AI in Hearing Aids: A Framework for Understanding Its Advantages and Limitations

Brian Taylor, AuD

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Learning Outcomes

After this course participants will be able to :

1) Define AI and DNNs as it applies to hearing aids.

2) Describe how AI is implemented in modern hearing aids

3) Apply a working framework to better understand AI in hearing including its advantages and limitations.

Limitations/Risks

Please review these bullets and make any revisions/additions as applicable for your course.

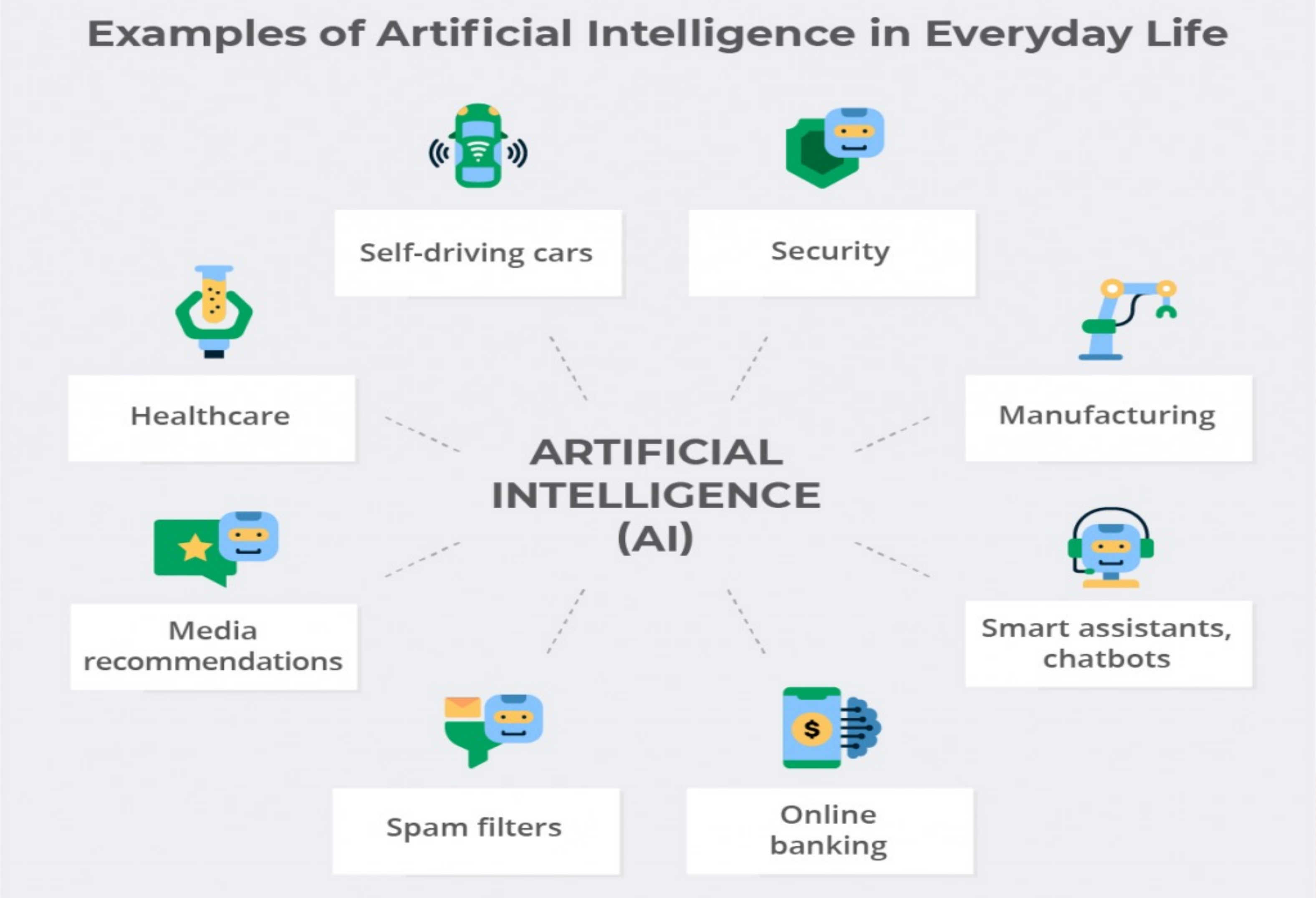
- The applicability and accuracy of the course content may vary by the clinical, geographical, and cultural context; you should evaluate the course accordingly.
- As healthcare is rapidly evolving, new findings may change the validity of the information presented in this course. Providers should always consult the latest research and guidelines from professional associations.
- The interventions discussed in this course may be limited in generalizability, requiring practitioners to consider specific individual and population factors.
- The course may not cover all possible risk factors, diagnostic methods, or treatment options, and complex cases may require additional considerations.
- Healthcare providers should apply cultural competence and sensitivity to ensure effective and respectful care based on their patients' diverse needs.
- Providers should always evaluate the limitations of diagnostic and screening tools, considering their potential for false results as well as any ethical implications.
- It is the responsibility of course participants to critically evaluate the evidence from multiple sources to guide professional practice.

Disclosures

- Senior Director, Audiology, WS Audiology
- Adjunct Instructor, University of Wisconsin
- Editor, Audiology Practices (ADA)
- Editor, Hearing Healthcare & Technology Matter (This Week in Hearing)

Today’s Key Questions

1. What is AI? What are DNNs?
2. How is AI implemented in hearing aids?
3. What are the advantages and limitations of these AI-based features?
4. How might AI change the way audiologists fit hearing aids?



Examples of Artificial Intelligence in Everyday Life

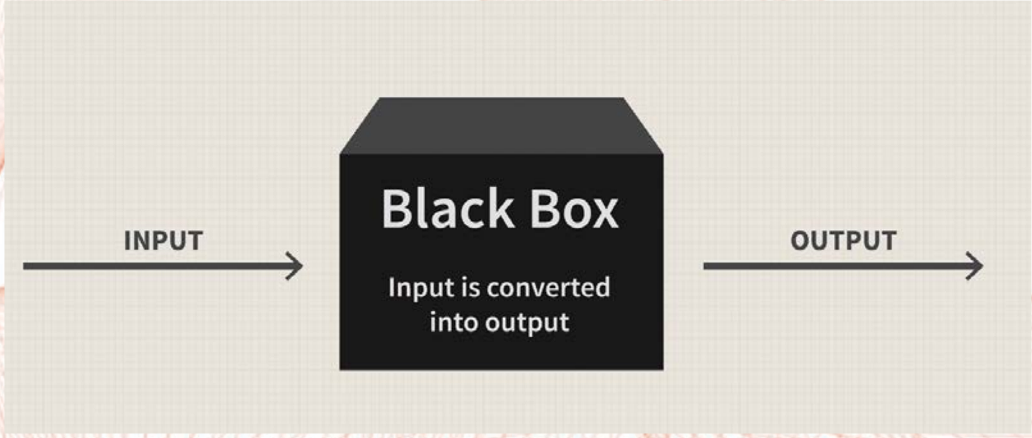
ARTIFICIAL INTELLIGENCE (AI)

- Self-driving cars
- Security
- Healthcare
- Manufacturing
- Media recommendations
- Smart assistants, chatbots
- Spam filters
- Online banking

Limitations and Downside of AI

Power Consumption & Ugly/Brutalis
In data center hotspots like VA, IL, OH
electric bills have climbed
much faster than the national average
with some areas seeing price increase
of as much as 267% compared to
5 years ago.

Limitations and Downside of AI



“Black Box Thinking”
Rely too much on AI tools and gradually lose sharpness in core diagnostic or decision-making skills, similar to how GPS weakened people’s navigation abilities

Recent product claims and marketing campaigns

“Superhuman Intelligence”

“AI-Powered Clarity”

“9 dB improvement compared to leading AI-powered hearing aid”

“AI-Powered Personalization”

“World’s Smallest AI Hearing Aid”

A gentle reminder

“Gee, if she says they have AI, they must be the best.”

“These new hearing aids have AI.”

What people think they’re using or how it’s presented can influence outcomes

How you frame the product and experience matter!

1. Labeling influences outcomes:
    a. Digital vs. conventional (Bentler at al 2003)
    b. New vs. conventional (Dawes. 2013)

2. Narrative framing shapes outcomes:
    a. Positive communication (accentuating positive experiences) influences outcomes (Rakita, et al 2022, Lelic, et al 2024)

3. Fitting process preference:
    a. comprehensive vs basic fitting processes …… 73% of participants believed two processes led to different real-world results (Wu et al 2024)

Important questions to ponder, as we cover today's material

- Does all this AI excitement translate into improved patient benefit?

- If so, how much?

What is AI?

