Western
National Centre
for Audiology

Clinical Implications of Noise Reduction Strategies for Supporting Hearing in Noise

Mohamed Rahme & Paula Folkeard.

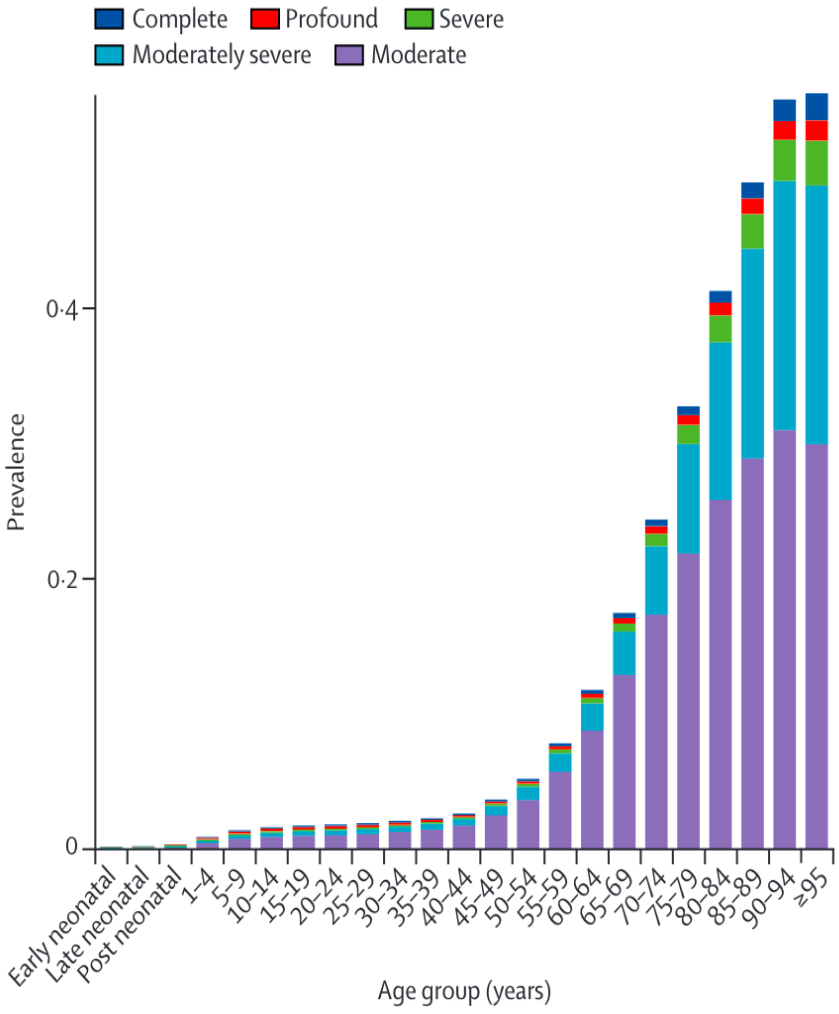
Hearing Loss is Highly Prevalent

- Nearly 2 billion people have hearing loss.

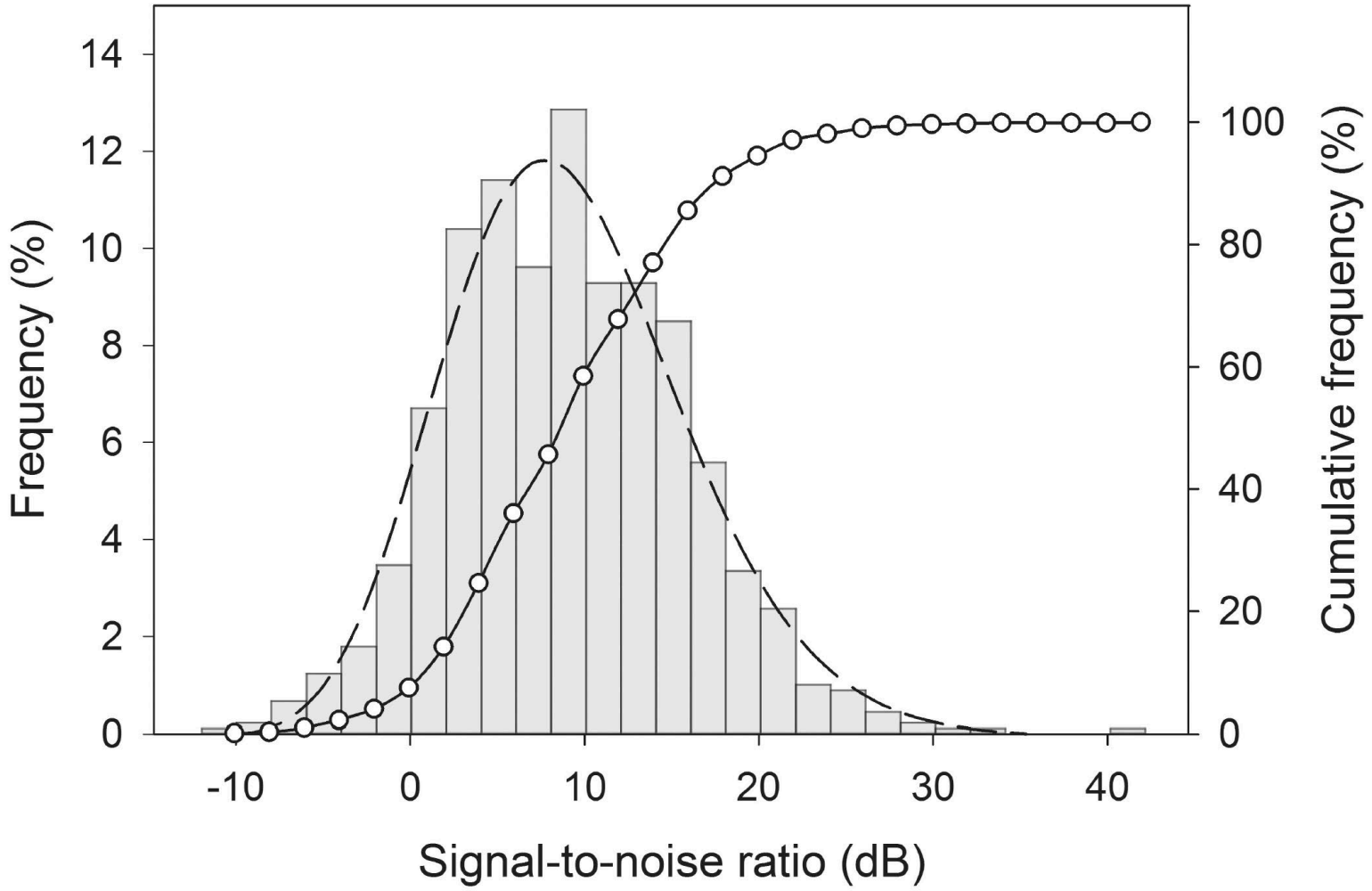
  (Haile et al., 2021)

