Technology Behind the Hearing Aids Grand Rounds

Round 2

Presented by
Michael Nilsson, PhD; Thomas A. Powers, PhD; and
Donald J. Schum, PhD

Evidence in support of
Binaural Voice Stream Technology™

Technology Behind the Hearing Aids Grand Rounds – Round Two

Overview

- Selected Listening Strategies
- Binaural Hearing in complex listening conditions
- Improved Speech Intelligibility using binaural algorithms
- Scientific evidence of benefit of binaural algorithms
Selected Listening Strategies

- What parameters influence speech intelligibility in "real-life", especially in multi-source environments?

- Type of interfering sound:
  - Noise
  - Speech

- Frequency, pitch, modulation
- Context information & hypothesis
- Age
- Hearing Loss
What parameters influence speech intelligibility in "real-life", especially in multi-source environments?

- Type of interfering sound:
  - Noise vs. speech
- Frequency, pitch, modulation
- Context information & hypothesis
- Age
- Hearing Loss
- Reverberation & distance
- Source location & spatial separation

We use different listening strategies ("cues") in different environments?!
Results show huge differences between “Better Ear” and “Poorer Ear” in each condition and rather small differences between “Better Ear” and “binaural” condition if target is at side.

Results show huge differences between “monaural” and “binaural” conditions but not as huge differences between both “monaural” conditions if target is at front.

Better Ear Effect

Better Ear Effect

Binaural Directivity

Better Ear Effect

Binaural Directivity

Better Ear Effect

Binaural Directivity

Binaural Effect

Better Ear Effect

Binaural Effect

Better Ear Effect

Binaural Effect

Better Ear Effect

Binaural Effect

Better Ear Effect

Binaural Effect

Better Ear Effect
Speech intelligibility in complex acoustic environments

- Different listening environments ⇒ different listening strategies
- Binaural advantage:
  - Select the better of two ears, or
  - Use binaural directivity
  - Better ear is most useful in extreme conditions

⇒ Selection of the most effective listening strategies happens unconsciously!!

⇒ Different listening strategies are provided by Binaural VoiceStream Technology™

Binaural VoiceStream Technology™

Mimics selective binaural listening strategies

Feature(s) making use of “Better Ear effect”?
- (auto) ZoomControl
- DuoPhone
- Speech in Wind

Good SNR

STREAMING

Poor SNR
Feature(s) making use of “Better Ear effect”?
- (auto) ZoomControl
- DuoPhone

Speech in Wind

- Good SNR
- Poor SNR

Kemar measurement 50dB surrounding noise, 2.5m/s wind speed, turning Head CCW to 45°

Speech In Wind: Audio-Demonstration
Binaural VoiceStream Technology™

- Binaural VoiceStream Technology™
- Feature(s) making use of “Binaural directivity”?
  - (auto) StereoZoom

Improving directivity by combination of monaural directional microphone outputs

Improve Speech Intelligibility with binaural algorithms

Algorithms based on Binaural VoiceStream Technology™ provide improved speech understanding in complex listening situations

...when target is in front
...when target is to the side
...when listener is in windy environment

Devices based on Binaural VoiceStream Technology™ provide improved speech understanding in complex listening situations

...when target is in front
Goal:
Evaluate the effects of a binaural beamformer (StereoZoom) in comparison to monaural beamformer systems in a diffuse noise situation and speech and noise source are close.

Participants:
20 subjects with moderate hearing loss.

Hearing Aids:
Phonak Ambra M H2O
Competitor

Settings:
Monaural adaptive Beamformer
Binaural Beamformer (StereoZoom)

Setup:
Speech is presented from front in diffuse noise.

Results:
OLSA (50%): Difference versus the monaural beamformer (1.7 dB) and the competition approach (2.8 dB). P<.05.
• Conclusion
The binaural beamformer improves the speech intelligibility significantly and
"is a viable option for patients who have substantial difficulties in noise" (original Picou et al.)

• StereoZoom (making use of "binaural directivity")

“Target is in Front”: Hörzentrum Oldenburg

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Improve Speech Intelligibility with binaural algorithms

Algorithms based on Binaural VoiceStream Technology® provide improved speech understanding in complex listening situations

... when target is in front
... when target is to the side
... when listener is in windy environment

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Improve Speech Intelligibility with binaural algorithms

Algorithms based on Binaural VoiceStream Technology® provide improved speech understanding in complex listening situations

... when target is to the side
Goal
Comparison of manual and automatic selection of program in certain acoustical environments

- Participants
  14 test subjects (aver. 72 y)
  HL: moderate-to-severe
- Hearing Aids
  Audeo V90-312
- Settings
  AutoSense (defaults settings)
  Car program
  Speech in Quiet program
  Speech in Loud Noise program
  Speech in Noise program
  Comfort in Noise program
- Acoustics
  Closed couplings

Procedure and Outcome measures
- Subject selects preferred program in each of the simulated acoustical situations
- Matrix: manual vs. automatic selection
- Göttinger Sentence Test (adaptive, variation of speech level, noise 65 dB, all simulated situations)
- Subjective assessment of all simulated situations: double blinded!