- Simulates how the human brain works
- Automated pattern recognition
- A way to teach computers to perform tasks that normally require human judgement
- AI outputs reflect training data and decisions of engineers, not “intelligence”

6 subfields of AI

Search and Plan

(Deep Blue)

Knowledge and "Reasoning"

(Chat GPT)

Natural Language Processing

(Alexa)

Physical Movement

(Robotics)

Perception (Acoustic and Motion Sensors)

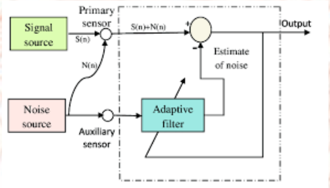
Machine Learning

(Just about everything)

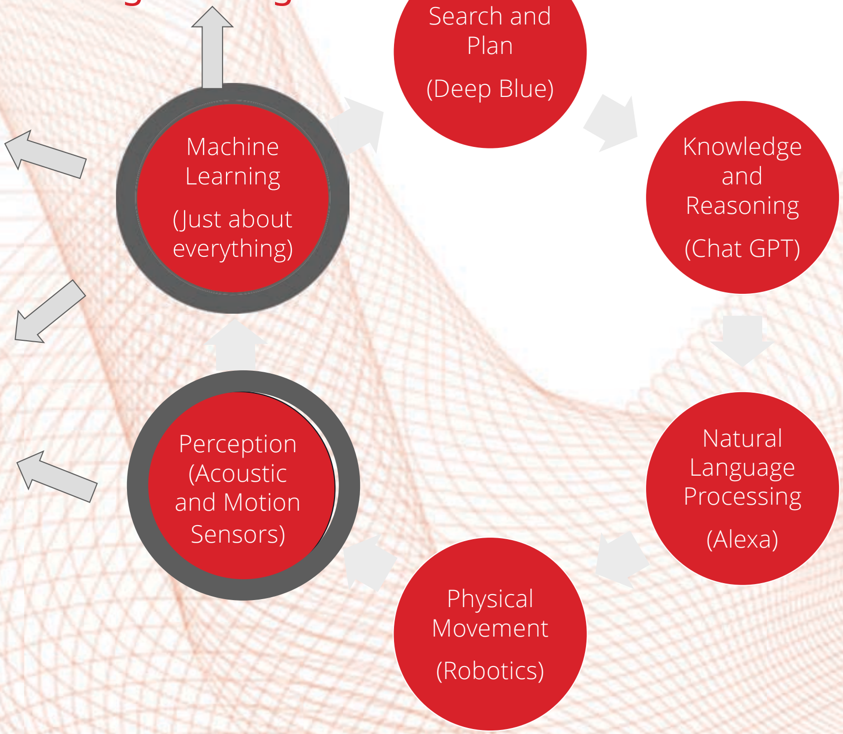
Implementation of AI in Hearing Aids

Self-fitting hearing aids

Digital Assistants



Noise Reduction



Machine Learning

(Just about everything)

Search and Plan

(Deep Blue)

Knowledge and Reasoning

(Chat GPT)

Natural Language Processing

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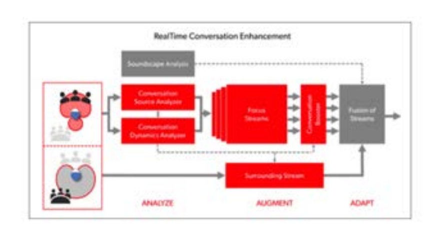
Physical Movement

(Robotics)

Perception (Acoustic and Motion Sensors)

Implementation of AI in Hearing Aids



Environmental Classification Systems

Machine learning for song recognition

- New song is posted on Apple Music
- Shazam’s DNN is trained to recognize the song
- Once training has occurred, Shazam will identify the song

Limitations of AI for Song Recognition

- If it’s a live version of the song or a cover version that the app has not been trained to recognize, the app must guess
- Humans, who are familiar with the song, will instantly recognize it – even when there is noise, or it’s a live or cover version.

Machine Learning in Hearing Aids

1. Collect large pools of data – sound files
2. Engineers create a network or model (DNN) - a **pattern recognition** machine
3. **Train** the model – e.g., teach it to recognize speech and attenuate noise
4. Validate the model – make sure it works with minimal artifacts and reasonable battery consumption
5. Deploy in the device – commercialize it

How is AI implemented in hearing aids?

- Personal Sound Optimization (Self-adjustment)
- Automatic Environmental Classification (Auto-steering)
- Noise Cancellation (Denoising, Noise Cleaning)

AI Framework

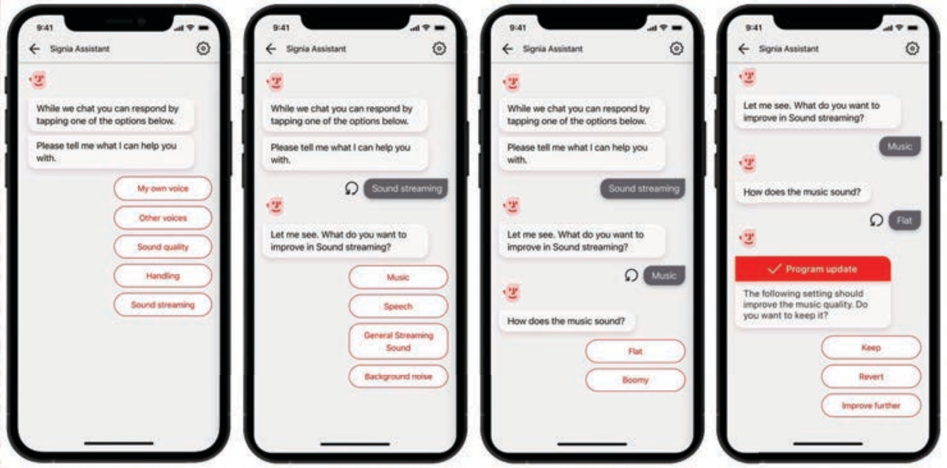
1. What human task or existing hearing aid feature does it replace or augment?	
2. How it works? / What it does?	
3. Is it effective?	
4. What are the limitations?	

AI Framework

What human task or existing hearing aid feature does it replace or augment?	Some element of hearing aid performance
How it works? / What it does?	Training data, training model, what patterns is the algorithms trained to recognize– usually a best guess
Is it effective?	Evaluate research to determine
What are the limitations?	Tasks AI has trouble doing or tasks simply do better

1. Personal Optimization/Self-adjustment

- Since 2006 (Siemens’ trainable gain)
- Example: Signia Assistant (2018)



While we chat you can respond by tapping one of the options below.

Please tell me what I can help you with.

While we chat you can respond by tapping one of the options below.

Please tell me what I can help you with.

Sound streaming

Let me see. What do you want to improve in Sound streaming?

While we chat you can respond by tapping one of the options below.

Please tell me what I can help you with.

Sound streaming

Let me see. What do you want to improve in Sound streaming?

Music

How does the music sound?

Let me see. What do you want to improve in Sound streaming?

Music

How does the music sound?

Flat

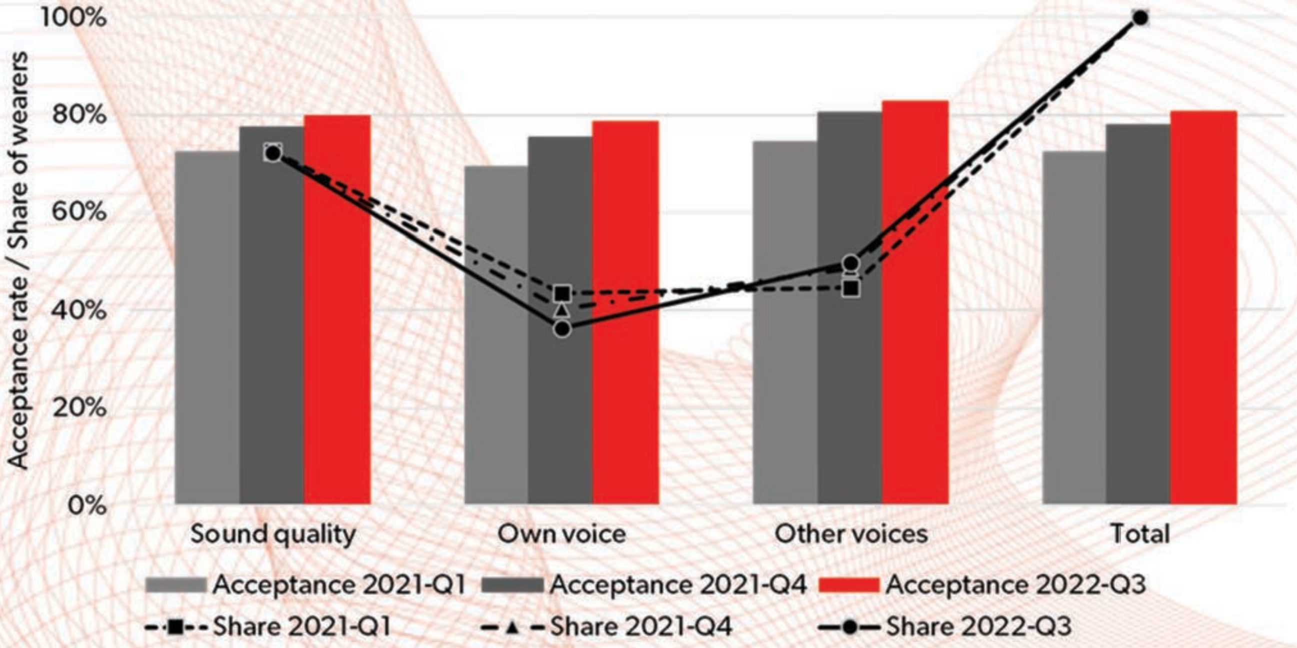
The following setting should improve the music quality. Do you want to keep it?

Personal Optimization

What human task or existing hearing aid feature does it replace or augment?	Wearer adjustments and in-office fine-tuning
How it works? / What it does?	Adapt settings (gain, compression, directivity, noise reduction) to the preferences of the wearer. Wearer trains settings using data collected from other wearers, stored in “the cloud”, to arrive at alternative settings.
Is it effective?	
What are the limitations?	