- Age-related hearing loss (presbycusis), is the most common type of hearing loss, affecting nearly 65% of older adults both nationally (Feder et al., 2015) and internationally.

  (Haile et al., 2021)

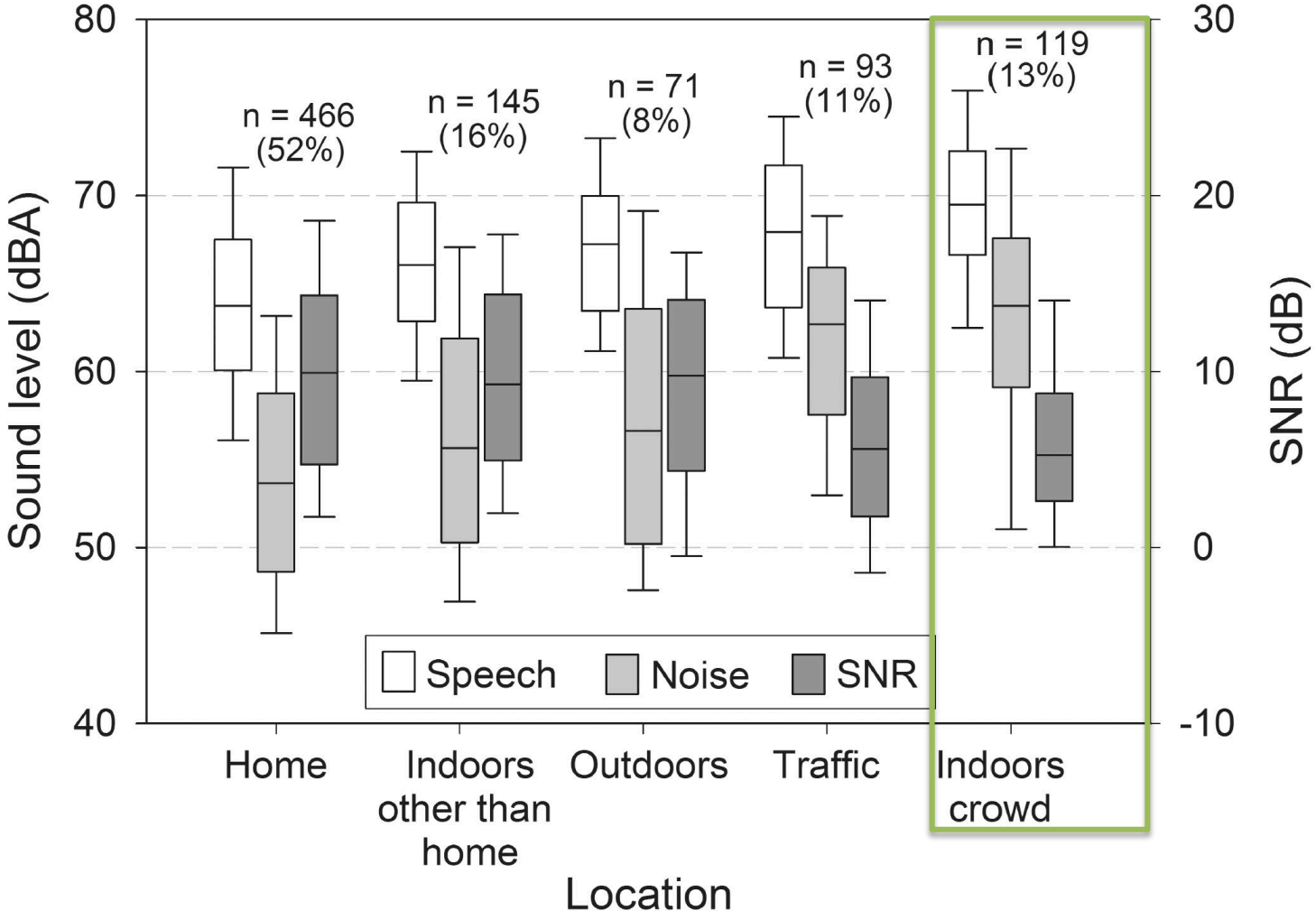


Signal to Noise Ratios Encountered by Hearing Aid Users



