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Hearing Aid Solutions for the Speech-in-Noise Problem

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Hearing Aid Month

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  Brad A. Stach, PhD
- Hearing Aid Solutions for the Speech-in-Noise Problem (#24702)
  Joshua M. Alexander, PhD
- Vanderbilt Audiology's Journal Club (#24207)
  Todd A. Ricketts, PhD
- An Evidence-Based Approach to Reporting Hearing Aid Benefit (#24714)
  Ron Leavitt, AuD
- Hearing Aid Technology Industry Roundtable (#24717)
  moderated by Catherine Palmer, PhD

Hearing Aid Solutions for the Speech-in-Noise Problem

Joshua M. Alexander

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Overview

1. The speech-in-problems
2. Digital noise reduction
3. Directional microphones
4. Wireless connectivity

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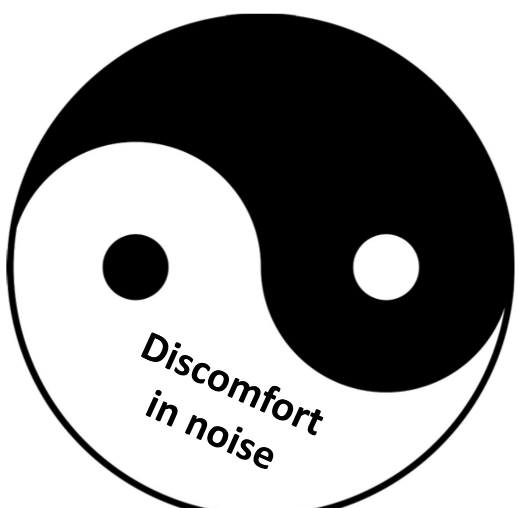
Two Noise Problems



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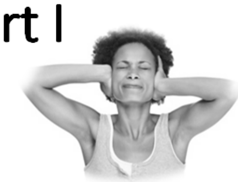
The Noise Problem, Part I



- **Discomfort in noise** is a primary reason for wearer dissatisfaction
- New hearing aid users are **more likely to be *annoyed*** by background noise ***after*** being fit (Palmer *et al*., 2006)
  - **Why?** Because when ***un-aided*** they are ***less*** annoyed by noise than normal-hearing listeners
  - When ***aided***, they are ***more likely*** to rate background noise as annoying compared to normal-hearing listeners
  - With a good digital noise reduction (DNR) algorithm, annoyance, while elevated (*re: not aided*), can be reduced to the **same levels as for normal-hearing listeners**
  - **NEED TO COUNSEL NEW USERS!**

Digital Noise Reduction (DNR) Types

1. **Spectral subtraction**
   - Short-term **Wiener filtering** is one type
   - Estimate the noise profile during **pauses in speech** and subtract it from the speech using **inverse filtering**
   - Requires as ***accurate*** as possible an estimate of the **spectral composition** of the noise
     - Works best over **short-term** segments and for stationary noise
2. **Noise suppression**
   - Identify and attenuate frequency bands with noise
     - Modulation frequency and depth are used to ID noise

Differences in DNR Systems

1. **Noise classification scheme**
   - Includes ability to classify music as such and not as noise
   - *Accurate classification across a variety of situations is* ***more important*** *than the amount of noise reduction*
2. **Noise reduction threshold or criteria**
   - At what point does the DNR system engage?
3. The **amount of noise reduction** as a function of frequency
4. Noise reduction **time constants**

DNR and Speech Intelligibility (the *other* noise problem)

- **<u>Little evidence</u>** to support the claim that DNR in hearing aids improves speech intelligibility – ***Why*??**
  - Often, **substantial overlap** in the spectral characteristics of speech and common noise sources
  - Since speech and noise in the same channel cannot be adjusted separately, **SNR does not change**
  - **DNR by itself is forced to separate the speech and noise based on characteristics other than location**
- **No evidence** that DNR *decreases* intelligibility either

DNR and Noise Tolerance

- Acceptable Noise Level (**ANL = MCL – BNL)**
  - People who accept background noise have **smaller ANLs** and tend to be **"good" users** of hearing aids
  - People who cannot accept background noise have **larger ANLs** and may only use hearing aids occasionally and are at **most at risk** of rejecting them

Make users out of non-users

- Some evidence to indicate that **DNR improves ANL** for those at greatest risk (Mueller *et al*., 2006)
  - DNR processing improved ANL for **20 of 22 subjects**
  - **Greatest benefit** was for those who had the **largest ANLs** with DNR Off (*i.e*., those who need the most help)

