral Shared Information
  - Emerging spatialization advantages.
- Remote microphone/FM
  - They work, lots of questions.
- Extended High Frequencies
  - Slight benefit and preference in listeners with flatter high frequency loss, hard to provide enough gain.
- Frequency Lowering
  - On average works in kids – no average benefit in adults
  - Newest outcomes less than hoped!
- Trainable Algorithms/Acclimatization Managers
  - May lead to better satisfaction, but starting from a validated and verified prescriptive gain is still critical.
Directional Technology: How Does It Work?

- The signal from two omnidirectional microphones (or two ports leading to a single microphone diaphragm) is altered to cause attenuation of signals from certain azimuths.
- Usually signals from sides or behind are attenuated.
- Signal alterations can be made to provide attenuation (polar pattern nulls) for a variety of azimuths.

Directional Technology: How Does It Work?

- The majority of directional hearing aids today are both automatic and adaptive:
  - **Automatic**: Based on the analysis from the signal classification system, the hearing aid will automatically switch to directional or omnidirectional depending on the listening environment.
  - **Adaptive**: Based on the analysis from the signal classification system, the polar plot will change in an effort to maximize the speech signal and minimize the background noise. This is only possible in twin microphone directional systems.
  - The most complex systems do not use discreet omnidirectional and directional states, but instead slide from lower to higher directivity depending on assumed acoustic environment.

Directional Technology: Potential Benefit?

- Patient must position himself correctly and the directional microphone must be functioning correctly.
- Directional microphones should improve the signal-to-noise ratio by 2-3 dB (20-35%) for many difficult listening situations.
- The actual benefit will depend on distance from the talker, room reverberation, and other factors.

Directional Technology: Patient Population?

- The potential for benefit applies to a wide range of patients:
  - **Adults with mild-severe hearing loss**
    - (e.g., Pumford et al., 2000; Ricketts, 2000; Ricketts, Lindley & Henry, 2001; Ricketts & Henry, 2002; Ricketts & Hornsby, 2003; Valente et al., 2000)
  - **Adults with severe-profound hearing loss**
    - (Ricketts & Hornsby, 2006; Ricketts, Henry & Hornsby, 2005)
  - **Children**
    - (Hawkins & Yacullo, 1984; Ricketts, Galster & Tharpe, 2007; Ricketts & Picou, 2013)

Other factors that might limit Directional benefits

- Interaction between visual cues and directional benefit
- Effects of hearing aid coupling type (open versus closed)
- Directional microphone stability over time (quality control)

What About Directional/Beamformer Benefit with Vision?

- Wu & Bentler (2012)
- Aspell, Picou & Ricketts (2013)
Wu and Bentler (2010)

Purpose

• The purpose of the investigation was to examine directional benefit in environments with low or moderate reverberation across three common SNRs (+3, +6, +9 and/or +12) for AV presentation modes.
• Selected individuals who struggled in noise (Quick-SIN +8 dB SNR or poorer)

Results

• Large directional benefits seen in all conditions
  • 21-30% (Average: 24.46%)

What About Coupling?

• Will a directional microphone work in an open fitting?
Findings from Valente and Mispagel (2008) comparing OC omnidirectional to OC directional

SO IS THERE POORER PERFORMANCE IN NOISE FOR DIRECTIONAL OC?

New Preliminary Data!

- The Effects of Hearing Aid Coupling and Signal Source Location on Benefit From Different Microphone Types

Harland, Picou, Hornsby, Tharpe, & Ricketts (in preparation)

Purpose

- To evaluate the potential interaction between coupling configuration (open versus closed), signal source location (on-axis versus off-axis), and microphone type (omnidirectional, directional, FM plus environmental microphone) on the speech recognition in noise abilities of pre-teens and teenagers with hearing loss (10 completed to date).

Test Environment

- Average reverberation time (60 dB decay) within the moderate range (500-800 ms)

Results – On Axis Listening
Clinical Implications

- The open fitting reduces speech recognition in noise performance for all microphone types by about 1 dB (10 percentage points).

- For patients who struggle the most with speech recognition in noise, fitting with closed coupling may be preferred to optimize benefit.

Current Conclusions – Directional Microphones when facing the talker

- In the hearing aids it works in - it works pretty well, even with vision.

- Do the directional microphones used in hearing aids general operate as expected, or are their quality control and/or failure in the field issues we should be concerned about?