Wu et al., (2018)

Signal to Noise Ratios Per Environment



Wu et al., (2018)

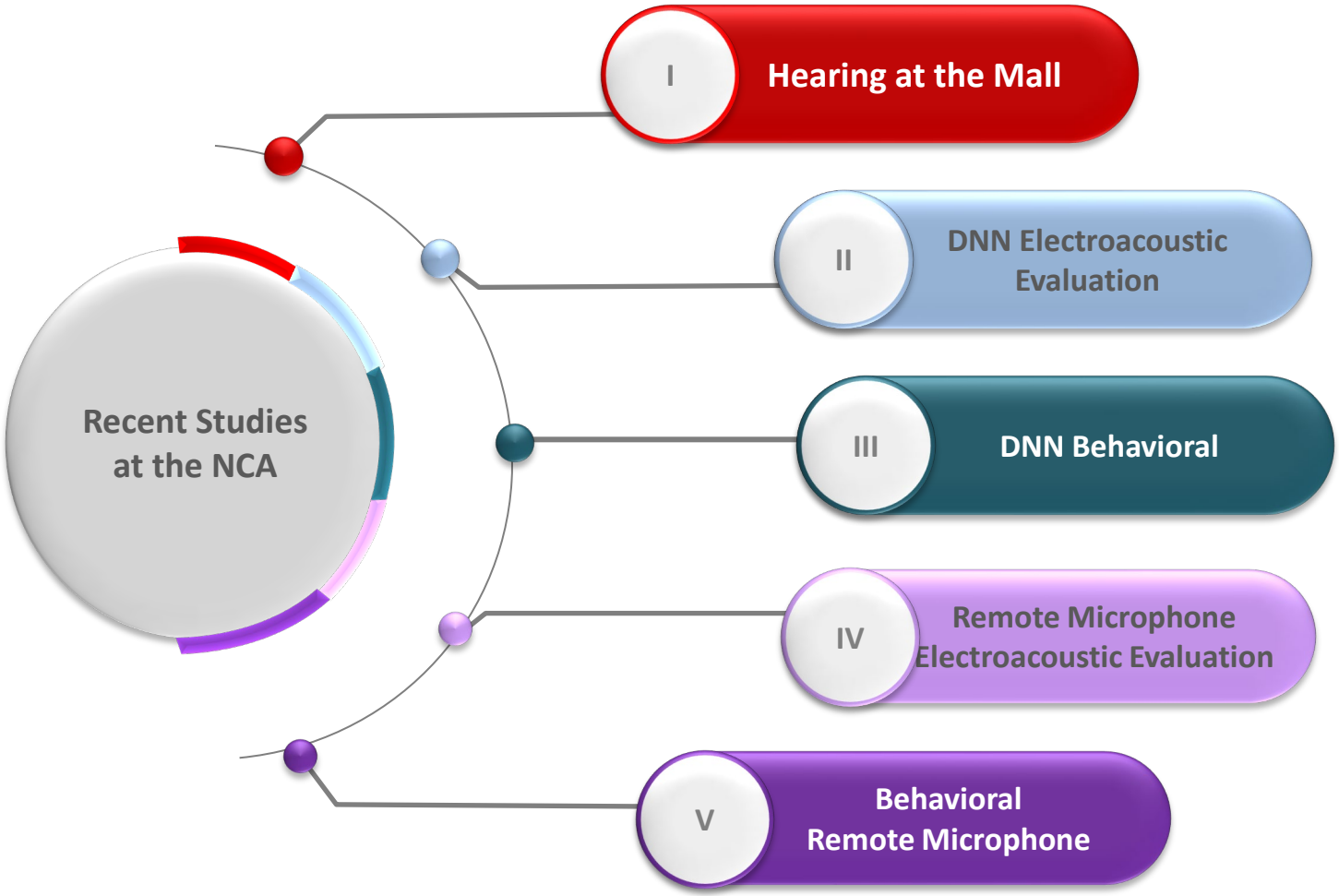
The Need for a Noise Management Plan

- Conversations in noisy places is important yet challenging
- Communication with 2 or more in noise