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Listening in Noise is *Effortful*

- Increased **concentration** and **attention** when listening is a fairly common complaint for people with hearing loss – actual quotes from internet blogs and message boards:
  - ❖ *"Listening IS exhausting!"*
  - ❖ *"On a typical day, it can be tiring to put in the effort to listen, especially when you deal with all kinds of people all day long…"*
  - ❖ *"I go to bed most nights with nothing left. It takes so much energy to participate in conversations all day that I'm often asleep within minutes."*
  - ❖ *"…at the end of every day I am physically exhausted."*

(Hornsby, 2012)

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DNR and Cognition/Learning

- DNR might **lighten users' cognitive load** that would have otherwise been devoted to pulling the redundant speech cues out of the noise and free up resources for other **simultaneous tasks**
  - **'Frees up' resources** to attend to multiple sound sources, store information in memory, use contextual information to improve understanding, resolve ambiguities, etc.

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Effects of Noise on Cognition/Learning

- Effects of noise in the lab/clinic may be **misleading**
  1. Subjects can devote **100% effort** to the listening task
  2. Do <u>not</u> capture the effects of listening in noise for an **extended period (fatigue)**

- **Effortful listening** over a prolonged period may cause fatigue
  1. May influence performance on **primary task**: following a conversation, classroom lesson, lecture, etc.
  2. May influence performance on **secondary task**: comprehending (**<u>learning</u>**), note taking, etc.

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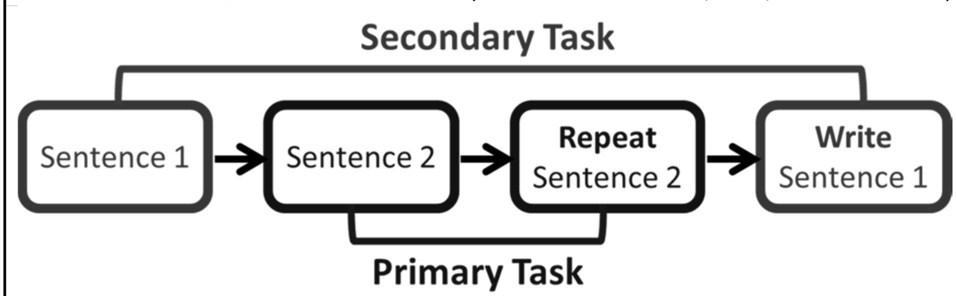
Dual Task Paradigms

- Subject is given a **primary** (listening) and **secondary task** (e.g., visual classification, storage & recall, semantic labeling)

  1. Role of the secondary task may be to increase effort on the primary task by '***consuming cognitive resources***'
  2. ***Or*** role of the secondary task may be to measure the '***reserve cognitive capacity***' left over after primary task
     - Increased effort on a primary task can lead to decreased performance on a secondary task **<u>even if performance on a primary task is not affected</u>**

Dual-Sentence Task

(Alexander & Plotkowski, 2014; HEAL Conference)



- Other secondary tasks do not necessarily reflect the listening demands of real-world situations

Avg. speaking rate ≈120-150 wpm

- '*Face validity*' because in **learning situations** listeners need to pay attention to a talker while mentally rehearsing or taking notes on the talker's previous point