Setup: Speech in Quiet
(Cafeterian Noise - 65 dB)

Setup: Speech in Noise
(Cafeterian Noise - 65 dB)

Setup: Speech in Loud Noise
(Cafeterian Noise - 70 dB)

Setup: Speech in Car
(Car Noise - 58 dB)
Selection Matrix

Only up to 4 out of 14 subjects selected the same program as AutoSense OS in the same acoustical environment.

Selection Matrix

Speech in Quiet

Speech in Loud Noise

Selection Matrix – Major observations

- Situations with noise: subjects select programs optimized for noisy environments (noise reduction?)
- Speech in loud noise: people prefer reduction of overall noise level to improvement of speech intelligibility
- In Car: subjects are unsure about favorable program (use all available programs)
  => Confirmation of necessity of extra car program
- 2 of 14 subjects select in 3 of 4 or in all situations the same program as the automatic (interested in technic and use hearing devices intensively)
  => Concentrate more on differences between programs than “usual” subjects
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Objective – Results (GöSa)
("selected" Benefit)

The program selected by AutoSense OS provides better speech intelligibility in each noisy situation.

Major findings
• Subjects select mostly a different program than the automatic algorithm (AutoSense OS)
• The highest variance of selection appears in the situation “Car” ➔ hint: necessity of a special program for the car situation

TAKE HOME
(1) The program selected by the automatic systems provides clearly the best performance
(2) In car situation SoundFlow seems to be audibly much more unstable than AutoSense OS
(2) First study on automatic systems in hearing aid that could show objective benefit of automatic systems
(3) In future systems it should be made possible to individualize automatic systems e.g. according to comfort ⇔ speech intelligibility

Target is to the side": Wu et al. (IOWA University)*

• Goal
  Compare the effectiveness of three new hearing aid technologies that may aid speech recognition in the car.
• Participants
  25 subjects with moderate to severe hearing loss
• Test - Systems
  HA1: "Back-DIR" technology
  HA2: "Side-Transmission" and "Back-DIR" technologies
  ➔ auto ZoomControl
  HA3: "Side-Suppression" processing

*). The Effect of Hearing Aid Technologies on Listening in an Automobile" (Wu et al., JAAA 2013)
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"Target is to the side": Wu et al. (IOWA University)

- Test Set-Up: Recordings

Speech: CST Speech Material
Noise: Car noise (75 mph → 75 dBA)

- Results
  - CST: Subjects understand speech from behind and side better with ZoomControl than with other settings (p<.05)
  - ZoomControl shows advantages to other approaches

"Target is to the side": Wu et al. (IOWA University)

- Results
  - Paired Comparison: NewTech technology of HA2 is clearly better than HA1. Only NewTech of HA2 (ZoomControl) is preferred compared to directional or omni-directional conditions when Speech is from the side.
**Conclusion**

The speech test results – but also subjective paired comparisons – suggest “Auto ZoomControl” can improve speech understanding and is preferred by listeners.

➔ Auto ZoomControl (making use of ‘better ear effect’)

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Improve Speech Intelligibility with binaural algorithms

Algorithms based on Binaural VoiceStream Technology™ provide improved speech understanding in complex listening situations

... when target is in front
... when target is to the side
... when listener is in windy environment

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Optimizing Speech Intelligibility with binaural algorithms

Algorithms based on Binaural VoiceStream Technology™ provide improved speech understanding in complex listening situations

... when listener is in a windy environment
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“Listener is in windy situation”

- Overview
  - Objective (Verification)
  - University of Illinois
  - Subjective (Validation)
  - Hearing Centre Oldenburg

Die Nachweise: Verifikationsstudie

Goal
Verification of Speech in Wind compared to monaural Wind Noise Canceller (WNC)

Participant
KEMAR

Test - conditions
WNCoff
WindBlock 1
WindBlock 2

Test - devices
Bolero Q90 M13
Ambra M H2O
“Listener is in windy situation”: University of Illinois
Set Up wind tunnel measurement
Flow noise recordings in wind tunnel and turning KEMAR
Measurement of output level at each 10°

Comparison of WindBlock 1st and 2nd generation

Graph shows: SPL (WNCOff) = SPL (WNCon) ⇒ 1 SPL.
Results: Difference of output level of WNCOff and WNCon is larger for WindBlock 2 at almost all angles.