- Hearing primary talker in noise or echo
- Listening while participating in other tasks




Recent Studies at the NCA
I
Hearing at the Mall
II
DNN Electroacoustic Evaluation
III
DNN Behavioral
IV
Remote Microphone Electroacoustic Evaluation
V
Behavioral Remote Microphone


I
Hearing at the Mall
Recent Studies at the NCA

ASHA American Speech-Language-Hearing Association

AJA

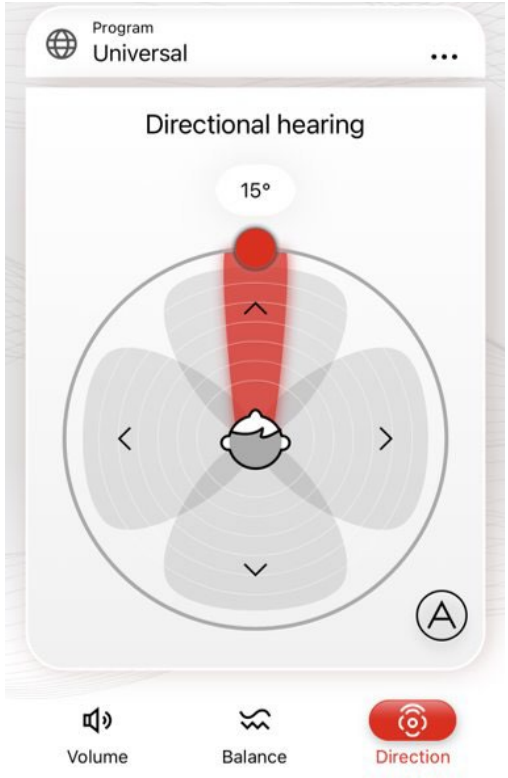
Research Article

Hearing at the Mall: Multibeam Processing Technology Improves Hearing Group Conversations in a Real-World Food Court Environment

Paula Folkeard,[a] Niels Søgaard Jensen,[b] Homayoun Kamkar Parsi,[c] Sascha Bilert,[c] and Susan Scollie[a,d]

[a] Faculty of Health Sciences, National Centre for Audiology, University of Western Ontario, London, Canada [b] WS Audiology, Lynge, Denmark [c] WS Audiology, Erlangen, Germany [d] Department of Communication Sciences and Disorders, Faculty of Health Sciences, University of Western Ontario, Canada

Directional Microphones
Primary Technology to Improve Signal to Noise Ratio



Real-Time Conversation Enhancement

Split Processing – Speech from the front to be processed differently than noise from the back.

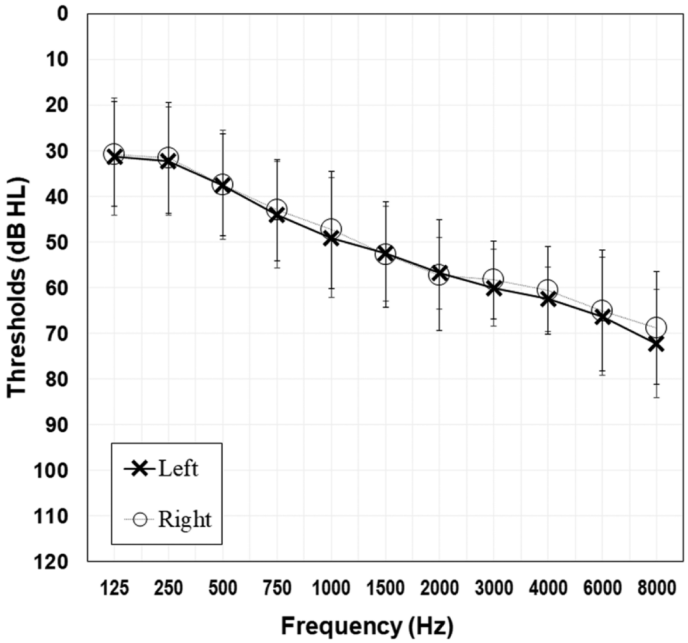
Front Analysis Determines:

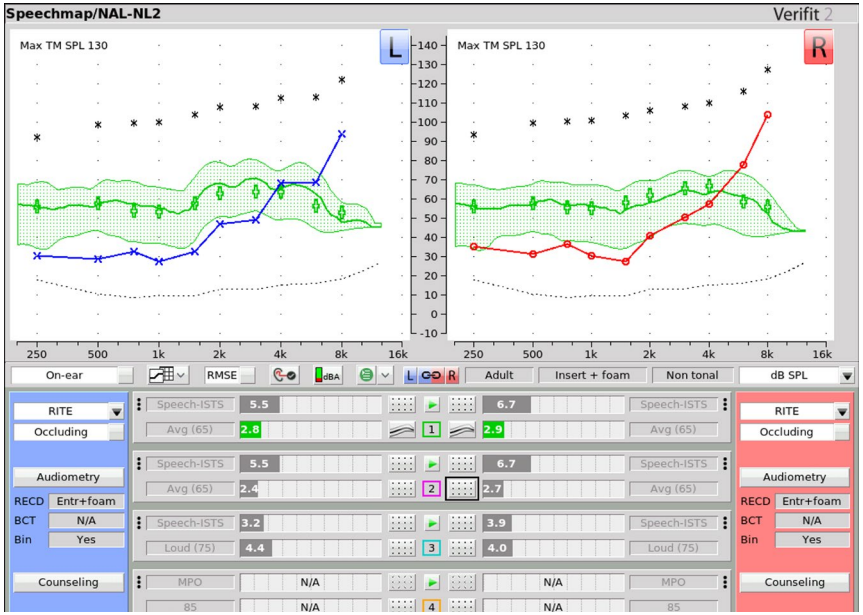
- Conversation layout.
- Locations of conversation partners
- Turn-taking dynamics in the conversation
- Locations and levels of non-speech sound sources.

