Cognition and ReSound: Applying What We Know about the Brain to Signal Processing

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Learning Objectives

- Describe how cognition plays a role in hearing instrument use, in terms of binaural fittings, directionality options, localization issues and sound quality adjustments to frequency lowering.
- Identify patient characteristics that would help determine candidacy for certain types of hearing instrument processing.
- Detail the ReSound features that support natural binaural processes in the brain.

Cognition, the Brain, and Hearing

- Visual cortex integrates both auditory AND visual inputs when viewing the world[1]
  - "Sounds create visual imagery, mental images and automatic projections"
  - "If hear an automobile approaching but see a horse instead, you would be very surprised"
- Precise rhythm of electrical impulses from IHCs early in life shown to aid in the brain's auditory processing organization development in mice[2]

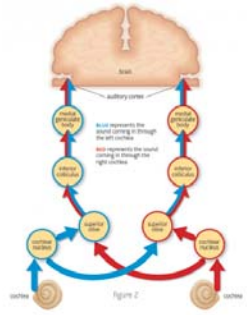
1. Vetter P, Smit FW, Muckli L. Decoding sound and imagery content in early visual cortex. *Current Biology*. 2014:24(11);1256-62.
2. Clause A, Kim G, Sonntag M, Weisz CJC, Vetter DE, Rubsamen R, Kandler K. The precise temporal pattern of prehearing spontaneous activity is necessary for tonotopic map refinement. *Neuron*. 2014: 82; 822-35.

Even Taste is Connected to Hearing!

- Research has shown that seafood tastes better when you hear ocean sounds while eating it, even if you are not anywhere near a real ocean*
- What can we conclude?

Multiple Stimuli to the Brain Can Impact a Sensory Experience

*Stuckey B. Taste: *Surprising stories and science about why food tastes good.* New York: Atria Books; 2013.



Two ears send distinct information to the auditory cortex of the brain to create a complete, rich and accurate portrayal of the auditory environment.

What's on the Board for Today:

- Cognition and Binaural Fittings
- Cognition and Directionality
- Cognition and Localization
- Cognition and Frequency Lowering

Binaural Fittings

"**The whole is greater than the sum of its parts.**"

-Aristotle (384-322 B.C.)

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A Few Advantages of Binaural Fittings

- Better localization abilities, or the ability to decipher the location of sound sources[1-3]
- Improved speech intelligibility in noise,[4-6] in part due to better spatial release from masking[7]
- Possible relief from tinnitus[13]

On the Benefits of Binaural, Stender, HR, July 2014
1. Punch J, Jenison RL, Durrant JD. Evaluation of three strategies for fitting hearing aids binaurally. *Ear Hear.* 1991:12;205-15.
2. Byrne D, Noble W, LaPage B. Effects of long-term binaural and unilateral fitting of different hearing aid types on the ability to locate sounds. *J Am Acad Audiol.* 1992:3;369-82.
3. Byrne D, Noble W. Optimizing sound localization with hearing aids. *Trends Amplif.* 1998:3(2);51-73.
4. Kaplan H, Picket JM. Effects of dichotic/diotic versus monotic presentation on speech understanding in noise in elderly hearing-impaired listeners. *Ear Hear.* 1981:2;202-7.
5. Stach BA. Hearing aid amplification and central processing disorders. In: Sandlin RE, ed. *Handbook of Hearing Aid Amplification: Vol 11 Clinical Considerations and Fitting Practices.* Austin, Tex: Pro-Ed;1990:87-111.
6. Dillon H. 2000. *Hearing Aids.* New York: Thieme: 370-403.
7. Dawes P, Munro KJ, Kalluri S, Edwards B. Unilateral and bilateral hearing aids, spatial release from masking and auditory acclimatization. *J Acoust Soc Am.* 2013:134(1);596-606.
13. Brooks DN, Bulmer D. Survey of binaural hearing aid users. *Ear Hear.* 1981:2;220-4

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Broad-Stroke Recommendations Never Hold True for Everyone

- Binaural interference, due to the coexistence of hearing loss and certain auditory processing disorders (for a review, see Holmes 2003).
- But, as Holmes also asserts, the benefits of fitting hearing instruments for both ears far outweigh the costs, in nearly all cases—and especially as patients age and as hearing loss progresses.