Digital Assistant Improves Wearer Satisfaction

- N = 58,765



Personal Optimization

What human task or existing hearing aid feature does it replace or augment?	Wearer adjustments and in-office fine-tuning
How it works? / What it does?	Adapt settings (gain, compression, directivity, noise reduction) to the preferences of the wearer. Wearer trains settings using data collected from other wearers, stored in “the cloud”, to arrive at alternative settings.
Is it effective?	Fewer in-office visits, higher levels of satisfaction, greater empowerment (maybe)
What are the limitations?	Requires wearer to be comfortable with smartphone and app working in combination with hearing aids, Very few wearers and clinicians seem to prefer this compared to conventional approaches

2. Signal or Sound Environment Classification Systems

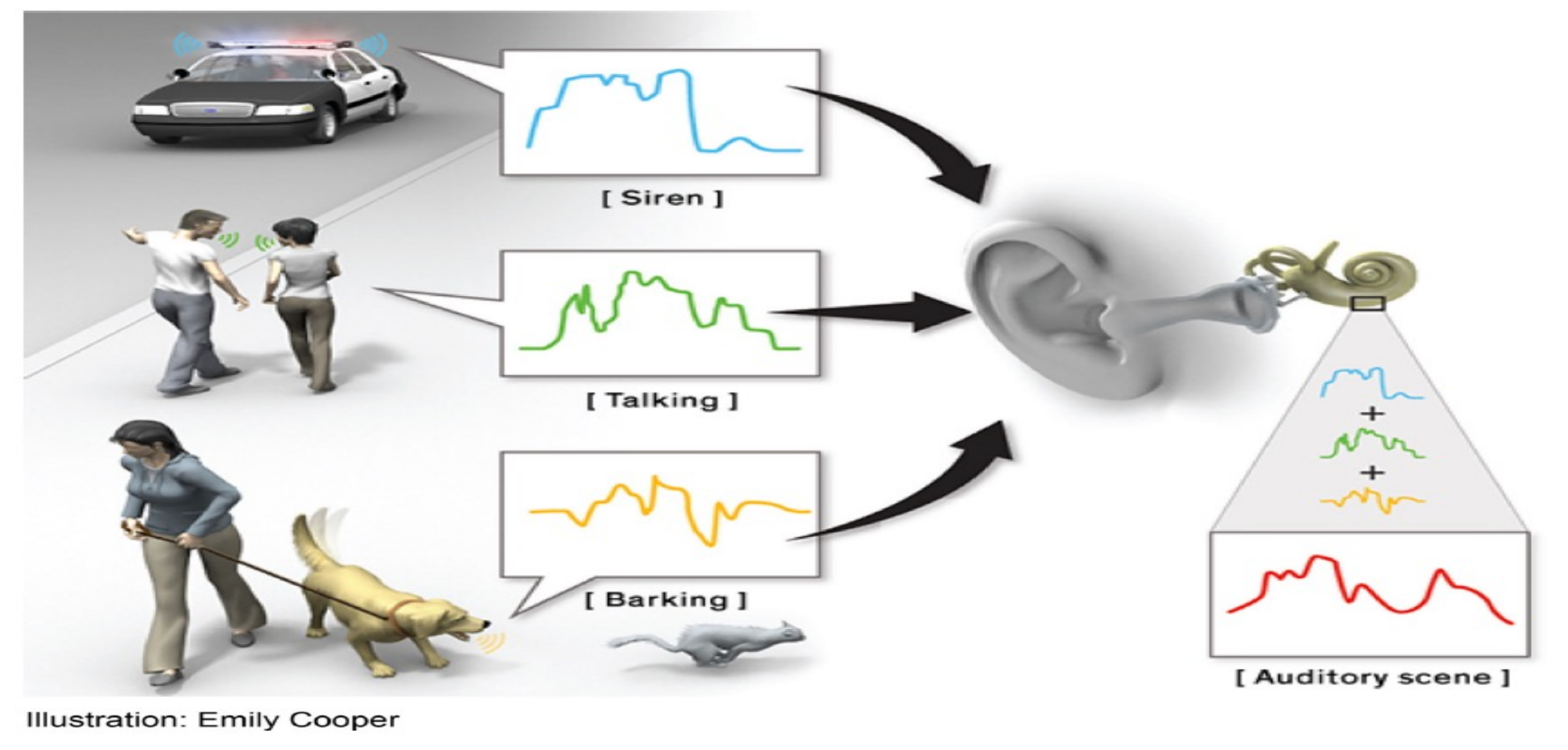
- Since ~2008: e.g., Unitron Indigo
- Automatic program switching or auto-steering
- “listen” and “decide” what kind of environment the wearer is in and apply the “right” mix of amplification and NR
- Branded names:
  - 4D Sensor
  - Dynamic Soundscape Processing
  - AutoSense OS
  - Environmental Optimizer

Environmental Classification Systems

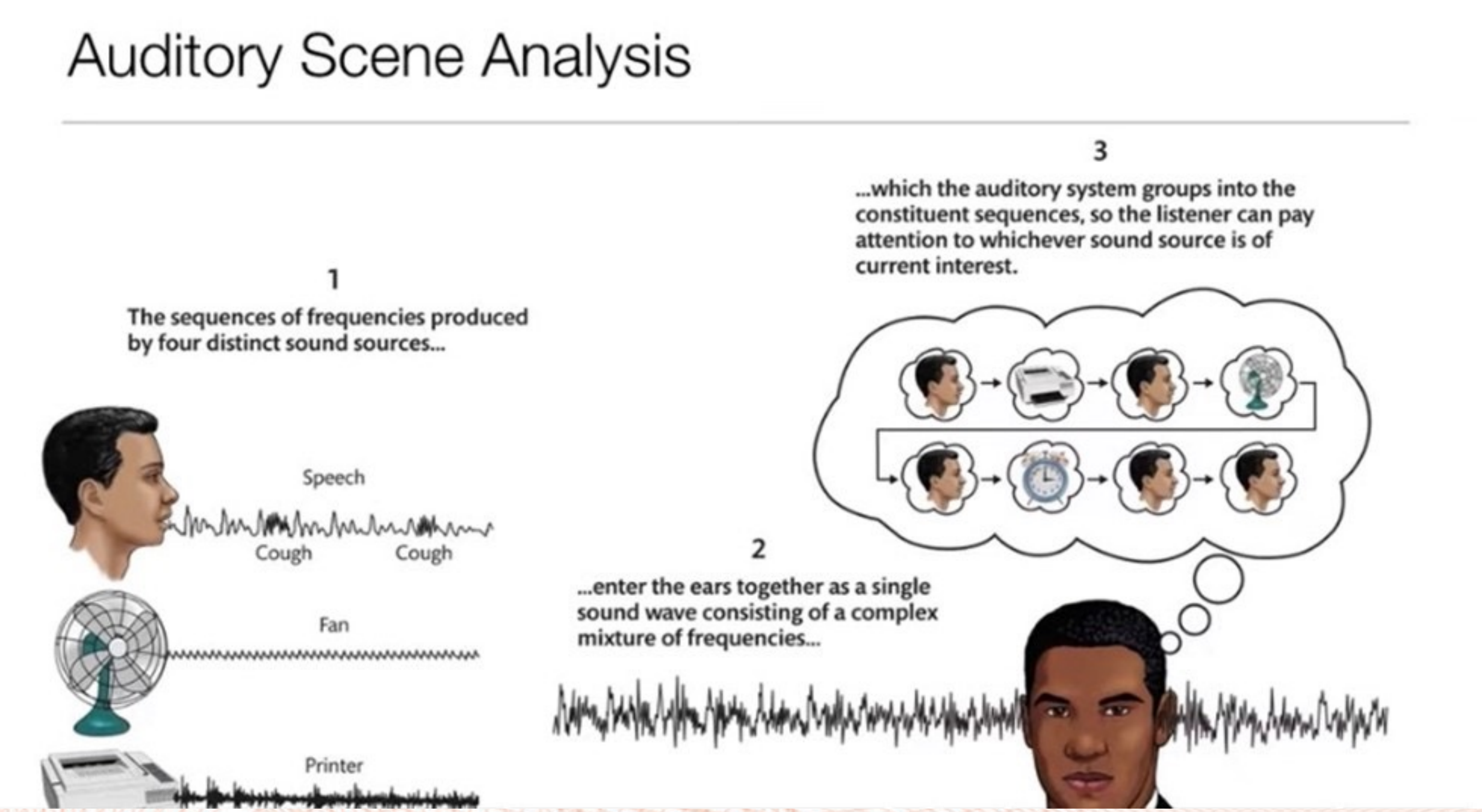
What human task or existing hearing aid feature does it replace or augment?	Manual program switching
How it works? / What it does?	Detect the listening situation of the wearer: Quiet room, restaurant, car, music and automatically activate necessary features to optimize performance. Tries to predict the listening intent of the wearer. "acoustic scene analysis"
Is it effective?	
What are the limitations?	

What AI-driven classifiers are trying to augment?

- Auditory Scene Analysis



The Human Auditory System: A Pattern Recognition Machine



Auditory Scene Analysis

1

The sequences of frequencies produced by four distinct sound sources...

2

...enter the ears together as a single sound wave consisting of a complex mixture of frequencies...

3

...which the auditory system groups into the constituent sequences, so the listener can pay attention to whichever sound source is of current interest.

Bregman, A. S. (1990) Auditory scene analysis: The perceptual organization of sound. Cambridge, MA: MIT Press.

Acoustic Scene Analysis

- Every listening situation has a characteristic acoustic fingerprint
- Detect sounds and use statistical analysis to determine the type of listening environment
    - Speech in quiet
    - Speech in noise
    - Loud noise
    - Music
    - Riding in car
- The type of listening environment determine what features are automatically activated

What it looks like in the fitting software

<u>Input Signal:</u>

- Intensity level

- Spectrum

-Physical movement

-

<u>Feature Extraction</u>:

-SNR

- Overall SPL

- Frequency distribution

- Dynamic range

How accurate are these AI-driven classifiers?

Trends in
HEARING

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Andrew J. Oxenham,
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Departments of Psychology and Otolaryngology
University of Minnesota

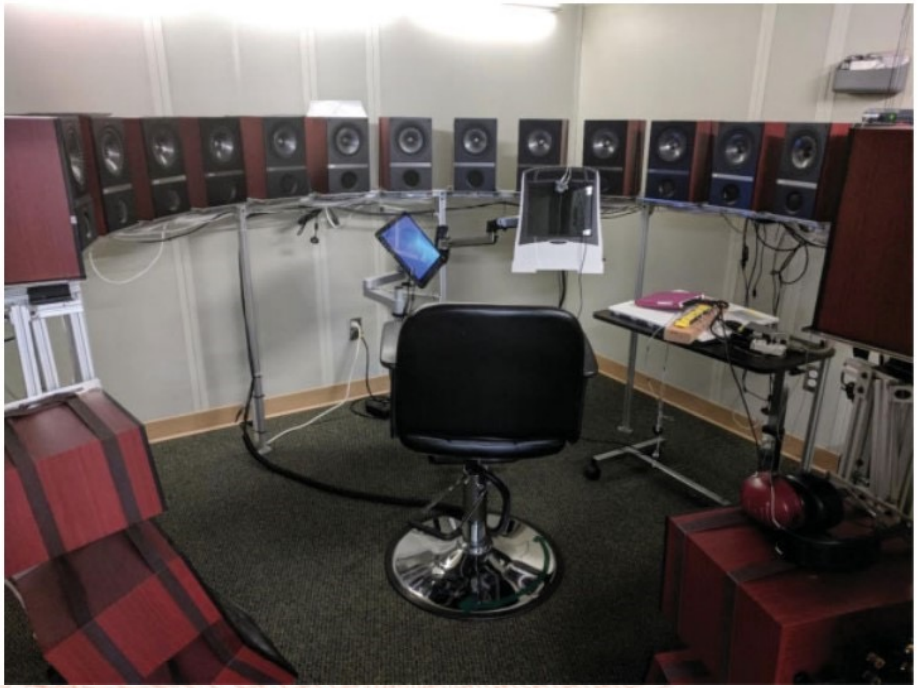
SAGE
http://tia.sagepub.com

Indexed in MEDLINE

A Comparison of Environment Classification Among Premium Hearing Instruments

Yellamsetty A, Ozmeral E, Budinsky R, & Eddins D.
Trends In Hearing, 2021

Klangfinder acoustic manikin head.