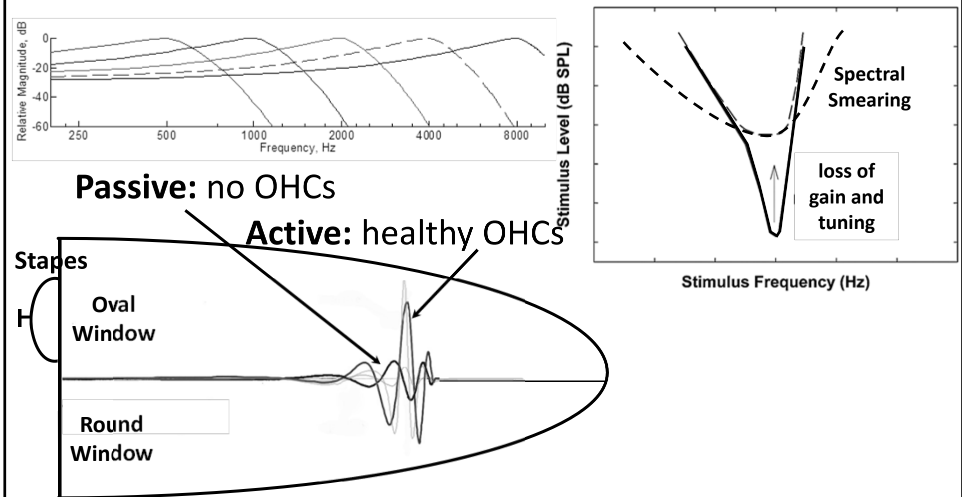
DNR and Cognition/Learning

- The role of DNR on cognitive aspects of listening (performance on dual tasks) is **inconclusive**
  - Some studies have not shown any improvement
  - More importantly, no studies have shown degradation
  - Some indicate that benefit is only seen for users with **higher cognitive processing**, others indicate that benefit is only seen for users with **lower cognitive processing**, and others indicate no relationship
- **Bottom line:** Maybe better dual processing with DNR, especially with more aggressive WRDC
  - **Clinical implication:** In challenging SNRs, DNR might improve ability to **remember** words spoken in noise and **respond quickly** to simultaneous complex visual stimuli

The Noise Problem, Part II: SNR

- An inability to understand speech in noise is a primary reason for wearer dissatisfaction
  - Speech intelligibility in noise is the **#1 improvement** sought in hearing aids
- Due, in part, to **reduced spectral contrast**, hearing-impaired listeners have a reduced ability to process speech at low SNRs **(SNR loss)**
  - Impaired listeners generally **need 6-10 dB greater SNR** to have the same performance levels as NH listeners

Reduced Frequency Selectivity



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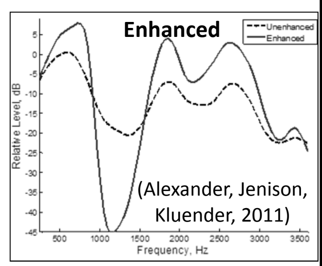
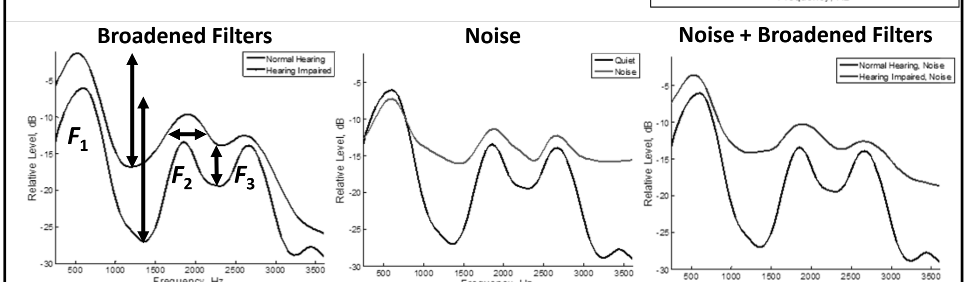
Reduced Spectral Contrast (SNR)

- Refers to peak-to-valley ratio of spectral prominences

1. **Broadened auditory filter tuning**
   - Absent/reduced suppression
   - Increased presentation levels
2. **Noise**
3. **Multichannel compression**

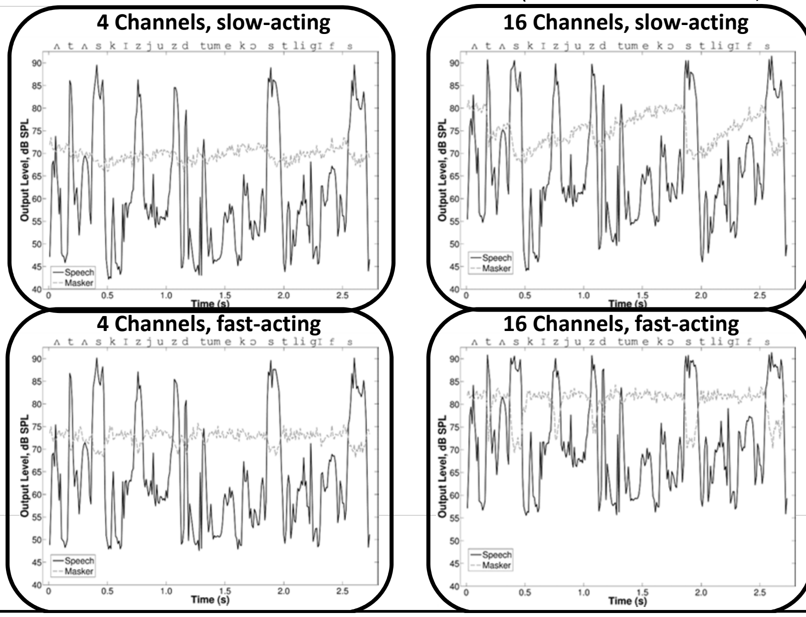




DNR might undo some of these effects (Wu & Stangl, 2013; Alexander & Plotkowski, 2014)