Holmes A. Bilateral amplification for the elderly: are two aids better than one? *Intl J Audiol.* 2003:42;2 S63-2 S67.

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Directionality

How hearing aids "think" of restaurants

How restaurants really are

How the Brain Processes Sounds in the Environment

DETECT	CHOOSE
A new sound in the environment draws your attention.	Filtering out sounds until you hear only what you want to hear.
Example: Someone whispering behind you in this lecture.	**Example:** Someone whispering ABOUT YOU behind you in this lecture.

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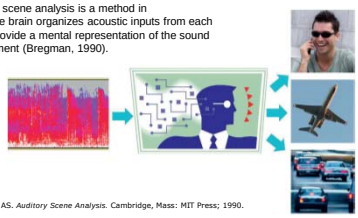
Auditory Scene Analysis

Auditory scene analysis is a method in which the brain organizes acoustic inputs from each ear to provide a mental representation of the sound environment (Bregman, 1990).



Bregman AS. *Auditory Scene Analysis.* Cambridge, Mass: MIT Press; 1990.

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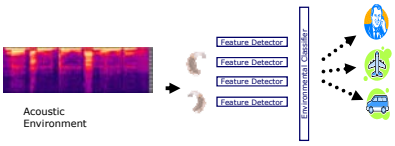
Compensation for directional deficit

- Some automatic directional microphone algorithms will analyze the acoustic environment and focus on the 'loudest speech signal' instead of the front signal
- Assumes that the listener is interested in the 'loudest speech' signal which is not always the case



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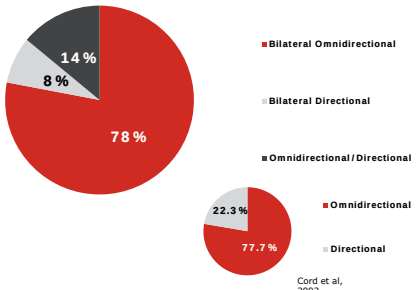
How Do We Develop a Hearing Aid Directionality Approach that Supports Auditory Scene Analysis in the Most Natural Way?

ReSound

rediscover hearing

Binaural Directionality Field Trial: Results



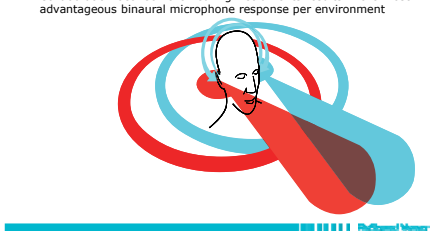
Cord et al, 2002

Right Hearing Instrument Mode	Left Hearing Instrument Mode	Rationale and Support from the Literature
Omnidirectional	Omnidirectional	Users strongly prefer a bilateral omnidirectional response in quiet environments.[6,7]
Directional	Directional	Provides the greatest benefit when the speech signal is predominantly in front of the listener.[8]
Omnidirectional Directional	Directional Omnidirectional	Asymmetric directionality improves ease of listening and awareness of surroundings as compared to bilateral fixed directional fittings,[9] without significantly degrading directional benefit.[9-11] In a noisy environment with speech to one side of the listener, the best intelligibility is achieved if there is an omnidirectional response for the speech side and a directional response for the opposite side.[12-14]