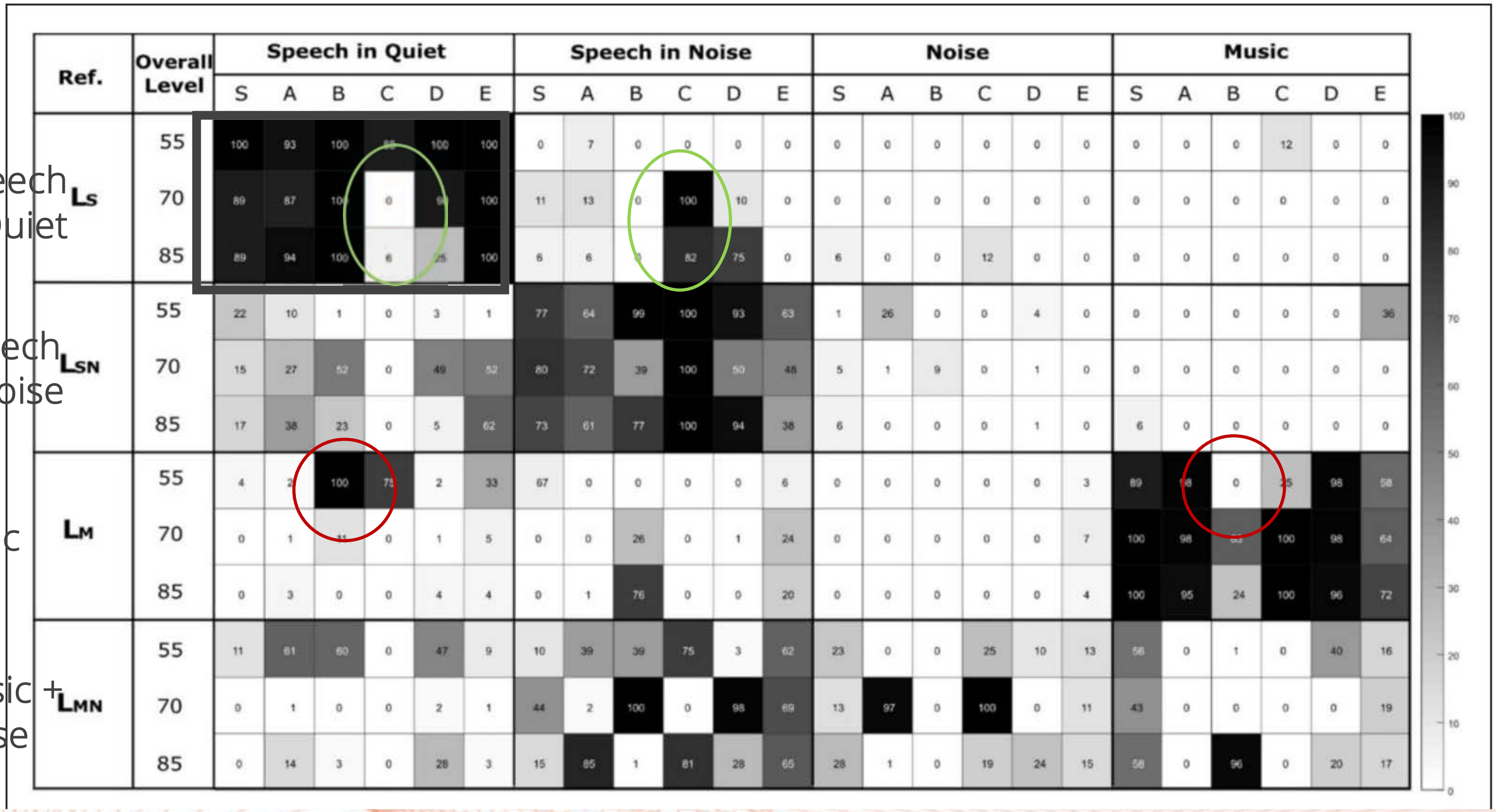
Auditory Speech Sciences Laboratory, University of South Florida

What they did . . .

- Compared the classifiers of five premium hearing instruments to a group of human listeners.
- Instruments programmed to each company’s default proprietary algorithm.
- 28 acoustic scenes representing various common listening environments were presented to the five devices mounted on an acoustic manikin.
- The scenes varied in content, overall SPL and SNR.