Quality Control

- Maximum directivity (average DI or AI-DI) across instruments varies from about 1.5 dB to about 5.7 dB

- Dirt and damage will affect the average instrument over time affecting directivity and the benefit our patients

Clinical experience suggest nearly all manufacturers continue to have at least some issues with quality control.

- Perhaps as high as 5-10%!

- This happens both with new and repaired instruments.

Effect of Time – Newer Data From a VA Study

- Clinically assessed FBR on all instruments before fittings and after every two month trial.

- For ITE instruments this was a single trial of approximately two months.

- For BTE instruments, were refitted on more than one patient for multiple (up to four) two month trials.

- Pilot work used to define average FBR for each type of instrument.

- A frequency averaged FBR of 6 dB less than average was considered a fail.

Directional Failure Rate for New and Fitted Instruments

A need for verification?

The Bottom Line: Clinical assessment of directional properties using a repeatable method is critical for QUALITY CONTROL!
Clinical Verification is Critical!

- Consider prior to or at the fitting and at every hearing aid check up.

- A few options….

- Does it function at all?
  - Directional Listening Test

- Does it function in an expected manner?
  - Front-to-back ratio (FBR/FSR)
  - Specialized Directional tests using hearing aid test equipment

SPECIALIZED TEST BOX
MEASURES OF DIRECTIVITY

Is Just Front and Back Enough?
Fonix 8000

The same compression, DNR and automatic switching issues as with FBR.

Specialized Directional Measure

- Some real ear or test box measures use two signals active at the same time (e.g. Audioscan) and can circumvent some of the FBR and polar plot issues such as compression
- DNR issues can also be alleviated by introducing speech as well
- Therefore it may be preferable if available as a quick clinical test.

Verifit Directivity Measure:
Interleaved Signal From “Front” and “Back” Loudspeaker

An Example of a Test Box Directivity Measure
Another Example of a Test Box Directivity Measure: Not So Great

Unfortunately, there are some strange interactions and some considerations!

- Feedback suppression interaction
- Should I use FBR or test box directivity measures for comparison across models?
  - No – Just quality control!

Why not compare across models with FBR or Test Box Measures?

Bilateral Lobe Steering: How Does it Work?

- Lobe steering is NOT an adaptive directional microphone
- The bilateral “direction of focus” is changed through one of a number of possible methods:
  - Bilateral directional control
  - Signal sharing
- Decisions about direction of focus are made by:
  - Automatic algorithms
  - Based on assumed speech of interest direction – so mistakes are possible
  - Manual Control
  - Requires user intervention

Some electroacoustic data from Wu & Bentler

Speech @ 0; Steady State Noise @ 180

Brand A

Brand B

Cardioid

Hypercardioid

Theoretical polar plots – so this is an oversell.
Compression interactions as well.
Speech @ 180; Noise @ 0

Speech @ 90; Noise @ 270

Some Behavioral Data
(HINT sentences from behind in steady noise from front)

Current Conclusions (Lab):
Bilateral Directional Steering

- For very specific listening situations - it works pretty well.

- Remaining Questions?
  - Automatic Switching Accuracy?
  - Manual Switching?
  - Best and worst environments? Car versus a restaurant

Bilateral beamforming:
How does it work?

- The signals from all four microphones across both hearing aids are used together to form an array with higher directivity.

- Potential problems:
  - Need to avoid a monaural signal or binaural cues will be distorted and localization will be destroyed.
  - Proprietary methods used to preserve binaural cues.
  - One method is to only apply the beamformer in the high frequencies which leaves low frequency interaural timing difference cues intact another attempts to preserve natural ILDs.
Cue Preservation in Slightly (natural) Directional, Directional and Beamformer?

Potential advantages to a beamformer (N = 18)

Are there significant downsides to this cue-preserving bilateral beamformer

• Higher battery drain
• Gross Localization?

Subjective Preference

• 13 of 18 participants preferred the beamformer or found it no different than standard adaptive directional when in noisy environments (including real “walking” trials).

• Why preferred?
  • Most common reasons were “louder” or “easier to hear”
Current Conclusions – Cue-Preserving Bilateral Beamformer

- Bilateral beamformer has the potential to provide additional speech recognition benefits over adaptive directional processing in moderate reverberation when listener is facing signal of interest

- Some localization issues, but preference was not significantly affected

Digital Feedback Suppression: How Does It Work?

- First, the feedback path is acoustically modeled in some cases for the individual patient.