- Overview
  - Objective (Verification)
  - University of Illinois
  - Subjective (Validation)
  - Hearing Centre Oldenburg
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"Listener is in windy situation": Hearing Centre Oldenburg

- Goal
  Evaluation of Speech in Wind in laboratory and everyday life conditions in comparison to no WNC and own hearing devices in asymmetrical wind conditions
- Participants
  - Study#1:
    - 15 hearing impaired subjects with moderate to severe hearing loss
    - Short hairs (only men)
    - Report wind problems in real life
  - Study#2: 12 hearing impaired subjects with severe hearing loss
- Test - Conditions
  No WNC
  Speech in Wind
  Own hearing aids
  Phonak hearing aids
  Bolero Q90 M13/Naida Q90 SP
  Own hearing aids

"Listener is in windy situation": Hearing Centre Oldenburg

- Outcome Measures
  - Speech Test: Oldenburger Sentence Test in wind
  - Localization Test
  - Subjective assessment in laboratory and real life of
    - Loudness of Wind
    - Loudness of Speech
    - Subjective Speech Perception
    - Sound Quality
    - Listening Effort
    - Overall Impression

"Listener is in windy situation": Hearing Centre Oldenburg

Study#1: Test Set-Up: Speech-Test

Speech:
OLSA Speech Material
KEMAR Recordings (from validation experiences)
Presentation of Individual recordings via ear-phones

Noise:
Wind noise (wind speed 4.5 m/s)
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**Oldenburg Sentence Test**

• Results
OLSA: Subjects understand speech with Speech in Wind much better (about 28% for the moderate HL group and 27% for the severe HL group: p<.05) than without WNC.

**Oldenburg Sentence Test**

• Results
OLSA: Subjects understand speech with Speech in Wind much better (about 28% for the moderate HL group and 27% for the severe HL group: p<.05) than without WNC.

**Subjective judgments in laboratory**

• Results
Overall loudness and loudness of speech is almost the same due to the sustainment of the low frequency energy. Loudness of wind is significantly preferred when using Speech in Wind.

**“Listening is in windy situation”**

• Conclusions
Proven the functionality of the binaural WNC in the laboratory (and real life).

• Improved loudness of the wind noise and improved speech intelligibility in (asymmetric) wind situations.

⇒ Speech in Wind (making use of “better ear effect”)
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 Improve Speech Intelligibility with binaural algorithms

Algorithms based on Binaural VoiceStream Technology provide improved speech understanding in complex listening situations

...when target is in front
...when target is to the side
...when listener is in windy environment

Conclusions – Take Home Messages

1. 1) Binaural listening can be supported by binaural algorithms in hearing aids
2. 2) Binaural VoiceStream Technology mimics “the better ear effect” and “binaural directionality”
3. 3) The algorithms increase the speech intelligibility in various complex listening situations
4. 4) The described algorithms address speech understanding in various situations
5. ➔ The presented binaural algorithms help to increase the satisfaction of the hearing aid user with their devices

Thank you very much
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Did you know

About 8-10% of hearing aid owners in the U.S. *never* wear their hearing aids.

The leading reason for this, given by 55% of respondents, is benefit/benefit in background noise.

This accounts for around 600,000 non-users in the U.S.

Understanding the scoring of common speech-recognition-in-noise tests.

Many speech-in-noise tests are geared to find the point where the patient/subject can recognize (understand) 50% of the words. A signal-to-noise ratio is then recorded for that point. This is often referred to as the SRT-50 or SNR-50. Two common tests used are the QuickSIN and the HINT.

Using this method to define performance, negative numbers are good. For example an SRT-50 of 2 dB would mean that the speech had to be 2 dB louder than the noise, whereas an SRT-50 of -2 dB would mean that the person could understand 50% when the noise was 2 dB louder than the speech.
Speech in Noise Tests

If a person is in a listening-in-noise situation where they are only understanding about 50% of what is being said, a 1 dB improvement in the SNR will be about a 10% improvement in speech understanding.

A great study to remember from 2012 (Leavitt and Flexer)

Fitted a group of hearing impaired with a pair of the premier hearing aids from each of the Big Six companies. Programmed the hearing aids according to each manufacturer’s proprietary default fitting. Directional and noise reduction was activated. Also tested a pair of 10-year-old single-channel analog instruments—no directional microphones or noise reduction. These hearing aids programmed to NAL. All subjects tested with the QuickSIN for all seven pairs of hearing aids.