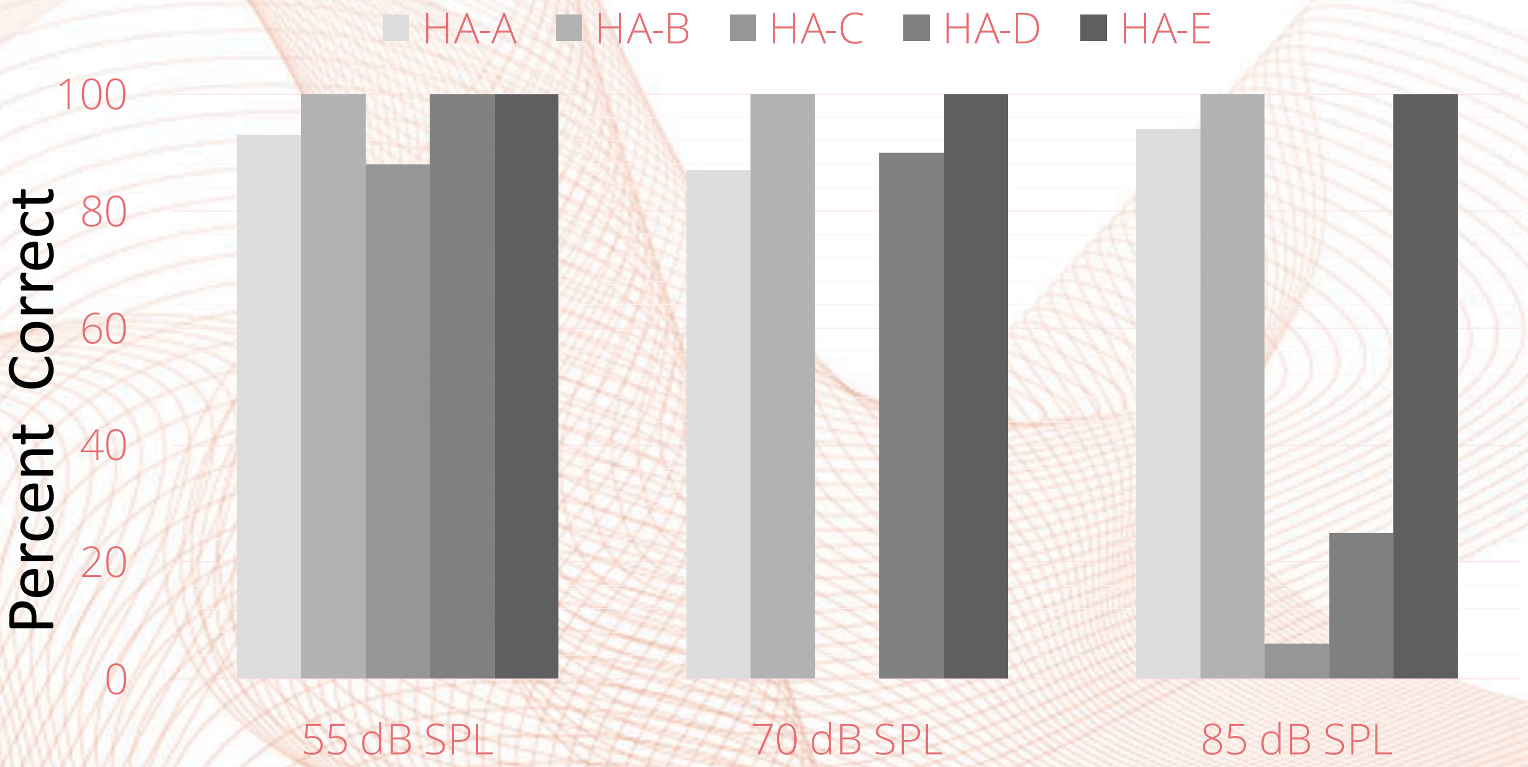
How each brand classified

The darker the square, the more frequent the classifier selected that category

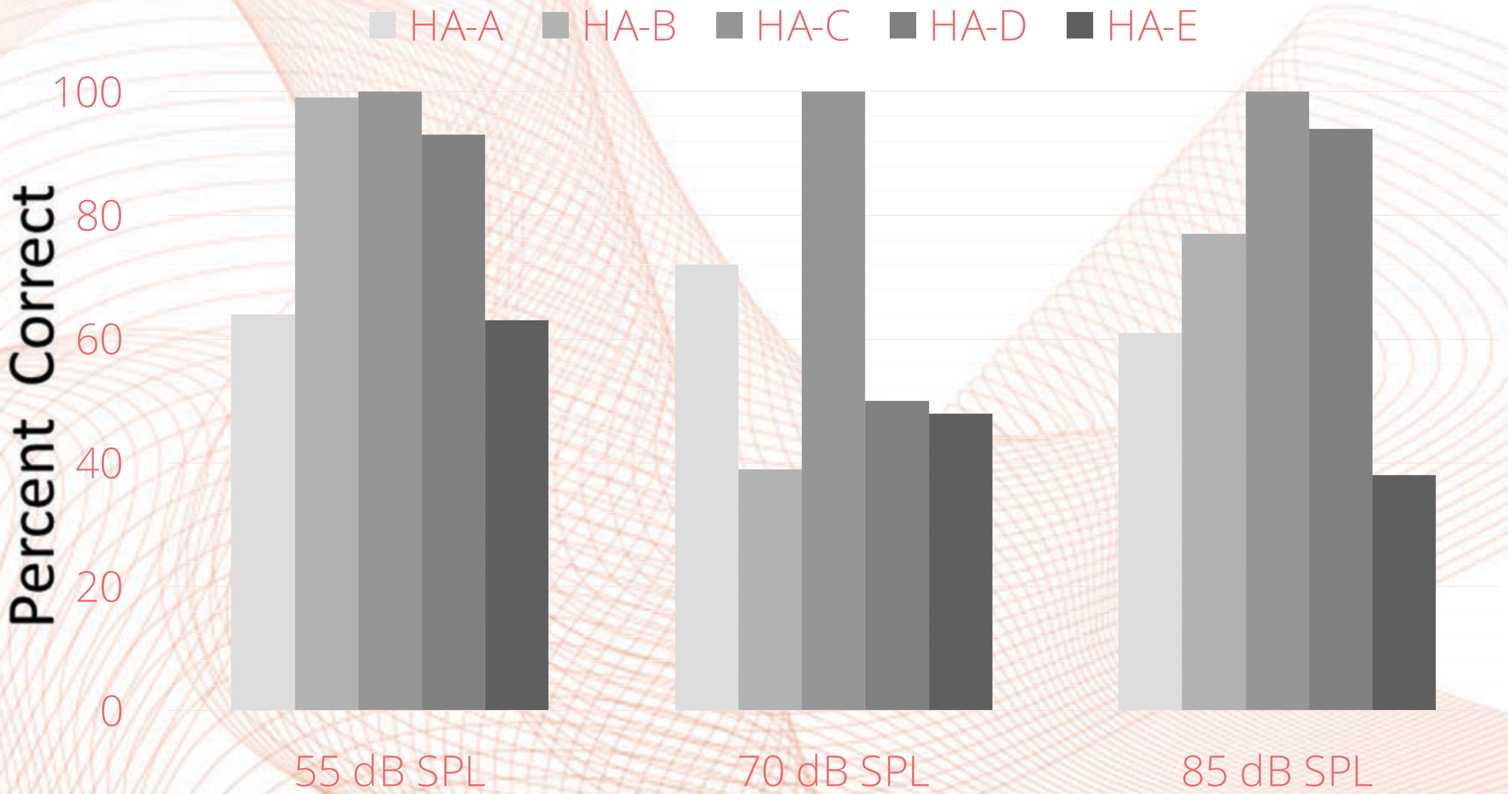


	Ref.	Overall Level	Speech in Quiet						Speech in Noise						Noise						Music					
			S	A	B	C	D	E	S	A	B	C	D	E	S	A	B	C	D	E	S	A	B	C	D	E
Speech In Quiet	L_S	55	100	93	100	88	100	100	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0
		70	89	87	100	0	[illegible]	100	11	13	0	100	10	0	0	0	0	0	0	0	0	0	0	0	0	0
		85	89	94	100	6	25	100	6	6	0	82	75	0	6	0	0	12	0	0	0	0	0	0	0	0
Speech In Noise	L_{SN}	55	22	10	1	0	3	1	77	64	99	100	93	63	1	26	0	0	4	0	0	0	0	0	0	36
		70	15	27	52	0	49	52	80	72	39	100	50	48	5	1	9	0	1	0	0	0	0	0	0	0
		85	17	38	23	0	5	62	73	61	77	100	94	38	6	0	0	0	1	0	6	0	0	0	0	0
Music	L_M	55	4	2	100	75	2	33	67	0	0	0	0	6	0	0	0	0	0	3	89	98	0	25	98	58
		70	0	1	11	0	1	5	0	0	26	0	1	24	0	0	0	0	0	7	100	98	63	100	98	64
		85	0	3	0	0	4	4	0	1	76	0	0	20	0	0	0	0	0	4	100	95	24	100	96	72
Music + Noise	L_{MN}	55	11	61	60	0	47	9	10	39	39	75	3	62	23	0	0	25	10	13	56	0	1	0	40	16
		70	0	1	0	0	2	1	44	2	100	0	98	69	13	97	0	100	0	11	43	0	0	0	0	19
		85	0	14	3	0	28	3	15	85	1	81	28	65	28	1	0	19	24	15	56	0	96	0	20	17

Back and forth conversation between a man and a woman in quiet



Male and female conversation at noisy food court: SNR -5 dB (@ 3 different SPL levels)



Assessing Classifiers in the Clinic

- 30-minute snippets, using datalogging

1. Conversation with background noise

   Speech = 66 dB SPL, noise = 60 dB SPL, **SNR = +6 dB**

2. Speech with music (relaxed cocktail party)

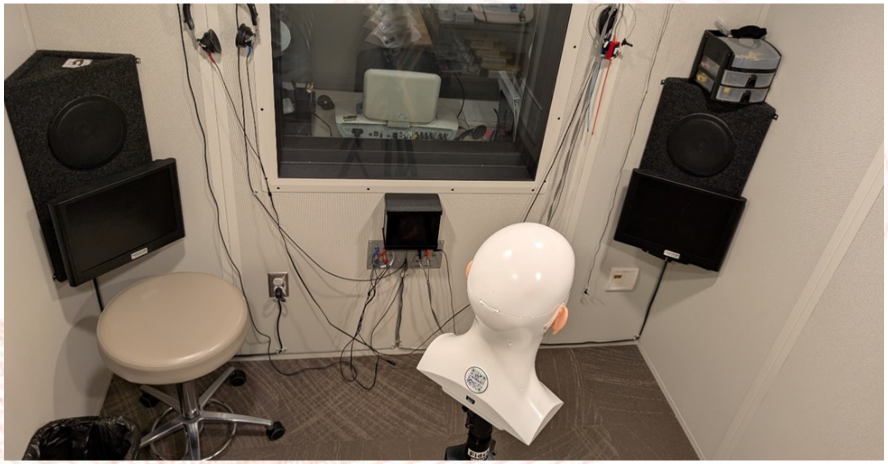
   Speech = 70 dB SPL, music = 67 dB SPL, **SNR = +3 dB**

3. Car environment (listening to podcast while driving)

   Speech = 70 dB SPL, noise = 70 dB SPL, **SNR = 0 dB**

4. Speech with babble in a busy area

   Speech = 67 dB SPL, noise = 70 dB SPL, **SNR = - 3 dB**



Acknowledgement: Josh Alexander, PhD, Purdue University

Brand A, Premium 2025

Programs

Acoustic Scene	Calm situation	Speech in noise	AI-based “denoiser”	Speech in car	Comfort in Noise	Music
Conversation with background noise	99%	1%	0	0	0	0
Speech with music	59%	36%	0	0	5%	
Car environment	87%	13%	0	0	0	0
Speech with babble in busy area	36%	47%	0	0	17%	0

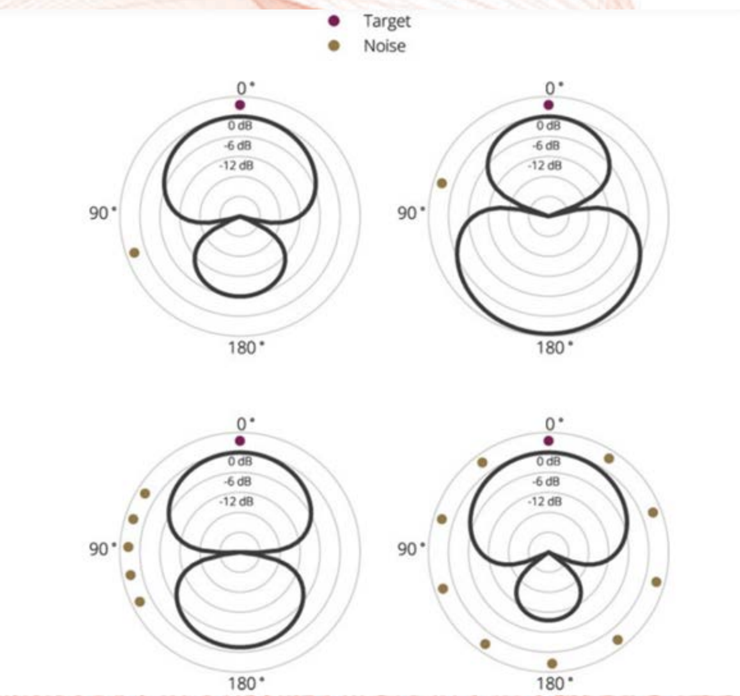
Environmental Classification Systems

What human task or existing hearing aid feature does it replace or augment?	Manual program switching, auditory scene analysis
How it works? / What it does?	Detect the listening situation of the wearer. Quiet room, restaurant, car, music and automatically activate necessary features to optimize performance. Tries to predict the listening intent of the wearer. "acoustic scene analysis"
Is it effective?	~80% accurate in quieter environments. The more complex the listening situation, the less accurate (more variability across brands)
What are the limitations?	May not be accurate in complex listening situations, don't know the intent of the wearer. Difficult to assess how these work in your clinic. Consider use of a manual program

3. DNN-based Noise Reduction

What human task or existing hearing aid feature does it replace or augment?	Remove as much unwanted noise as possible without removing target sounds, usually speech.
How it works? / What it does?	
Is it effective?	
What are the limitations?	

What it augments?