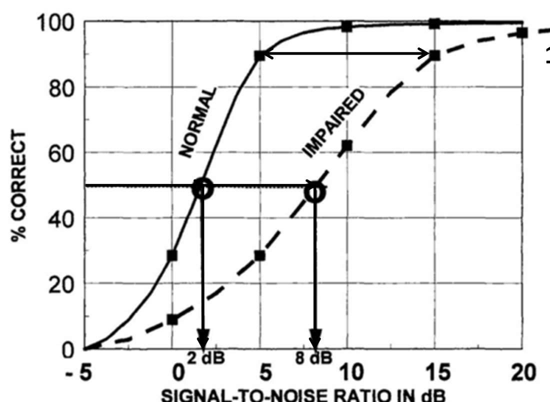
WDRC reduces SNR

(Alexander & Masterson, submitted)



Definition of SNR loss

- The increase in signal-to-noise ratio required by a listener to obtain **50% correct**, compared to normal performance



10 dB difference for high-level understanding of low context sentences

(Killion, 2002)

SNR LOSS: 8 dB - 2 dB = 6 dB

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Solving the SNR Problem

- The key is to separate the speech from the noise ***before*** they reach the impaired ear
- ***Very difficult*** to do with single microphone strategies (e.g., DNR and speech 'enhancement')
- **Directional and remote microphones** are the only hearing aid technologies that have been shown to overcome SNR loss in certain conditions
  - *As SNR loss increases, so does the need for higher levels of technology*

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Directional Microphones: Basic Principles

- The **physical separation** between the **signal** of interest and sources of **interference** is exploited to **improve SNR** by preserving the target in front and **attenuating** interfering sound from back and sides
- ***Spatial separation*** *is not done by the directional mic system, it is* ***up to the user*** *to place the sounds they want to hear in directly front of them and the noise off the side or behind them . . .* (Taylor & Mueller, 2011)
- SNR improvement in real world conditions (0-3 dB) is less than half in optimal lab conditions (4-6 dB)

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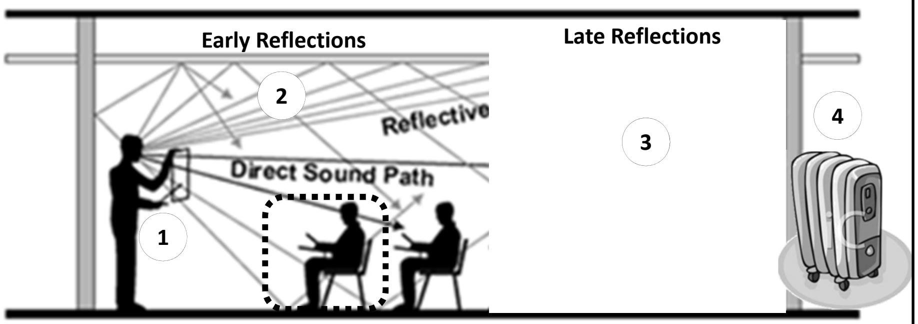
Reverberation

- Single noise sources end up being diffuse (omni-directional) because **reverberation** creates many '**virtual source locations**' that cannot be cancelled



http://www.acousticalsurfaces.com/acoustic_IOI/reverberation.htm

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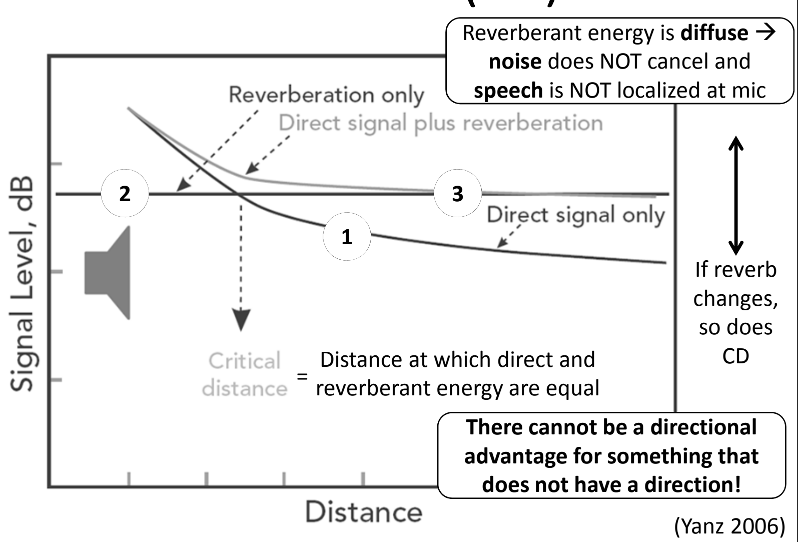
Critical Distance (CD)