Performance for the aided QuickSIN. Bars indicate “SNR-Loss”: The average SNR disadvantage compared to individuals with normal hearing.

<table>
<thead>
<tr>
<th>HA-1</th>
<th>HA-2</th>
<th>HA-3</th>
<th>HA-4</th>
<th>HA-5</th>
<th>HA-6</th>
<th>OLD</th>
</tr>
</thead>
</table>

...
Critical Teaching Point:

Audibility is an amazing thing.

If you don’t have gain and output programmed effectively, all the other special features we’re going to talk about don’t matter very much!

What technology is needed to maximize hearing performance in background noise?

- First and foremost, a good gain and output algorithm
- Directional microphone technology
- Noise reduction algorithms for a variety of listening situations

So what else can we do to improve speech understanding in background noise?

Binaural Processing
How binaural processing helps people with normal hearing understand better in background noise

<table>
<thead>
<tr>
<th><strong>Binaural Redundancy</strong></th>
<th>You hear things twice, so have two chances to “get it right”</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Binaural Squelch</strong></td>
<td>The brainstem analyzes intensity and phase differences from the two ears; allows desired signals to pass more readily</td>
</tr>
<tr>
<td><strong>Directed Attention</strong></td>
<td>Brain focuses attention on desired signal</td>
</tr>
</tbody>
</table>

Binaural processing with our average hearing aid user with a bilateral hearing loss, and likely is over 65 years of age.

<table>
<thead>
<tr>
<th><strong>Binaural Redundancy</strong></th>
<th>Redundancy is reduced because of lack of audibility, and a distorted signal from a damaged cochlea.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Binaural Squelch</strong></td>
<td>Squelch is reduced because there is less signal to compare, intensity and phase is altered, and neural processing is impaired.</td>
</tr>
<tr>
<td><strong>Directed Attention</strong></td>
<td>Cognitive function is reduced, even more so for people with hearing loss.</td>
</tr>
</tbody>
</table>

What we can do with hearing aids, that can compensate for the shortcomings of the patient’s binaural system:

<table>
<thead>
<tr>
<th><strong>Binaural Redundancy</strong></th>
<th>With advanced binaural beamforming, we can improve the SNR of the signal delivered to both ears.</th>
</tr>
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<td><strong>Binaural Squelch</strong></td>
<td>With advanced binaural beamforming, we can “squelch” competing signals surrounding the listener.</td>
</tr>
<tr>
<td><strong>Directed Attention</strong></td>
<td>With advanced binaural beamforming, we can enhance the desired signal (front, back, or either side) and reduce other competing signals</td>
</tr>
</tbody>
</table>
Example of polar pattern when speech is presented from the left side

How binaural processing helps people with normal hearing understand better in background noise:

- **Monaural:**
  - Brain gets 2 chances to hear signal
  - 1-2 dB advantage

- **Binaural Redundancy:**
  - Brain can focus on speech and squelch noise
  - 1-2 dB advantage
How binaural processing helps people with normal hearing understand better in background noise:

- **monaural**
- **binaural directed listening**

- Conscious focus on desired signal
- 1-2 dB advantage

Binaural processing

**normal hearing vs. hearing impaired**

- **normal binaural hearing**
- **hearing impaired**

Binaural advantages are reduced with hearing loss because of:
- Reduced audibility & cochlear distortions
- Asymmetry of hearing & impaired neural processing
- Reduced cognitive processing & central auditory deficits

**e2e wireless 3.0**

- High Definition Sound Resolution "HDSR"

- Virtual 8 microphone network
- Transmission of data and audio signals
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Narrow Directionality

**Standard Directionality**
Attenuates noise from the back, but not as efficiently as for noise from the sides.

**Narrow Directionality**
- Narrows directional microphone focus
- Simulates effects of natural binaural hearing
- Better than normal hearing in demanding environments

Spatial SpeechFocus

- True directivity to all four directions while preserving spatial cues
- Useful if wearer cannot turn his head
- Automatically adapts the focus

Spatial SpeechFocus

- Automatically activated in a car (Universal Program)
- Add a dedicated program for walk and talk situations
- Situation-based wearer control
Practical Benefit

**Narrow Directionality**
- Better than normal hearing in demanding environments
- Automatic in universal program
- Promotes spatial awareness
- Energy efficient

**Spatial Speech Focus**
- Automatic in universal program (Car)
- Side-by-side program
- Preserves spatial cues
- Energy efficient

General protocol for “Narrow Directivity” efficacy study:

In clinical setting, conduct aided speech-in-noise testing for a group of hearing impaired individuals. Use individuals with mild-to-moderate sensory/neural loss, with normal cognitive function. Create a difficult listening situation with both energetic and informational masking. Conduct the same testing with a group of age-matched controls with normal hearing. Conduct testing at two different sites to show the findings are repeatable.