Directional Microphones

- Rely of spatial separation of speech and noise
- “Spatial filtering”
- Unilateral beamformers
- Bilateral beamformers

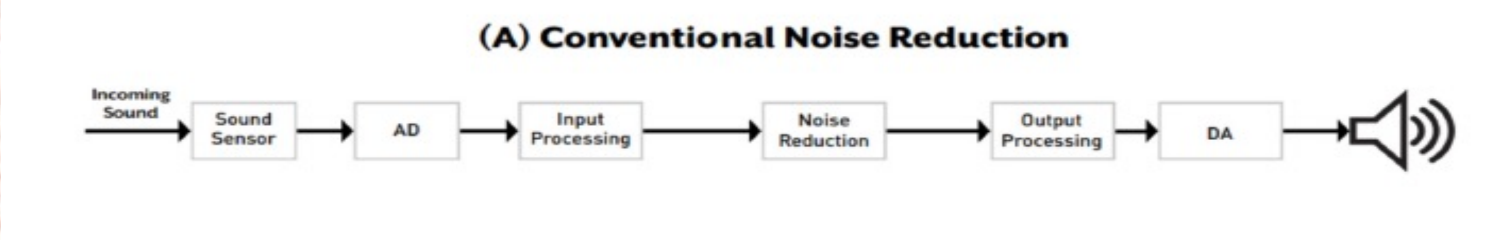
Limitations of directional microphones/beamformers

- Attenuate signals coming from off-axis directions (nulls)
- Alter binaural cues , particularly in monaural beamformers

What it replaces?

Static, Fixed and Adaptive Filters a/k/a "single-channel NR"

- Use statistical rules to estimate target signal (speech) and background noise
- Models make compromises – attenuate LF's even though important speech cues are present there
- Examples: Weiner filter, spectral subtraction, MMSE estimators



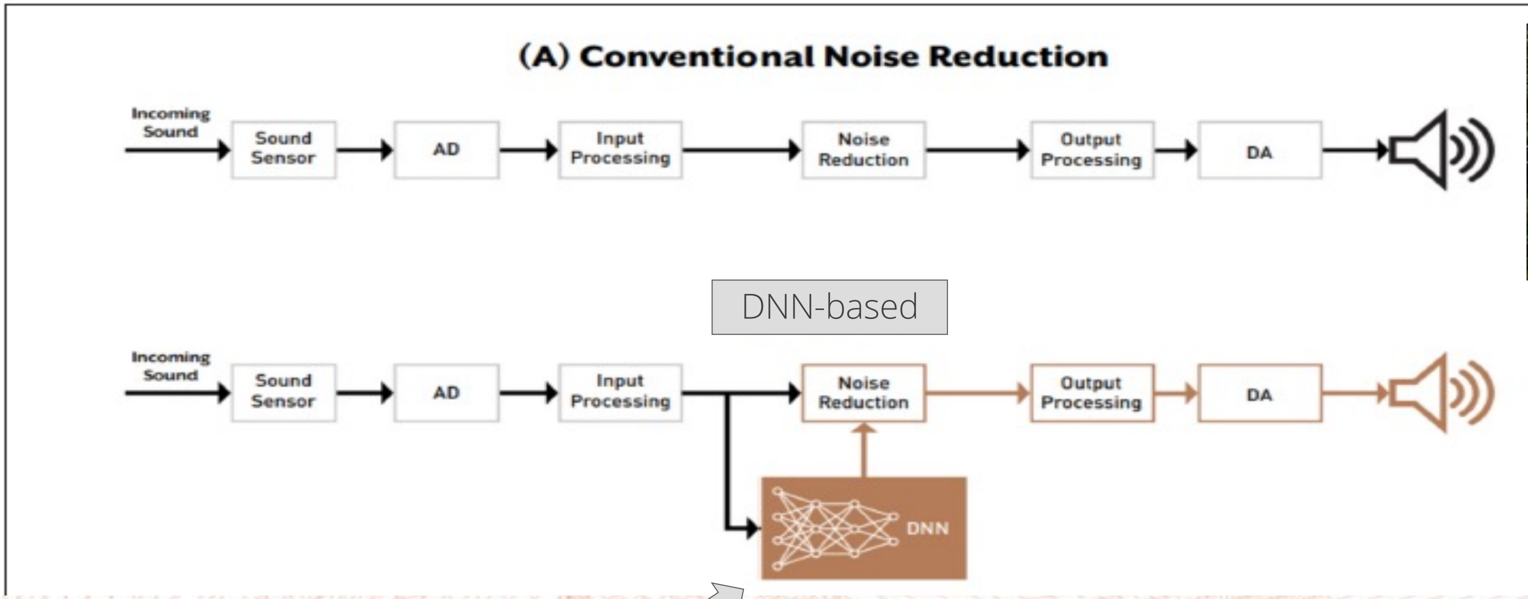
Limitations of Single Channel Noise Reduction (filters)

- Limited effectiveness in low SNRs (-3 dB SNR or lower)
- Their effectiveness depends on the input signal….if the estimated noise target is different than the actual noise, they are not effective
- Although traditional methods tend to improve listening comfort or effort, they do not improve speech intelligibility in noise

3. DNN-based Noise Reduction

What human task or existing hearing aid feature does it replace or augment?	Remove as much unwanted noise as possible without removing target sounds, usually speech.
How it works? / What it does?	It involves a lot of math, super fast calculations & pattern recognition…deep neural networks
Is it effective?	
What are the limitations?	

DNN-based Noise Reduction



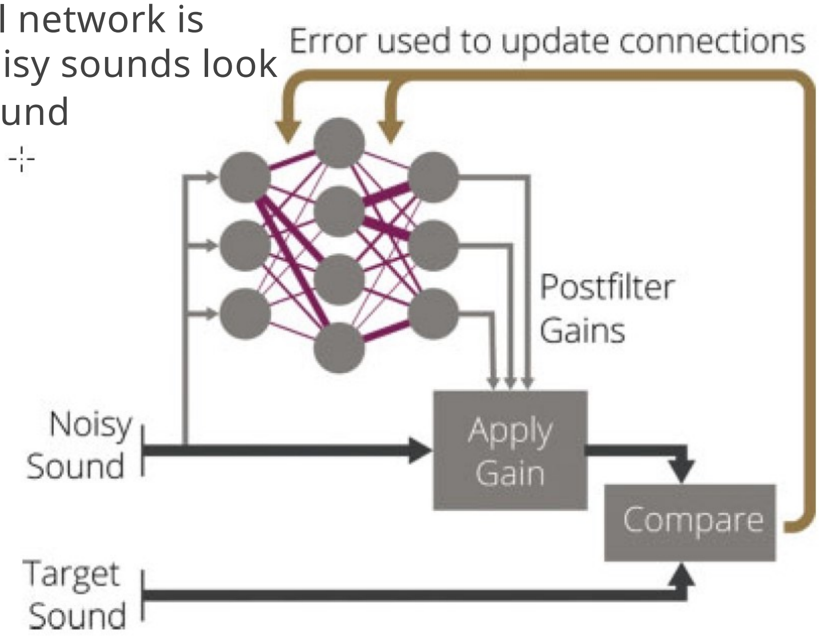
DNN is trained to recognize speech and increase it

Denoising: How it works?

Goal: make the noisy signal similar to the clean target signal

4. As more acoustic scenes are fed into the system, the more accurate the DNN can adjust the input to look more like the ideal

3. Through a series of mathematical calculations, the neural network is trained to make the noisy sounds look more like the target sound



2. Noisy inputs are compared to target sound (typical listening Situations)

“the ideal”

1. Target sounds are “clean” speech signals, as determined by DSP engineers

signia
Audiology

DNN-based Noise Reduction

What human task or existing hearing aid feature does it replace or augment?	Remove as much unwanted noise as possible without removing target sounds, usually speech.
How it works? / What it does?	It involves a lot of math and super fast calculations…deep neural networks
Is it effective?	Let's go to the research….. One caveat: reviewing research from first generation products
What are the limitations?	

Brand A

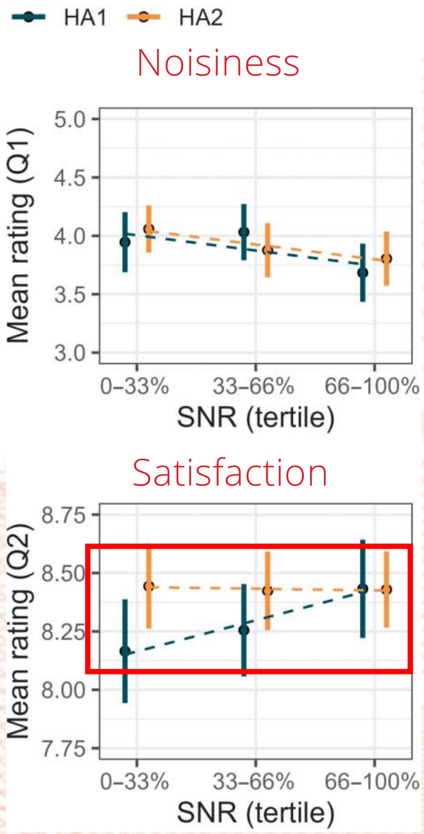
What they did?

- Compared “fixed” filter NR to “DNN-based” NR
- 40 adults, average age = 64.8 years
- 2-week trial with each device. Blinded
- EMA ratings of noisiness and satisfaction for 8 listening situations
- Conducted at U of Manchester, UK (Christensen, et al, 2024)

Brand A

What they found?

- Noisiness ratings: No difference
- For more adverse SNRs:
- Decrease in satisfaction for traditional NR



Noisiness

Satisfaction

Brand B

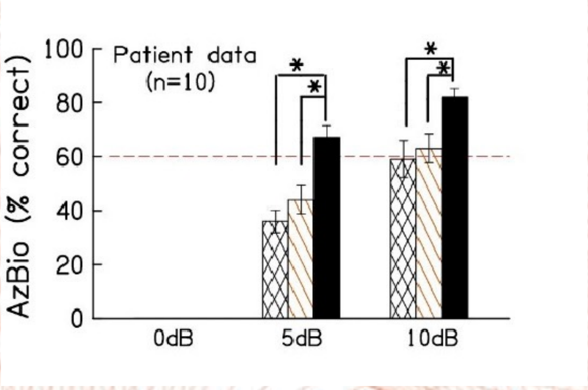
What they did?