(Yanz 2006)

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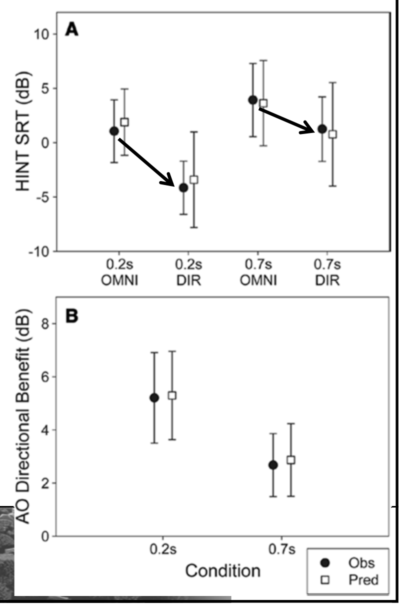
Effects of Reverberation

- Wu and Bentler (2012) found that increasing RT60 (time it takes for SPL to drop 60 dB) from 200 to 700 ms **reduced directional benefit** from 5.2 dB to 2.7 dB in a **laboratory experiment**



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Real-World Performance

- **Ricketts *et al*. (2003), Walden (2003; 2004)**
- Patients prefer directionality < 1/3 of the time
- Directional microphones work effectively only when a <u>specific set of environmental conditions</u> exist
  1. **The talker needs to be in front of the listener and not too far away**
  2. **The noise needs to be to the back or the sides**
  3. **The reverberation must be low**

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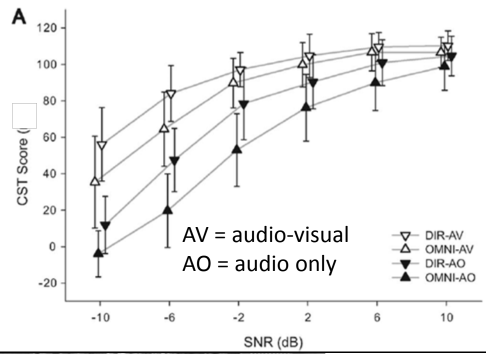
Visual Cues

Wu & Bentler (2010)

- With visual cues, differences between directional and omni go away (performance is near ceiling)

- **Real world benefits of directional mics might be less when listeners have access to visual cues, especially for excellent lip readers**



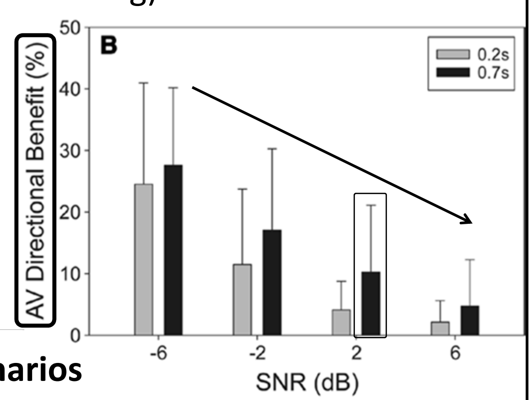
Visual Cues

Wu & Bentler (2012)

- 4 different SNRs, with low (0.2s) or moderate (0.7s) reverb
- Directional benefit decreased as SNR increased (because performance approaches the ceiling)

- However, **unlike the low reverb condition**, benefit was still observed at SNRs **up to +2dB** when **reverb was moderate** (performance ≠ ceiling)

- **Perhaps, there is benefit after all in real-world scenarios**



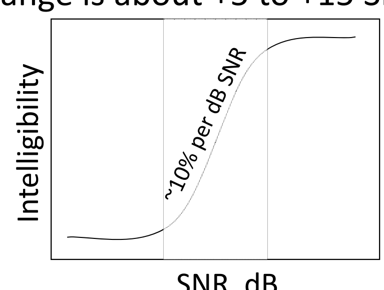
Visual Cues

Aspell & Ricketts (2012)