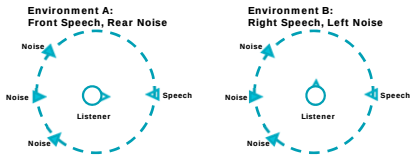
Proven benefits of ReSound Binaural Directionality, ReSound WP, Stender, Kirkwood and Jespersen, 2014
6. Walden B, Surr R, Cord M, Dyrlund O. Predicting hearing aid microphone preference in everyday listening. J Am Acad Audiol. 2004:15;365-96.
7. Walden B, Surr R, Cord M, Grant K, Summers V, Dittberner A. The robustness of hearing aid microphone preferences in everyday environments. J Am Acad Audiol. 2007:18;358-79.
8. Hornsby B. Effects of noise configuration and noise type on binaural benefit with asymmetric directional fittings. Seminar presented at: 155th Meeting of the Acoustical Society of America; June 30-July 4, 2008; Paris, France.
9. Cord MT, Walden BE, Surr RK, Dittberner AB. Field evaluation of an asymmetric directional microphone fitting. J Am Acad Audiol. 2007:18;245- 56.
10. Bentler RA, Eippe JLM, Tubbs JL, Dittberner AB, Flamme GA. Quantification of directional benefit across different polar response patterns. J Am Acad Audiol. 2004:15;649-59.
11. Kim JS, Bryan M. The effects of asymmetric directional microphone fittings on acceptance of background noise. Int J Audiol. 2011:50(5);290-296.
12. Hornsby B, Ricketts T. Effects of noise source configuration on directional benefit using symmetric and asymmetric directional hearing aid fittings. Ear Hear. 2007:28;177-86.
13. Coughlin M, Hallenbeck S, Whitmer W, Dittberner A, Bondy J. Directional benefit and signal-of-interest location. Seminar presented at: American Academy of Audiology Convention; 2012; Charlotte, NC.
14. Cord MT, Surr RK, Walden BE, Dittberner AB. Ear asymmetries and asymmetric directional microphone hearing aid fittings. Am J Audiol. 2011:20;111-122.

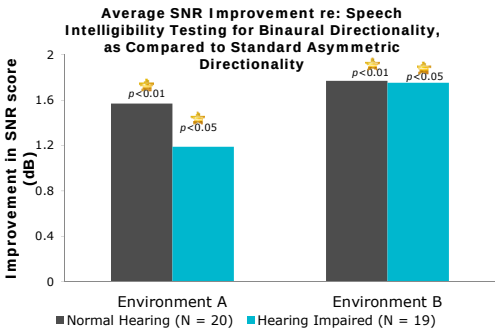
Binaural Directionality

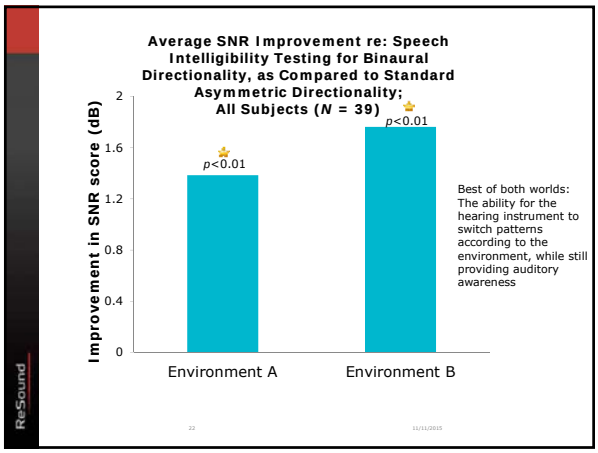
Collaboration between the hearing instruments results in the most advantageous binaural microphone response per environment



How Much Better is Binaural Directionality than an Approach that Uses Fixed Asymmetric Directionality?






Average SNR Improvement re: Speech Intelligibility Testing for Binaural Directionality, as Compared to Standard Asymmetric Directionality; All Subjects (N = 39)
Improvement in SNR score (dB)
2
1.6
1.2
0.8
0.4
0
p<0.01
p<0.01
Environment A
Environment B
Best of both worlds: The ability for the hearing instrument to switch patterns according to the environment, while still providing auditory awareness
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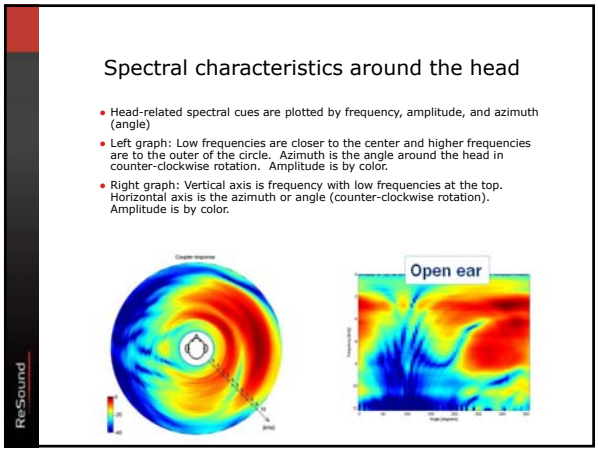
Localization
You are here
ReSound