- Uses a multi-beam architecture to track multiple speakers



Participants and Hearing Aid Fittings



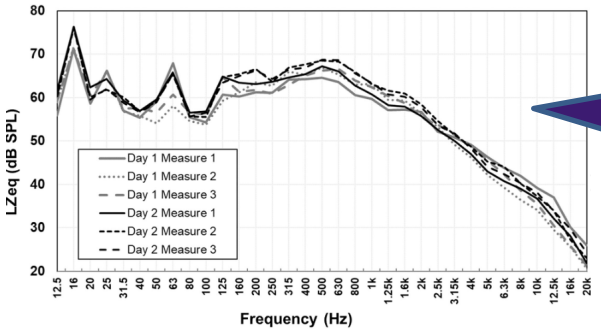


- 20 Older Adults
- Ages 61-84 (mean 73.6) years
- Eleven (11) Women / Nine (9) Men
- Average of 12.7 years HA experience (1-35 years)

- Hearing Aids were fit and verified using the Audioscan VF2 with an average RMSE of 3.8 (SD 1.19) from the target.

Test Environment: Cherryhill Village Mall





Bkgd noise levels 77-80 dB SPL

Location	$T30_{500\ Hz}$ [s]	$T30_{1\ kHz}$ [s]
Location 1	1.00	0.91
Location 2	1.01	0.80
Location 3	1.07	0.84

T30 Reverb Time of 1 second

Tasks: Hearing Aid Ratings

- While listening to the male and female talker have a conversation participants were asked to do 2 different tasks.
  1. Rate each program
  2. Comparing the two programs



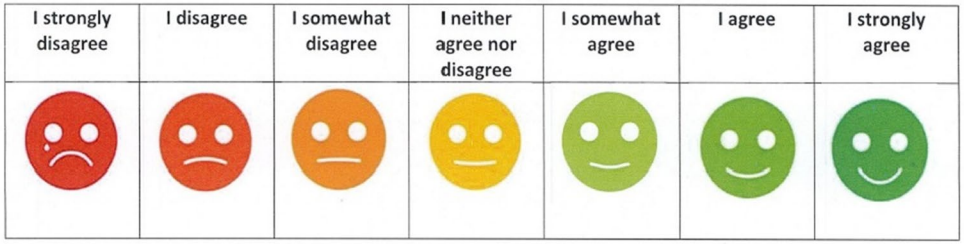
A series of scripts was created on familiar topics such as food, travel, pets, weather, and weekend activities.

The male and female talkers had an equal amount of dialogue in a turn-taking conversation that lasted 35–45 seconds

Task 1: Single Program Ratings

Participants rated the extent of their agreement with 10 positively worded statements specific to the conversation.

1. I can understand what is being said in the conversation.
2. I hear my conversation partners clearly.
3. The volume of my conversation partners is just right.
4. I don't have to work hard to follow the conversation.
5. I can focus on the conversation in front of me.
6. I find the sound of my conversation partners pleasant.



7. The voices I am listening to are coming from the correct direction.
8. The background noise I hear is at an appropriate level for communicating.
9. The overall loudness is just right.
10. I am satisfied with the overall sound.

Results Task 1
Single Program Ratings

Satisfied with the overall sound

Overall loudness is just right

** Background noise is appropriate

Voices coming from right direction

Sound is pleasant

** Can focus on conversation in front

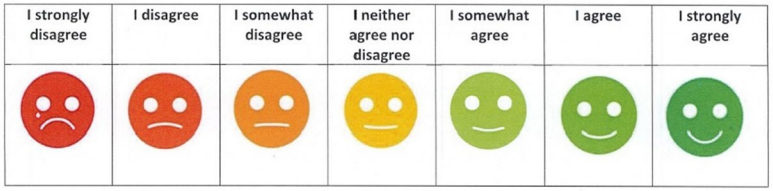
** Don't have to work hard to follow

Volume of conversation is just right

** Hear converstional partners clearly

** Understand what is being said

- **Both programs were positively rated**
- **The program with Multi-Beam Activated was rated significantly better in the categories marked ****
- **Specifically, in areas related to background noise reduction, conversational focus, clarity and understanding.**