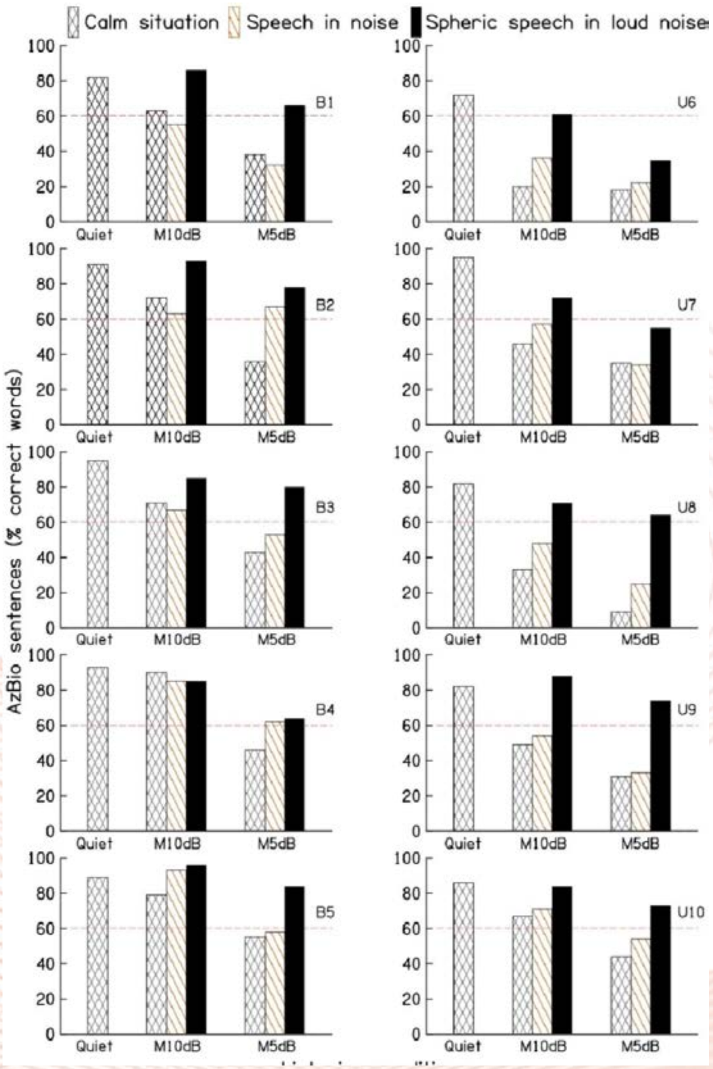
- Compared “denoising” algorithm to 2 other settings that used traditional NR
- 10 patients (5 bilateral loss, 5 unilateral)
- Moderate to profound HL, undergoing a CI Evaluation
- AZ Bio, speech fixed at 60 dB SPL
- Speech and noise presented from 0 degrees
- Conducted at Mayo Clinic, Rochester MN (Saoji et al, 2024)

Brand B

What they found?

- DNN-based NR outperformed the other 2 settings with traditional NR by 5 dB
- DNN-based NR could be a good alternative to CIs





Brand C

What they did?

- Compared traditional NR to DNN-based NR (A/B comparison)
- 20 adults, average age = 77 years
- In the booth, conducted several speech in noise tests (speech =75 dB SPL)
- CNC test (multi-talker babble, +5 dB SNR)
- Quick SIN (multi-talker babble, adaptive SNR)
- WIN test (multi-talker babble, adaptive SNR)
- NST (speech-weighted noise, +5 dB SNR)
- All tests conducted with 3-speakers: 0, 135 and 225 degrees (speech presented at 0)
- Conducted at the Stanford Ear Institute (Fitzgerald et al, 2025)

Brand C – What they found?

Quick SIN (dB SNR loss)

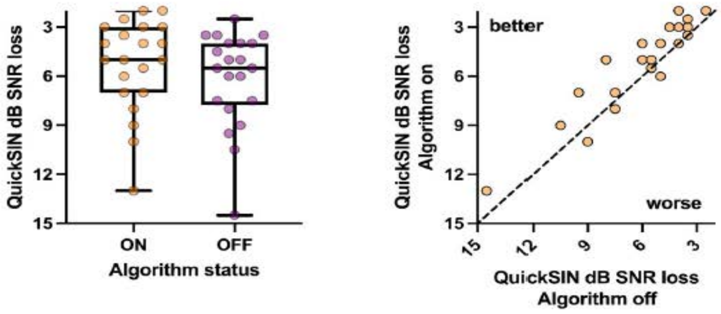
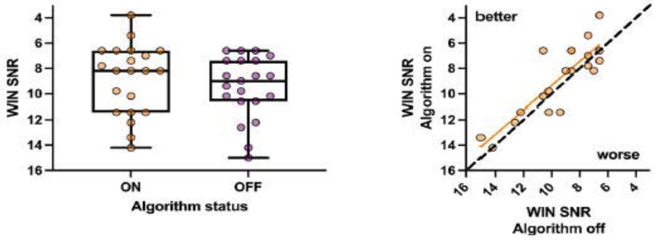
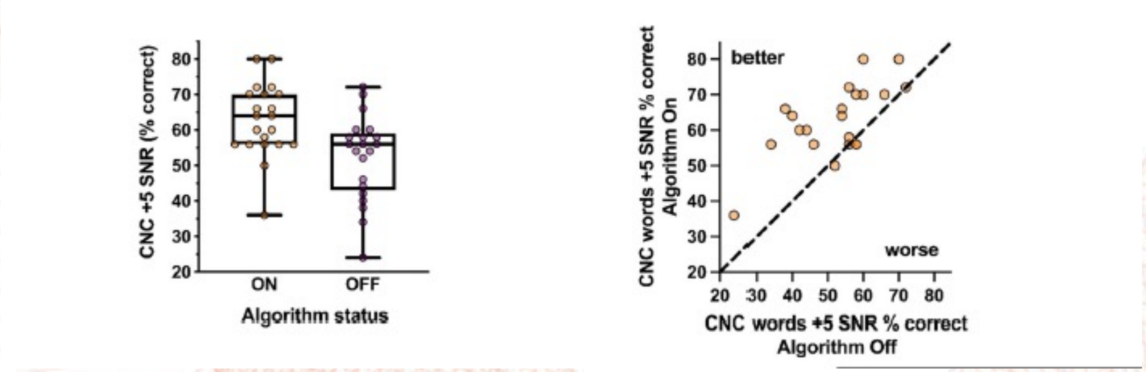


FIGURE 6

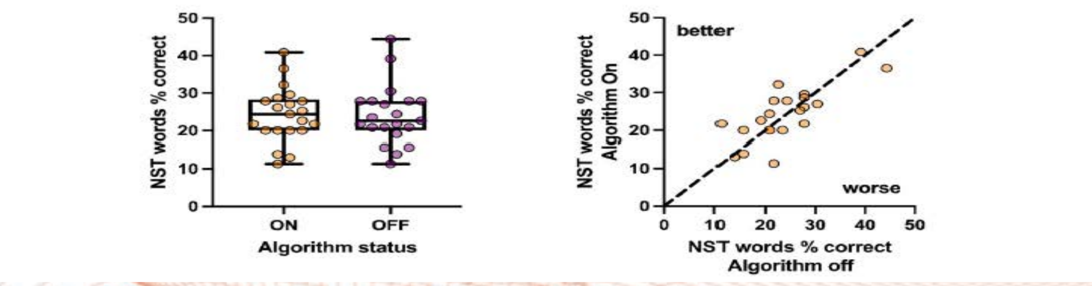
WIN (SNR)



CNC +5 (%correct)



NST +5 (% correct)

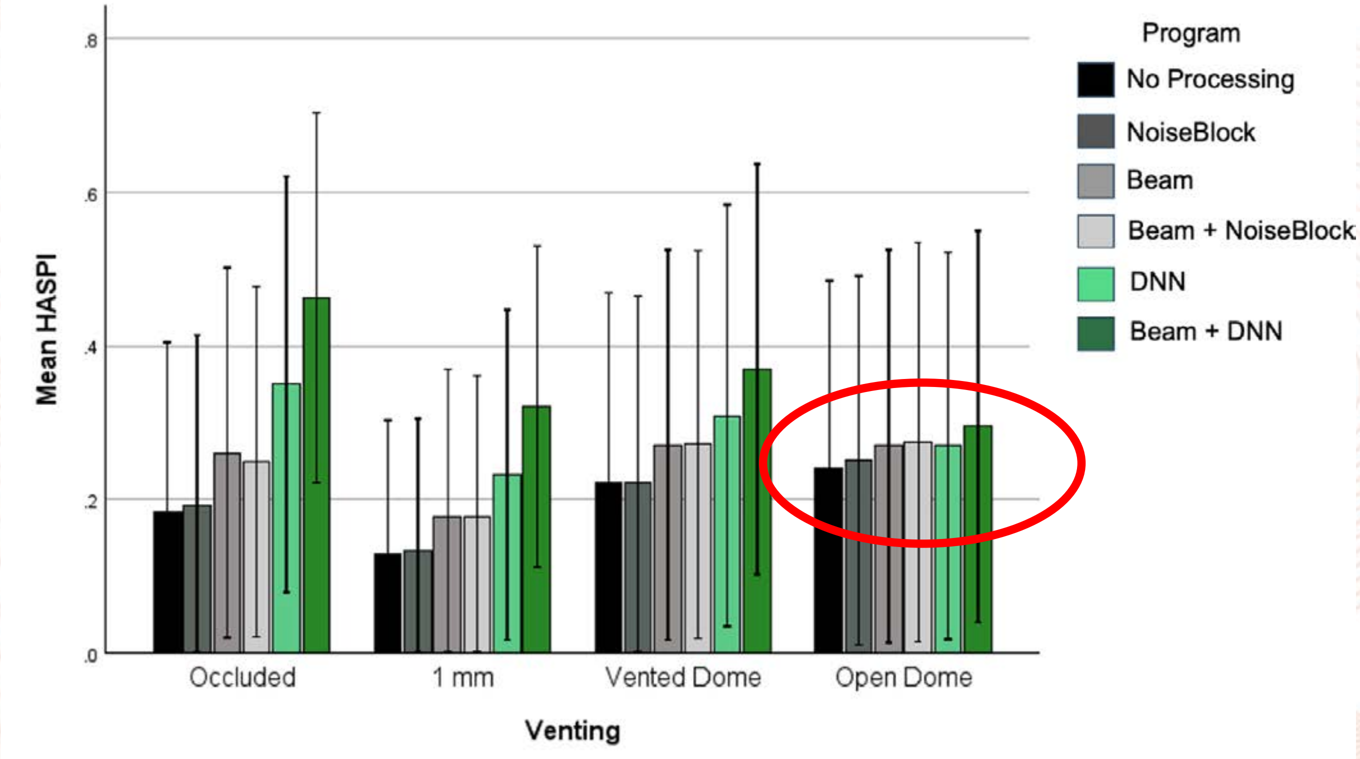


Brand C - Results

- DNN-based NR reduction yields small improvements compared to traditional NR
- No improvement for NST +5 dB likely because the DNN system was not trained on speech-shaped noise.