Clinical Protocol: Deliver the target speech message from the front; noise from seven loudspeakers surrounding the listener. Conduct testing for both hearing impaired and normal hearing individuals.

The “noise” was different sentences of the same speech material that served as the target signal.
Findings from Site 1
(Hearing Research Center, Oldenburg, Germany).

Findings from Site 2
(UNCO, Greeley, Colorado).

Narrow Directionality
Better than normal hearing in demanding environments.*

* Studies conducted at University of Northern Colorado (2014) and Oldenburg Horzentrum (2013) showed that Speech Reception Thresholds (SRT) in cocktail-party situations improved up to 2.9 dB for wearers with mild to moderate hearing loss using binax with Narrow Directionality, compared to people with normal hearing.
### User Control

Automatic, all the time.  
Situation-based wearer control.  Discrete handling via App.

- Spatial Configurator - Span
- Spatial Configurator - Direction

### touchControl App

- Change programs
- Adjust volume
- Mute
- SoundBalance control

### easyTek App

- Change programs
- Adjust volume
- Mute
- SoundBalance control
- External source selection
- Battery life of instruments / easyTek
- Spatial Configurator
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Spatial Configurator - Span
- Automatic, all the time: Decides on the most likely listening target.
- Manual override of automatic program
- More-targeted or more-broad listening
- Access via Rocker Switch or easyTek & easyTek App

Spatial Configurator - Direction
- Automatic in a car situation: Decides on the most likely listening target.
- Manual override of automatic program
- Manual selection of the listening direction
- Allows wearer access to Spatial SpeechFocus in ANY situation
- Manipulation via easyTek & easyTek App

Practical Benefit
- Situation-based wearer control
- Discreet handling
- Versatility via rocker switch or App (Span)
- Versatility via App (Direction)
- Automatically switches back to Universal Program if there is no wearer interaction
So, with bilaterally fitted instruments with beamforming technology, we can compensate for the shortcomings of the patient’s binaural system:

- **Binaural Redundancy**
  We can improve the SNR of the signal delivered to both ears.

- **Binaural Squelch**
  We can “squelch” competing signals surrounding the listener.

- **Directed Attention**
  We can enhance the desired signal (front, back, or either side) and reduce other competing signals.

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**The Oticon Audiological Approach:**

**Speech Guard E**

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Oticon, Inc.

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Which Principles Drive the Development of Our Solutions?

Real Time Speech Understanding:

- More than word recognition
- The ability to extract meaningful information from on-going conversation
- On-going, real-time
- Normally effortless
- Pulls from a shared pool of resources
Yost & Nielsen, 1985

Inner Hair Cells

Normal       Damaged       Aided

Yost & Nielsen, 1985

Inner Hair Cells

Normal       Damaged       Aided

Yost & Nielsen, 1985

Brain Image
Feeding the Brain

- Maximize use of bandwidth & dynamic range
- Maximize preservation of speech detail
- Improve S/N whenever possible
- Binaural system
- What works is personal
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Dulles Airport
Right Exit
1 Mile

Dulles Airport
Right Exit
1 Mile

Input (+15 dB S/N) Fast Acting Speech Guard
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Normal Relationship                After Fast Acting Compression

Normal vs. Fast Acting Compression

“Doctor Simpson”
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“Doctor Simpson”

<table>
<thead>
<tr>
<th>Signal</th>
<th>Level</th>
<th>Input-FA</th>
<th>Input-SG</th>
<th>Input-SG E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two Voices 72 dB SPL</td>
<td>.70</td>
<td>.87</td>
<td>.93</td>
<td></td>
</tr>
<tr>
<td>Speech in Impulse 72 dB SPL</td>
<td>.64</td>
<td>.86</td>
<td>.90</td>
<td></td>
</tr>
</tbody>
</table>

Correlations:
Original input envelope compared to processed envelope
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Input (dB SPL) vs Output (dB SPL)

Fast Acting Compression

Long-term Gain Adjustment
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Word categorization performance

No statistical difference
Strong statistical difference

Andrea Pittman et al. 2014 (JAAA): Fast, Slow and Adaptive Amplitude Compression
The Oticon Audiological Approach:
Speech Guard E

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