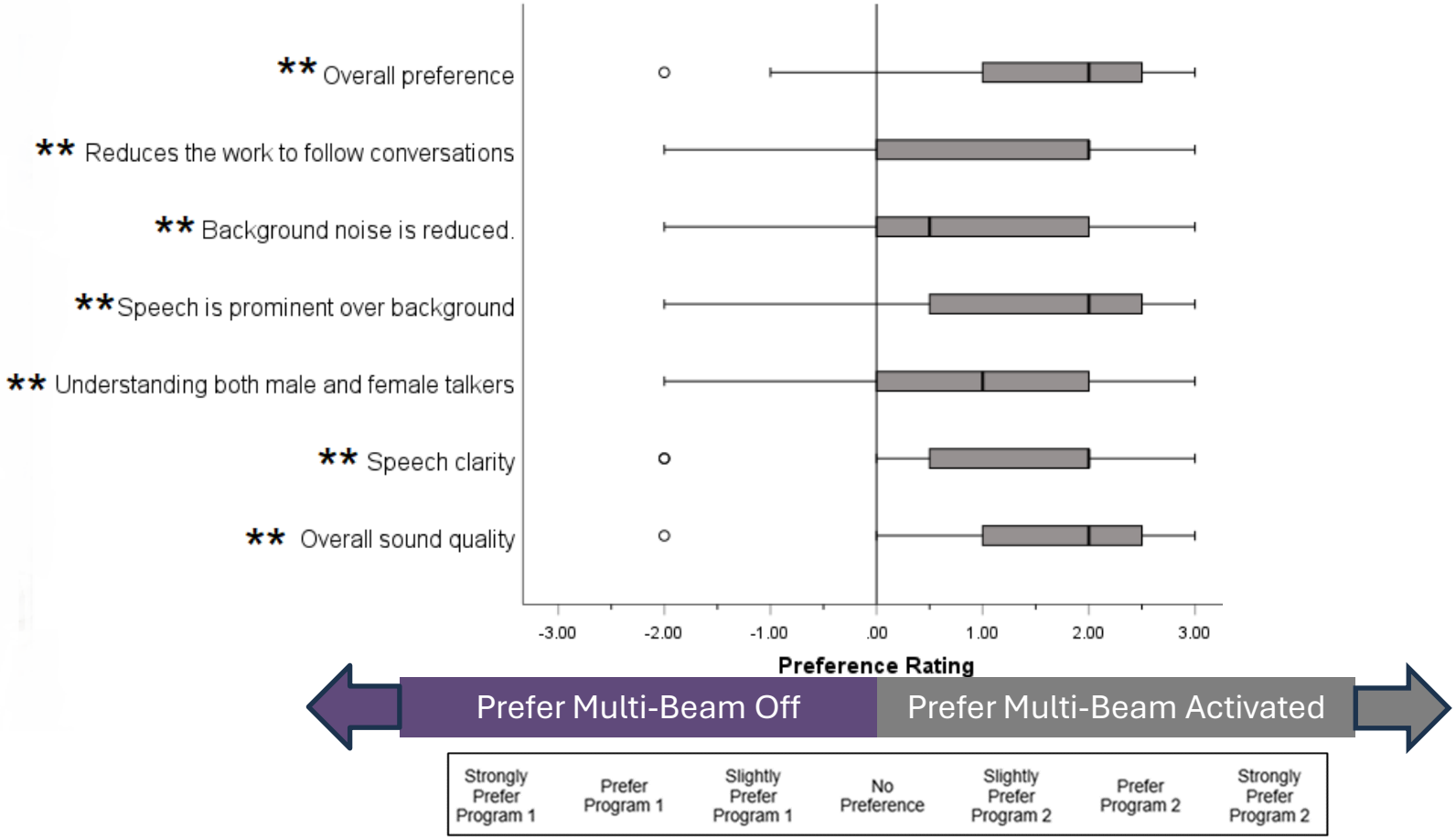
Task 2: Comparing the two programs back- to-back

Participants were asked to provide program-preference ratings for 7 aspects of a conversation during which the programs were switched back and forth by the researcher.

1. Which program do you prefer for overall sound quality?
2. Which program do you prefer for speech clarity?
3. Which program do you prefer for understanding both the male and the female conversation partners?
4. Which program do you prefer for making the conversation partners more prominent against the bkgd noise?
5. Which program do you prefer for reducing bkgd noise?
6. Which program do you prefer for reducing the work it takes to follow the conversation?
7. Which program do you prefer overall?