Spectral characteristics around the head
Head-related spectral cues are plotted by frequency, amplitude, and azimuth (angle)
Left graph: Low frequencies are closer to the center and higher frequencies are to the outer of the circle. Azimuth is the angle around the head in counter-clockwise rotation. Amplitude is by color.
Right graph: Vertical axis is frequency with low frequencies at the top. Horizontal axis is the azimuth or angle (counter-clockwise rotation). Amplitude is by color.
Open ear
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Preserving spectral cues

- BTE and RIE models have microphones placed above the pinnae
- Distortions to the spatial sound image as pinnae spectral cues are reduced compared to open ear
- Need to compensate for the artificial microphone position

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Localization Ability

- Localization ability is based on two cues
  1. The interaural timing differences (ITD) between the two ears is predominately a low-frequency cue and is the time of arrival difference of a sound between the two ears. This cue is preserved in Binaural Directionality by using bandsplit directional processing where the low-frequencies are processed with an omnidirectional pattern.
  2. The interaural level differences (ILD) between the two ears is predominately a high-frequency cue and is the intensity difference of a sound between the two ears – due to the head shadow. This cue is added with Binaural Directionality II with Spatial Sense signal processing.
- Low-frequency ITD cues are most important for localization in the horizontal plane and are the most robust cues
- High-frequency ILD cues are more important for localization in the vertical plane

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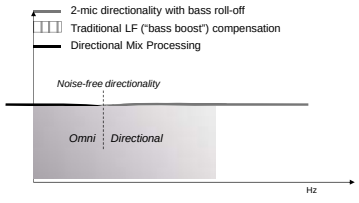
Split Band Directionality



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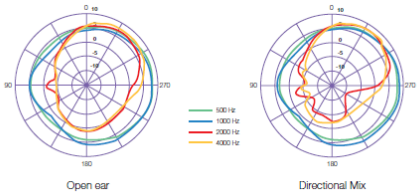
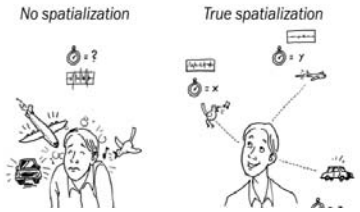
ReSound Directional Mix Processing



Open ear | Directional Mix

Spatial Hearing: Externalization of sounds



Binaural Directionality: Current and Future

- Binaural Directionality provides improved signal-to-noise ratio (front-to-back) as long as the signal of interest is in front of the listener and the competing signal is to the sides or the back.
- Binaural Directionality provides awareness and audibility to sounds that are not in front of the listener when in an asymmetric directionality mode
- Binaural Directionality II with Spatial Sense will improve sound quality and localization in the omnidirectional listening mode

Spatial Sense

- Accounts for three hearing-instrument-related issues that can interfere with spatial cues
  1. BTE and RIE models have microphones above the pinna and thus removes spectral pinna cues
  2. BTE and RIE models have microphone placement that distorts interaural level difference (ILD)
  3. Wide dynamic range compression that is independent in right and left devices can distort the interaural level difference (ILD)
- Spatial Sense integrates two technologies to preserve acoustic cues for spatial hearing
  1. Pinna restoration
  2. Bilateral compression

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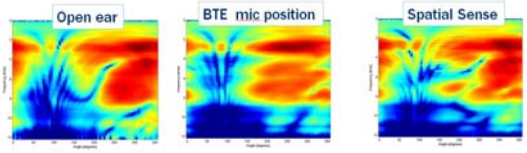
Spectral characteristics for BTE model

- Open ear: Spectral cues are maintained as the signal travels around the pinna, into the concha, and down the ear canal
- BTE microphone position: Spectral cues are distorted as signal travels to the top of the pinna to BTE microphone location and pinna, concha, and ear canal resonances and shadows are eliminated
- Spatial Sense: Spectral cues lost due to BTE/RIE microphone placement are digitally applied so spectral cues are more similar to the open ear