- Ongoing cancellation within the feedback path is accomplished in a variety of ways including cancelation and frequency shifting.

Digital Feedback Suppression: Potential Benefit?

- When feedback is minimized or eliminated, patients are more apt to wear their hearing aids.

- Acoustic feedback is known to be a stigma associated with hearing aid use.

- With less feedback, there is a high probability that more use-gain will be available without venting alterations.

- The reduction of feedback allows for OC fittings for greater degrees of hearing loss.

Factors related to assessing feedback suppression effectiveness

- Magnitude of feedback reduction (e.g. additional stable gain before feedback, maximum REIG/REAR before feedback)

- Entrainment
  - Some systems are much more susceptible than others

- Speed in Dynamic FS systems

AGBF for 35 different hearing aid models (20 were OC) From Ricketts, 2008 (Nov)

Picking the “right” product can have a big impact on your success with OC fittings!

Ricketts & Marcrum (2012)
Digital Feedback Suppression
Individual Patient Differences?

- Essentially all patients could potentially benefit from digital feedback suppression
- Data suggest considerable variability in effectiveness across individual listeners

Feedback Suppression in Dynamic and Static Conditions for 14 Participants

Maximum REIG Before Feedback

Duration of Feedback (Past Initial FB Distance)

Distance (phone to ear): Initial point of feedback and distance for sustained feedback (or touching ear)

Note: 7 mm distance is touching the ear. Gain at 75% of AGBF

QUANTIFYING DIGITAL FEEDBACK SUPPRESSION IN THE CLINIC

Note: Half Way between Initial and Final Distance. Gain at 75% of AGBF
Quantifying DFS Clinically with Probe Microphone #1

- Completion once per model is probably adequate.
- This procedure is easiest using a patient with profound hearing loss in at least one ear.
- AGBF/Maximum Stable Gain/REAR Before Feedback
  - Start with maximal venting and a gain configuration and feature settings that matches a typical hearing loss you fit.
  - With FS disabled increase overall gain, while holding the frequency response the same, until you find the point just below feedback.
  - Finding feedback in a clinically relevant manner?
  - Enable FS and repeat
  - Importance of system stability and feedback "quality!"

Quantifying DFS Clinically with Probe Microphone #2

- Artifacts/distortion/entrainment
  - Set up your probe microphone system so that you can listen over the probe microphone monitor while measuring AGBF or Maximum stable REAR
  - Set gain to the midpoint between MSGBF with FS enabled and disabled.
  - Introduce music (flute concertos can work nicely) and/or pure tones (pulse on and off with different timing).
  - Listen for distortions, new signals
  - Consider doing this for all FS settings!
  - Max low frequency gain?

Example: Maximum REAR/ Additional Gain Before Feedback

Example: Maximum REAR/ Additional Gain Before Feedback

ISSUES RELATED TO CLINICAL ASSESSMENT OF FEEDBACK SUPPRESSION

How important are:

1) The FS settings?
2) The specific gain configuration?
3) Other feature settings?
4) Style?

Potential Equalization Problem With OC Fittings

- Sound leaking out of ear is picked up by reference mic
- Sound leaking out of ear may be greater than the input to reference mic from loudspeaker
- Reference mic thinks it is output from loudspeaker, and so loudspeaker output to ear is then turned down
- The result will be less measured hearing aid output (and gain) than is actually present.
- Complaint? When I match targets with OC, patients complain that is too sharp/harsh.
Test OC products with hearing aid turned off during Probe-mic calibration and the Probe-mic system’s reference mic turned off during verification (stored equalization - some probe microphone manufacturers refer to this as “open” testing). The more gain employed, the bigger the “mistake” will be using concurrent (real time) equalization.

It is NOT inappropriate to attempt to verify the REAR of open canal style hearing aids against traditional targets using modern probe microphone techniques. You just have to use the right technique.

Note what happens when you increase gain in the highs!

(input = real speech @ 65 dB SPL; hearing aid gain ~34 dB)

Concurrent vs. Stored equalization
(input = real speech @ 65 dB SPL; hearing aid gain ~26 dB)

OC PROBE MICROPHONE VERIFICATION STEP BY STEP

Disable Reference Microphone (Frye 7000)

Disable Reference Microphone (MedRx Avant)

Click Open Fit and Select Calibrate
Disable Reference Microphone (Verefit)

Equalize, Level or Calibrate (Depending on the System)

After Equalization the reference mic is disabled

Then Present the Signal and Measure REAR (Or REAG for calculation of REIG)

A Little Head Movement: The Other Direction

A Little Head Movement: Leaning In

OPEN FITTING FOR CHILDREN?
Problems with RECD: Is REAR Possible?