Strongly Prefer Program 1	Prefer Program 1	Slightly Prefer Program 1	No Preference	Slightly Prefer Program 2	Prefer Program 2	Strongly Prefer Program 2

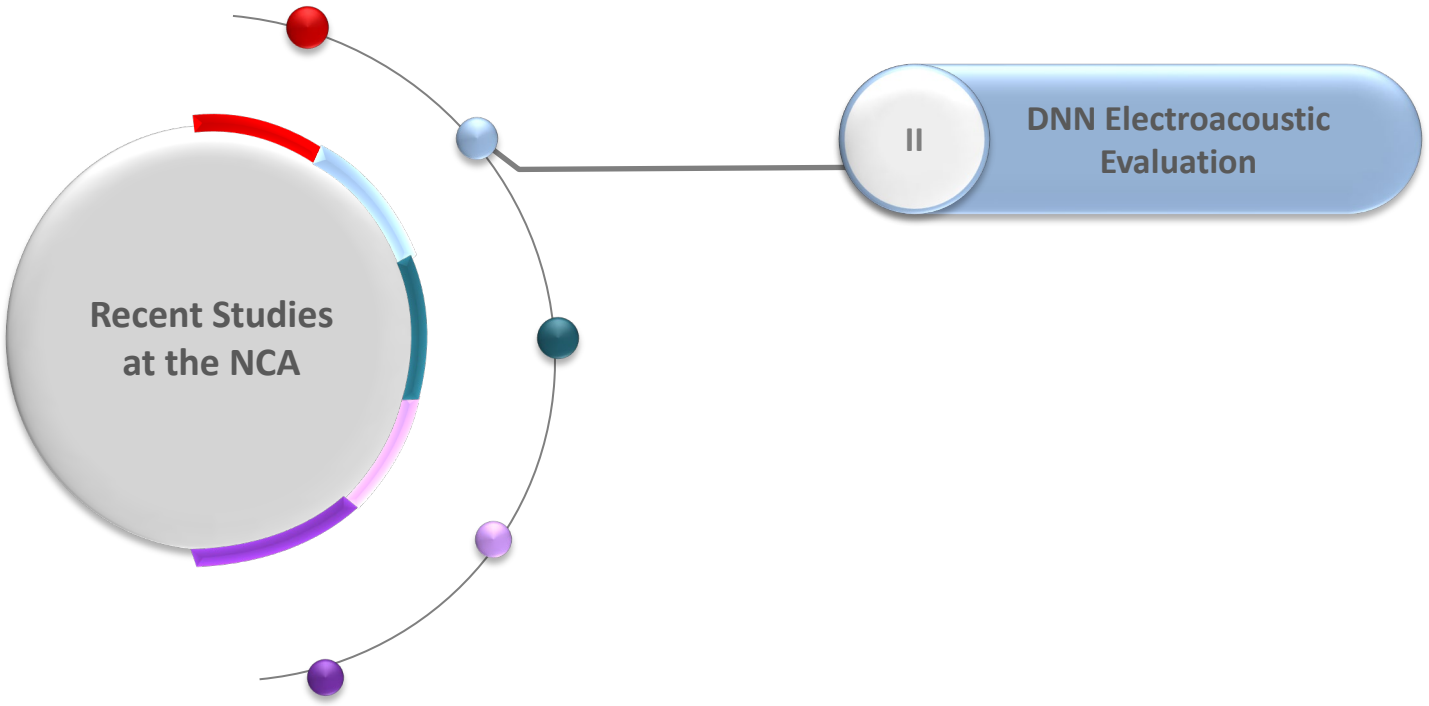
Results Task 2
Significant Preference for Multi-Beam



Take Away



The results of this study showed that Signia's multi-beam system improved subjective benefit as measured in a real-world setting that is noisy and reverberant with older hearing aid wearers for listening to small group conversations compared to their conventional directionality.


Recent Studies
at the NCA
II
DNN Electroacoustic
Evaluation

Electroacoustic Assessment of Phonak's Infinio Sphere DNN

Research Article

Objective Evaluation of a Deep Learning-Based Noise Reduction Algorithm for Hearing Aids Under Diverse Fitting and Listening Conditions

Trends in Hearing
Volume 29: 1–26
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Sage

Vahid Ashkanichenarlogh[1,2], Paula Folkeard[1,3], Susan Scollie[1,3], Volker Kühnel[4] and Vijay Parsa[1,2,3]

Electroacoustic Assessment of Phonak's Infinio Sphere DNN





Kemar was fitted with the Study Hearing Aids

- Settings tested varied in signal processing and beamforming
- 5 different audiograms types
- Clinically typical venting
- Closed venting