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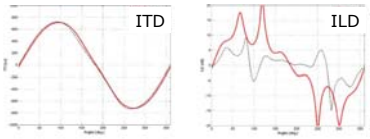
Binaural Directionality preserves ITD

- Desired open-ear response is red line
- Binaural Directionality (without Spatial Sense) is the red line
- ILD contributes to localization but ITD is more dominant
- ILD errors can reduce sound quality as it will sound less natural



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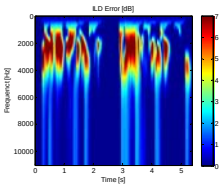
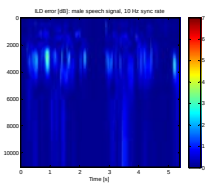
Binaural Directionality II with Spatial Sense fixes ILD problem



Compression introduces ILD errors

Indicated by the more red colors

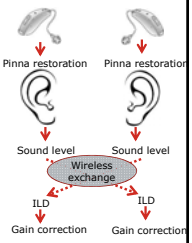


Spatial Sense removes ILD errors

Indicated by the more blue color

Spatial Sense processing diagram

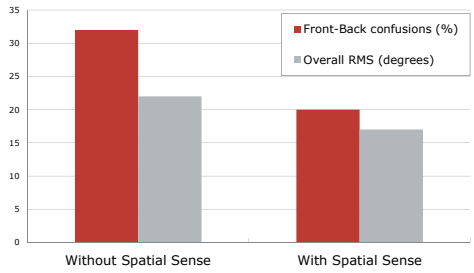
- Spatial Sense first applies pinna restoration to each of the devices (BTE or RIE) to accommodate for lost spectral characteristics due to microphone placement
- Sound level at the hearing instrument microphone is recorded to determine the interaural level difference (ILD) due the head shadow
- Spatial Sense exchanges data wirelessly between the hearing instruments to apply an ILD gain correction to preserve the natural ILD



Spatial hearing – Why is it important?

- Allows an auditory image of the environment to be formed
  - If you close your eyes and listen, you can guess what type of environment you are in, what types of sound sources are in that environment and where they are located.
  - With this auditory image, your brain can unconsciously focus on sounds of interest and ignore others.
- Spatial hearing also creates a sense of natural sound quality
  - Hearing aid wearers may report that they hear sounds better, but that they have difficulty reconciling what they hear with their visual impression of the environment.
  - For example: A user who is at work in his office hears people talking outside the office, but senses them inside his head, as if their voices are played through headphones.
  - Being able to place sounds spatially in the environment makes it easier to focus and understand, but also helps externalize the sounds, making the environment sound natural.

Localization with Binaural Directionality II with Spatial Sense



Binaural Directionality II with Spatial Sense

- Binaural auditory steering strategy
  - Insures on and off axis audibility
  - Insures audibility and intelligibility across environments
  - Maintains comfort and sound quality across environments
- Accomplished by
  - Analyzing the presence and direction of speech
  - Analyzing the presence of noise
  - Choosing the optimum microphone mode to support these goals
  - Using bandsplit directional processing for seamless transitions between microphone modes
  - Using Spatial Sense

Details of Binaural Directionality II with Spatial Sense

- Restoration of spectral cues to compensate for unnatural microphone location above the pinna (BTE and RIE)
  - Crucial for front-back localization ability
  - Enhances speech understanding when speech is in front
- Bandsplit processing (preserves interaural time differences in low frequencies)
  - Low frequency timing differences between the ears are the most important cue for localization from other directions than front-back
  - Supports orientation to environment using head movement
- Bilateral compression (preserves interaural level differences in high frequencies)
  - Supports orientation to environment using head movement, especially for high frequency sounds
  - If ILD is consistent with ITD, then sounds become externalized, leading to the most natural experience of sound quality

Frequency Lowering

"Because you know I'm all about that bass/
'Bout that bass, no treble…"

Recent Research on Frequency Compression

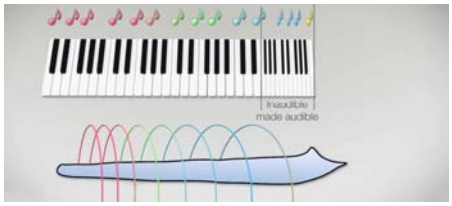
- Arehart et al., 2013
  - **Working Memory, Age, and Hearing Loss: Susceptibility to Hearing Aid Distortion**
    - Older listeners with hearing loss and poor working memory are more susceptible to distortions caused by at least some types of hearing aid signal-processing algorithms and by noise, and that this increased susceptibility should be considered in the hearing aid fitting process.