- Looked at directional benefit with visual cues for speech at favorable SNRs in moderate reverb and low reverb (test booth)
- Selected listeners with poor QuickSIN scores
- Benefit across all SNRs indicates that **if performance is <u>not</u> <u>near</u> <u>ceiling</u>, users may benefit even with visual cues**

Real-World Performance

- Directionality will have greatest effect when the noise is not too high (floor) and not too low (ceiling) because the **performance intensity function is steep**
  - Generally, range is about +5 to +15 SNR for HI listeners



Reverberation, visual cues, etc. will shift this curve to the left or right, respectively

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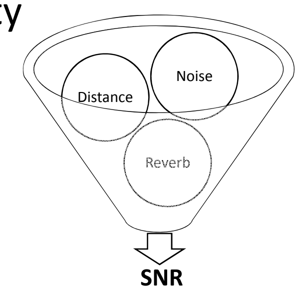
Counseling Patients

- Counsel patient on how to **set up the situation** to make the most out of directionality
  - Generally, they work best when the talker is located in front and relatively near the listener, the noise is to the sides or back, and reverberation is not too high



- Emphasize the importance of **VISUAL CUES** since they can provide more benefit than directional mics, especially when reverberation is high

Adaptive Directionality

- A system in which the polar response changes with changes in the spatial characteristics of the noise
- Directional patterns where the null is in front are excluded from consideration to prevent an inadvertent or undesirable attenuation of sounds coming from the front – **with some exceptions!**
- If target is in front, directivity pattern with the **greatest noise attenuation** (**highest SNR**) will also yield the **lowest power output** from the dual mic
  - ***Why?*** Because the *direct* noise energy falls in a null

Real World Effectiveness

- Relatively **rare** to encounter a situation with just one noise source
- **Diffuse background noise and reverberation** limits the usefulness of adaptive directionality
- Adaptive nulls only demonstrate benefit in **contrived lab situations**, in which a **single** noise source arriving at the wearer's ear is dominated by the direct sound field

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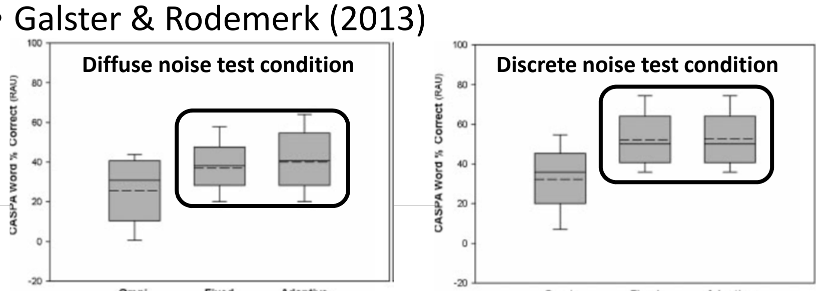
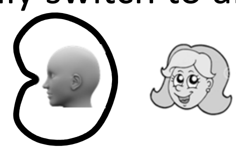
'Real World' Efficacy

- Less effective when **low-level diffuse noise** is concurrently present with the interferer
  - Bentler *et al.* (2004)
    - 1 of 5 noise sources behind listeners presented along with an 8-speaker diffuse noise source
    - **Adaptive system was not able to follow the dominant noise source in the presence of lower level noise sources**
  - Galster & Rodemerk (2013)



Anti-Cardioid Directional Pattern

- Sometimes the talker of interest is **behind or off to the side**, and the user is not able to turn his/her head, e.g., (while driving)
- Some manufacturers have recently developed products that will automatically switch to an anti-cardioid (**reverse cardioid**)



- Instead of 'null steering' this might thought of as '**speech steering**'

(Bentler & Mueller, 2011)

Wu *et al.* (2013)

- Compared omnidirectional and conventional adaptive directional strategies to 3 strategies intended to improve SNR for conditions in which talker is not in front

1. **Anti-cardioid**
2. **Side Suppression:** gain on side with poorer SNR is reduced and DNR is made more aggressive
3. **Side Transmission:** bilateral steaming of audio from side with better SNR (anti-cardioid) to side with poorer SNR

Wu *et al.* (2013)

- **What they found:**
  - In almost all cases **conventional adaptive was detrimental** compared to omni