- Kim and Ricketts (2013)
- REAR in 22 children aged 4 to 13
- Fitted Both Open (stored equalization) and Closed (concurrent equalization) using the Verifit.
- Examined Test – Re-Test Reliability

Conclusions

- No correlation between child’s age and magnitude of test re-test error.
- Only three children were 4 or 5 yo; however, REAR appears approximately as reliable in children 4-13 as in adults, even when fitting OC.

A related issue which applies to all mini-BTEs including Open: Custom versus non-custom eartips

- Efficiency issues
- Retention issues
- Durability issues
- Feedback issues
  - Is it really still open – subjective versus objective “open”
  - Consistent placement for feedback suppression

Wireless Routing: How Does It Work?

- Signals from external devices (telephone, stereo, TV) are routed to a single or multiple “middle men” devices or in some of the newest hearing aids, directly from smartphone to hearing aid.
Wireless Routing: Potential Benefit?
- Improve the SNR for several common listening situation such as the telephone, television, etc.
- Bilateral signal for devices such as the telephone
- Convenience for linking to or switching between multiple external devices
- Smartphone control of the hearing aid

Wireless Routing: Target Population?
- Applies to a wide range of hearing loss groups, but best suited for patients who place a high priority on using external devices.
- Patient also needs to be somewhat “gadget savvy”

Experiment 1
(Picou and Ricketts, 2011)
- 20 participants with mild-to-moderate SNHL
- Fitted with either open or closed domes
- Listeners seated in a noisy room
  - 55 or 65 dB
- Speech recognition tested in several conditions
  - Unilateral routing
  - Bilateral routing
  - Acoustic telephone
- Participants instructed to hold the telephone receiver where they could hear the best

Experiment 1: Results

Experiment 2: Rationale
(Picou and Ricketts, 2013)
- Experiment 1: Significant advantage for bilateral wireless routing if using closed eartips. What about listeners with more hearing loss?
  - Typically fitted using more gain and less venting which is expected to improve the (wireless) signal to (room) noise ratio.
  - May have more difficulty with acoustic telephone programs due in part to feedback issues.
- What about unilateral t-coil?
  - Expected to provide similar speech recognition in noise performance to unilateral wireless routing.
Speech Recognition Results (65 dB SPL room noise)

<table>
<thead>
<tr>
<th>Performance</th>
<th>Phone</th>
<th>t-call (U)</th>
<th>Wireless (U)</th>
<th>Wireless (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Correct (CST)</td>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
<td><img src="image3.png" alt="Graph" /></td>
<td><img src="image4.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

Speech Recognition Results (55 dB SPL room noise)

<table>
<thead>
<tr>
<th>Performance</th>
<th>Phone</th>
<th>t-call (U)</th>
<th>Wireless (U)</th>
<th>Wireless (B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent Correct (CST)</td>
<td><img src="image5.png" alt="Graph" /></td>
<td><img src="image6.png" alt="Graph" /></td>
<td><img src="image7.png" alt="Graph" /></td>
<td><img src="image8.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

Performance Predictable from SNRs Across Listening Conditions?

- Telephone position in the t-call mode not consistently optimal

Clinical implications

- Acoustic telephone not ideal for listeners with severe hearing loss
- Unilateral wireless transmission results similar to telecoil results, but without the positioning constraints
- If you do use wireless routing, bilateral is always better than unilateral
  - But not needed for all listeners, some will prefer to monitor with the other ear.

FEATURE REPORT CARD

<table>
<thead>
<tr>
<th>Hearing Aid Feature</th>
<th>Real-World Benefit?</th>
<th>Wide Applicability?</th>
<th>Benefit Consistent?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directional Technology</td>
<td>B+</td>
<td>B-</td>
<td>MD</td>
</tr>
<tr>
<td>Advanced Array Processing</td>
<td>B</td>
<td>C</td>
<td>LD</td>
</tr>
<tr>
<td>Digital Feedback Suppression</td>
<td>A-</td>
<td>A+</td>
<td>LD</td>
</tr>
<tr>
<td>Wireless Technology</td>
<td>B</td>
<td>A-/C</td>
<td>LD</td>
</tr>
</tbody>
</table>

THANK YOU!