Arehart KH, Souza P, Baca R, Kates JM. Working Memory, Age, and Hearing Loss: Susceptibility to Hearing Aid Distortion. Ear Hear. *2013:34(3);251-60.*

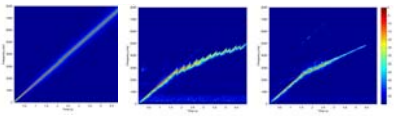
What is ReSound Sound Shaper™

ReSound Sound Shaper:
- Improves audibility of speech cues
- Maintains the best sound quality possible

What is ReSound Sound Shaper™



Proportional vs. non-proportional

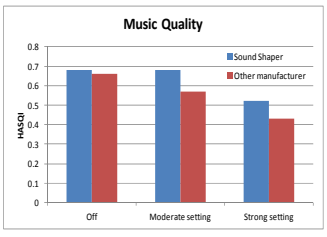


Unprocessed
Pure tone sweep

Non-proportional
Approach – more
distortion

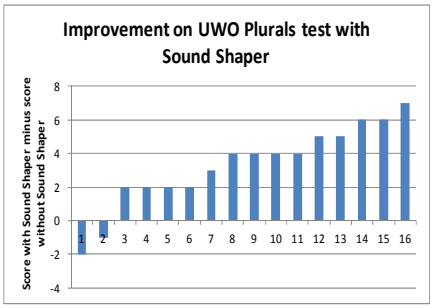
Proportional
Approach – less
distortion

Comparison to Other Approaches



Results in agreement with preferences of normal hearing listeners, and those with hearing loss

Clinical results



Applying Sound Shaper™

- It is difficult to determine who might be a candidate for frequency lowering thus, Aventa will always default for Sound Shaper to be **off**
  - In most cases, you will be able to provide good audibility without activating Sound Shaper
  - Conventional amplification can be expected to provide good audibility for a wide bandwidth for most hearing losses
- If the fitting professional decides to activate Sound Shaper, Aventa will recommend a setting when the hearing loss may also be appropriate for it

How Do You Ensure Audibility? General Principles:

1. Verify/fine-tune frequency response without frequency lowering
2. Evaluate whether there could be benefit (also considering factors other than the real ear results like cognition, previous experience, etc.)
3. Turn on frequency lowering to manufacturer-recommended setting and measure.
   - If audibility is still not achieved, it could be that the hearing aid is not powerful enough for the hearing loss

Objective is to find the least aggressive setting that increases audibility.

Cognition and Binaural Fittings:

Compared to Monaural Fittings, Binaural Fittings provide
- Better localization abilities
- Improved speech intelligibility in noise
- Possible relief from tinnitus

May be contraindicated in rare cases involving APD

"The whole is greater than the sum of its parts."

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Cognition and Directionality:

- The brain organizes acoustic inputs to create an auditory scene
- Individuals are able to detect and choose which input is most important
- Hearing aids that provide auditory awareness to other directions can be beneficial in daily listening situations

ReSound Binaural Directionality provides auditory awareness to off-axis sounds while improving the signal-to-noise ratio in difficult listening situations.

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Cognition and Localization:

Spectral cues and interaural level difference cues important for the brain to localize sounds in the environment can be distorted by hearing aid technology (behind-the-ear mic placement and WDRC)

ReSound Binaural Directionality II with Spatial Sense integrates binaural compression and pinna restoration to improve sound quality and localization

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Cognition and Frequency Lowering:

- Audibility vs. distortion trade-off of frequency lowering signal processing
- Certain individuals may have more deleterious effects of distortion than others, based on cognitive factors

ReSound Sound Shaper provides audibility with less distortion, and can be beneficial for individuals based on the hearing professional's judgment

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Thank You!

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