Speech from the Back

	Anti-Card	Side Supp	Side Trans
Omni	↑	↓	↑
Adapt	↑	X	↑

Speech from the Side

	Anti-Card	Side Supp	Side Trans
Omni	X	↑	↑
Adapt	X	↑	↑

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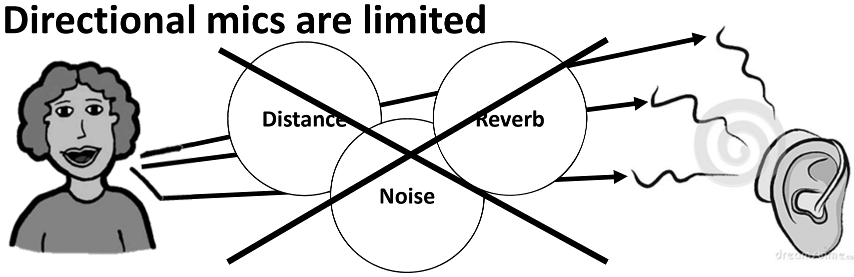
The SNR Problem and Directional Mics

- **Directional mics are limited**



- Solution is to pick up the signal at its source and deliver a higher-quality, more intelligible speech signal to one or **both ears**
  - Remote or "companion" microphones
  - Accessory devices for the TV, phone, etc.

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Benefits of Connectivity

- Improved SNR and added convenience
- **The ability to better meet patients' needs can significantly increase the value of and improve the satisfaction of the original hearing aid purchase**
- More than 4 out of every 5 hearing aids sold during the first half of 2014 contained wireless technology
  (*www.hearingreview.com/2014/07/hearing-aid-sales-2-9-first-half-2014*)

Wireless Ear-to-Ear

- Communication of information between the left and right hearing aids
  1. **Coordinate** volume and program settings
  2. **Exchange** information about the acoustic scene
     - Improved feedback identification and noise reduction
  3. **Stream** audio signal from one hearing aid to the next
     - Alternative directional patterns
     - Bilateral beamforming
     - Modified Bi-CROS (e.g., listening in a car) and CROS (phone)

Methods of Wireless Connectivity

- **Near-Field** Magnetic Induction (NFMI)
  - *Uses magnetic induction to transmit and T-coil to receive*
  - *Short distance signal transmission (up to **1 meter**)*
  - 3-15 MHz

- **Far-field** wireless communication using license-free radio frequencies
  - *Uses radio transmitters and receivers*
  - *Longer distance signal transmission (**5-7 meters**)*
  1. **900 MHz**
  2. **2.4 GHz**

  } **Proprietary → direct & efficient**

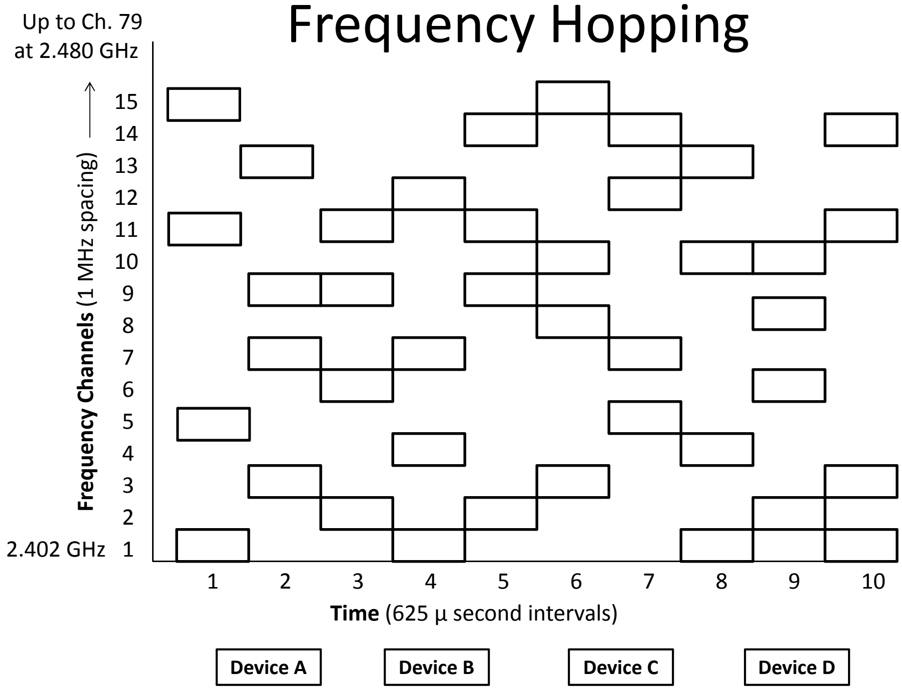
  3. **Bluetooth (2.4 GHz): generic, requires a relay device**