DNN-based Noise Reduction

What human task or existing hearing aid feature does it replace or augment?	Remove as much unwanted noise as possible without removing target sounds, usually speech.
How it works? / What it does?	It involves a lot of math and super fast calculations…deep neural networks
Is it effective?	Depends, Small, incremental SNR improvements in ideal listening conditions compared to traditional NR technologies. Ideal = situations that align with training
What are the limitations?	Black box quality – when is it activated? how has it been trained? Battery consumption Artifacts/distortion



Mean HASPI
.8
.6
.4
.2
.0
Occluded
1 mm
Vented Dome
Open Dome
Venting
Program
No Processing
NoiseBlock
Beam
Beam + NoiseBlock
DNN
Beam + DNN

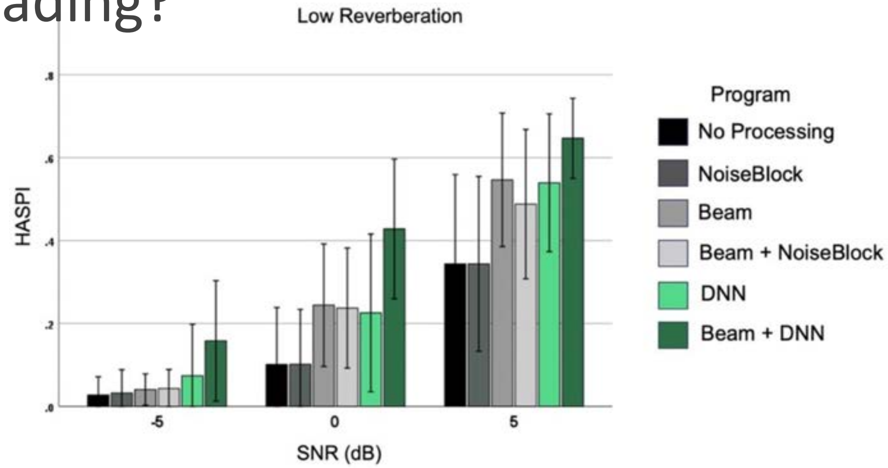
Denoisers: Prone to artifacts and distortion

- When the input does not closely match patterns that the network has “seen” during training—such as unusual voices, accents, music, or novel noise types—the denoiser must guess. Incorrectly suppressing or alter parts of the speech signal can produces distortions such (musical noise or a “warbling” quality)

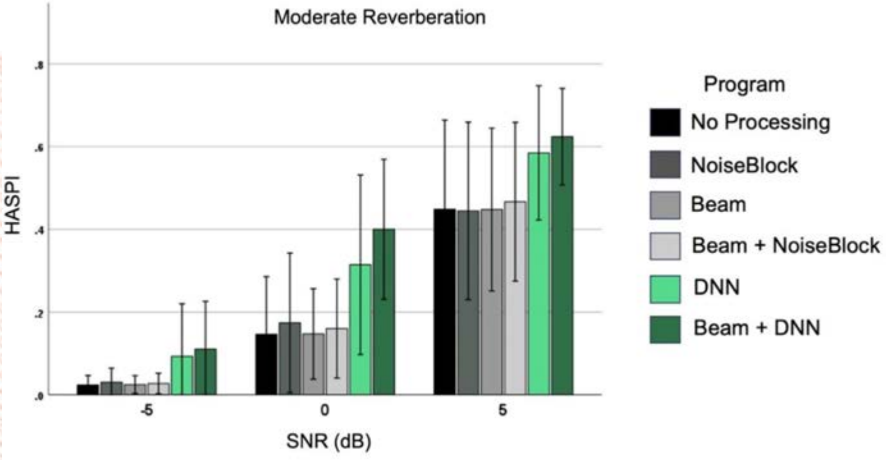
- When the DNN denoiser is optimized to strongly reduce noise, it may partially remove low-energy speech components leading to speech sounding thin or unnatural.

DNN-based NR: Where it might be heading?

- Ashkanichenarlogh, et al (2025) Western U.
- Hearing Aid Perception Index (HASPI) with KEMAR, calculated at -5, 0 and 5 dB SNR
- Objective measure that simulates how an impaired ear processes sound compared to a normal ear (proxy for subjective intelligibility)
- 6 signal processing schemes (1 brand)
  - No Processing (Omni-only)
  - Single-channel NR-only
  - Beam-only
  - Single-channel NR + Beam
  - DNN-NR-only
  - DNN-NR + Beam
- Open, vented, closed coupling
- 4 audiogram configurations
- 2 reverberant conditions, 2 noise types
- 2 talker locations (front and side)



(a)



(b)

DNN-NR: Where it might be heading

- In one benchtop study, DNN-NR outperforms traditional NR methods and there appears to be an additive effect when DNN-NR is combined with beamforming
- Lab studies of first generation denoisers show some incremental improvements, depending on the noise type and other variables

Resist the easy button!

- AI in hearing aids in 2026 represents incremental improvements over existing features
- AI and DNN-based NR are not replacements for a “best-practice fit”
- Sounds must be audible for these advanced features to work!
  - Less venting/more closed fit
  - Match a prescriptive target
  - Ensure adequate headroom (MPO just below LDLs)

How will AI change the way we fit hearing aids?

Audiology and Wine Pairing

THE GREAT COURSES

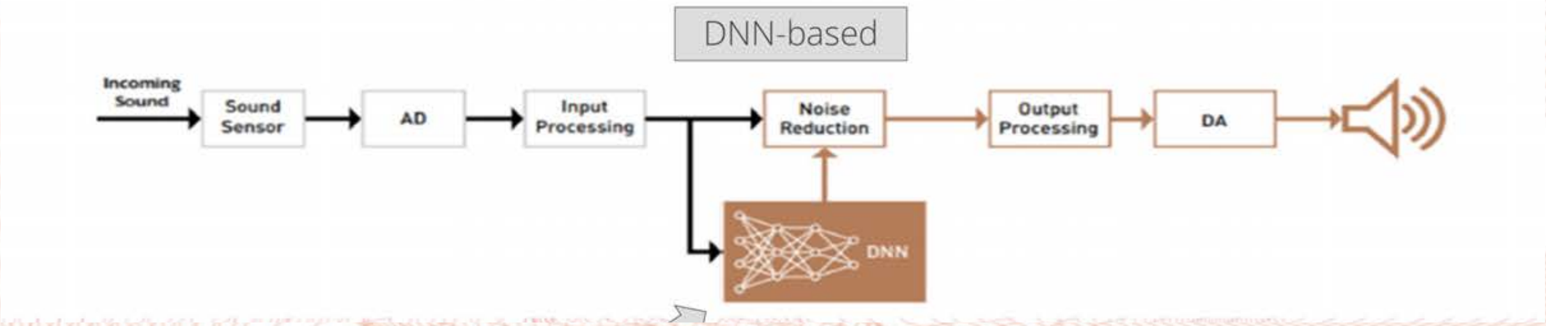
PERFECT PAIRINGS

A GUIDE TO FOOD & WINE PAIRINGS

– FOOD –	– WINE –	– WHY –
Filet Mignon	Cabernet Sauvignon	Textures are complemented - both are rich and full-bodied
Salmon	Sancerre (Sauvignon Blanc)	Contrast between oil and acid enhances experiences of both
French Fries	Champagne	Acid in the wine cuts through the oil from the potatoes
Fettuccini Alfredo	Oaked Chardonnay	Notes of butter and cream will match
Smoked Holiday Ham	America-Oaked Shiraz (Australia)	Notes of smokiness will match
Pork Chops	Pinot Noir	Red-berry flavors will complement meal
Curry Chicken	Off-Dry Riesling	Contrasting flavors of fruit and spice
Dark Chocolate	Ruby Port	Bitterness of chocolate offset by sweetness of Port
Salted Almonds	Gamay	Salt will enhance fruit flavors of wine

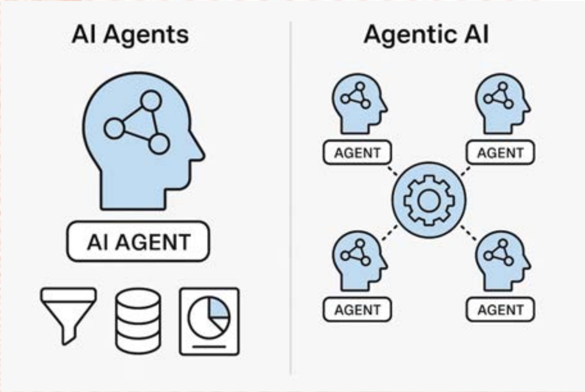
Precision Audiology

- Each manufacturer has a different “flavor” of DNN-based noise reduction:
  - At-risk for cognitive decline: Brand 1
  - Socializing is highest priority: Brand 2
  - Listening fatigue is the #1 problem: Brand 3



Agentic AI in Hearing Aids – The Future?

- **Proactive Environmental Adaptation** – AI predicts when the wearer is about to enter a noisy room and preemptively adjusts devices
- **Autonomous Focus Switching** – AI identifies the most important sound (person speaking) in a complex environment and actively steers the mics to that sound, instantaneously
- **Wearer-Intent Detection** – By analyzing context clues (head movements, ambient sounds, biometric signals of wearer) the AI guesses what the wearer wants to hear and adjusts settings accordingly



Humanistic Audiology

- Counseling, listening with empathy are the human intelligence and wisdom that cannot be replaced with AI

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Questions?