Differences to be Aware of

1. Transmission delay
2. Audio transfer (bitrate)
3. Mono vs. Stereo
4. Audio bandwidth
5. Transmission range
6. Current drain of hearing aid <u>and</u> relay device
7. Accessory pairing required?
8. Type of ear-to-ear information

(Kuk *et al*., 2011)

Frequency Hopping



Bluetooth Limitations

1. Long transmission delay
2. High power consumption
3. Large components (chip, antenna, battery)
4. ‘Limited’ audio bandwidth
   - Trades off with delay

(Filips & Meyers, 2010)

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Bluetooth SMART (Bluetooth v4.0, Low Energy)

- Dramatically reduced power consumption and size
- Enhanced range
- Low cost
- Open to any one

- Currently, only a **proprietary** profile is available
  - "Made-For-iPhone" (MFi) hearing aids Made for iPhone
- Efforts are underway to develop a new hearing profile that will be supported by **all 6 major hearing aid manufacturers**
  - Offers the potential to replace loop systems someday

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References

- Alexander, J., Jenison, R., and Kluender, K. (2011). Real-time contrast enhancement to improve speech recognition. *PloS one*, 6(9), p.24630.
- Alexander, J. M., and Masterson, K. M. (in press). Effects of WDRC release time and number of channels on output SNR and speech recognition. *Ear and Hearing*.
- Alexander, J. M., and Plotkowski, A. R. (2014). A dual-sentence paradigm using PRESTO to assess the effects of hearing aid algorithms on cognitive processing. *HEAL (HEaring Across the Lifespan) Conference*, Cernobbio (Lake Como), Italy.
- Bentler, R., and Mueller, H. G. (2011). 20Q: Hearing Aid Features-The Continuing Search for Patient Benefit. *AudiologyOnline*.
- Bentler, R., Tubbs, J., Egge, J., Flamme, G., and Dittberner, A. (2004). Evaluation of an adaptive directional system in a DSP hearing aid. *American Journal of Audiology*, 13(1), pp.73-79.
- Filips, G., and Meyers, C. (2010). Answers for life – Connecting wirelessly with Siemens. *AudiologyOnline*, Webinar #18162.
- Galster, J., and Rodemerk, K. (2013). Individual Variability in Benefit from Fixed and Adaptive Directional Microphones. *Seminars in Hearing*, 34(2), pp.110-117.
- Hornsby, B. (2012). 20Q: Hearing Loss, Hearing Aids, and Listening Effort. *AudiologyOnline*.
- Killion, M. (2002). New thinking on hearing in noise: A generalized articulation index. *Seminars in Hearing*, 23(1), pp.47-62.

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References

- Kuk F., Korhonen, P., Crose B., *et al*. (2011). Digital wireless hearing aids, Part 2: Considerations in developing a new wireless platform. *Hearing Review*, 18(6).
- Mueller, H. G., Weber, J., and Hornsby, B. (2006). The effects of digital noise reduction on the acceptance of background noise. *Trends in Amplification*, 10(2), pp.83-93.
- Palmer, C., Bentler, R., and Mueller, H. G. (2006). Amplification with digital noise reduction and the perception of annoying and aversive sounds. *Trends in Amplification*, 10(2), pp.95-104.
- Ricketts, T., and Hornsby, B. (2003). Distance and reverberation effects on directional benefit. *Ear and Hearing*, 24(6), pp.472-484.
- Taylor, B., and Mueller, H. G. (2011). *Fitting and dispensing hearing aids*. 1st ed. San Diego: Plural Publishing.
- Walden, B., Surr, R., Cord, M., and Dyrlund, O. (2004). Predicting hearing aid microphone preference in everyday listening. *Journal of the American Academy of Audiology*, 15(5), pp.365-396.
- Wu, Y., and Bentler, R. (2010). Impact of visual cues on directional benefit and preference: Part I—Laboratory tests. *Ear and hearing*, 31(1), pp.22-34.
- Wu, Y., and Bentler, R. (2012). The influence of audiovisual ceiling performance on the relationship between reverberation and directional benefit: perception and prediction. *Ear and hearing*, 33(5), pp.604-614.
- Wu, Y., Stangl, E., Bentler, R., and Stanziola, R. (2013). The effect of hearing aid technologies on listening in an automobile. *Journal of the American Academy of Audiology*, 24(6), pp.474-485.
- Yanz, J. L. (2006). Directional speech detector: A truly smart directional design. Starkey Hearing Research & Technology White Paper.

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