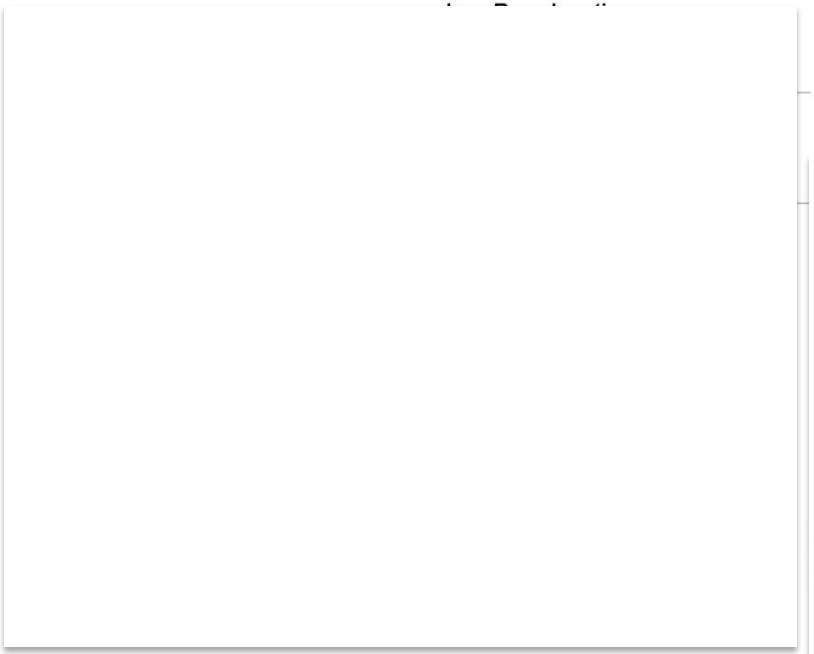
Stimuli and Environment

- CST with Babble
- CST with noise
- 2 Azimuths
- 3 SNRs
- 2 Levels of Reverberation

Electroacoustic Assessment of Phonak's Infinio Sphere DNN

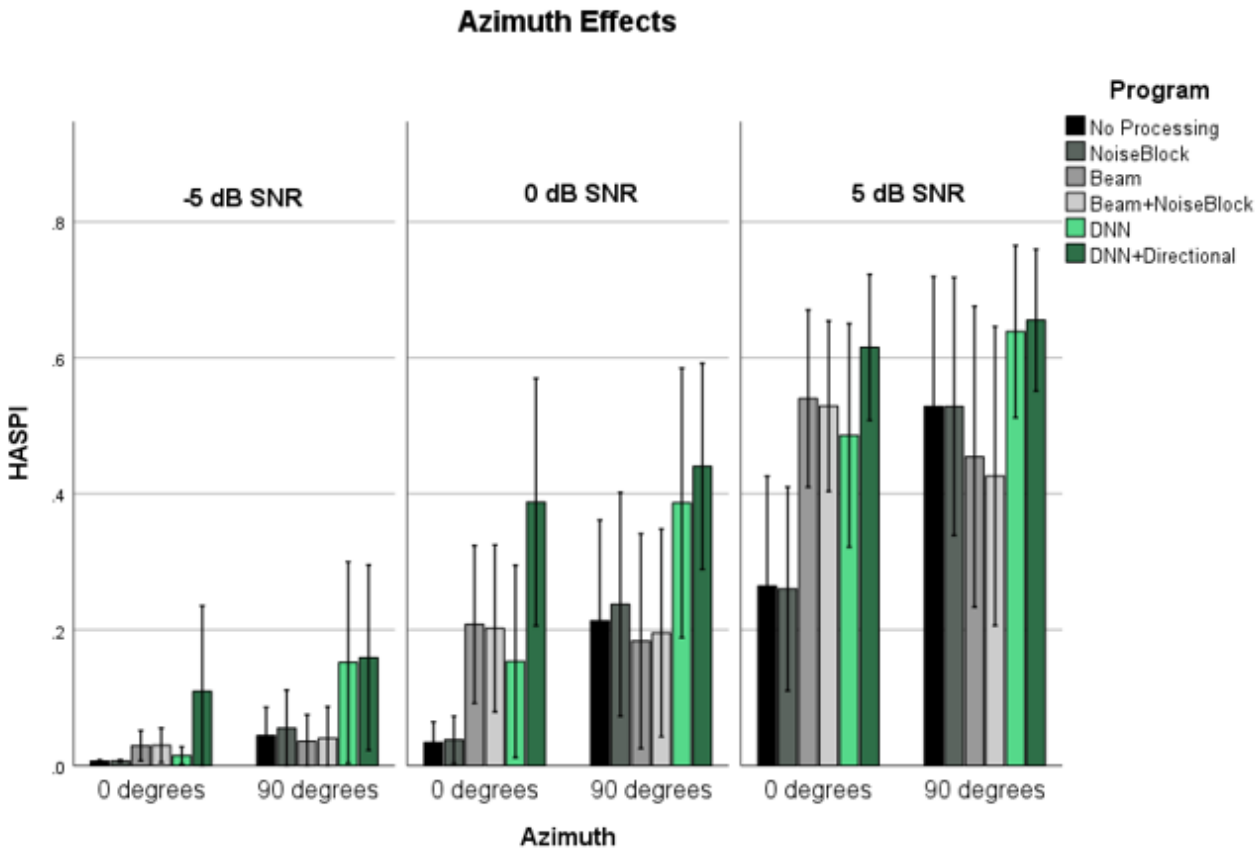
Program Name	Noise Reduction	Directionality
❑ No Processing	Off	Omni
❑ NoiseBlock	Non-DNN noise reduction	Omni
❑ Beam	Off	Adaptive binaural beamforming (Stereo Zoom)
❑ Beam + NoiseBlock	Non-DNN noise reduction	Adaptive binaural beamforming (Stereo Zoom)
❑ DNN	DNN denoising	Omni
❑ Beam + DNN	DNN denoising	Monaural beamforming

Key Findings:
DNN is effective in both low and moderate reverberation
Even at poorer SNRs



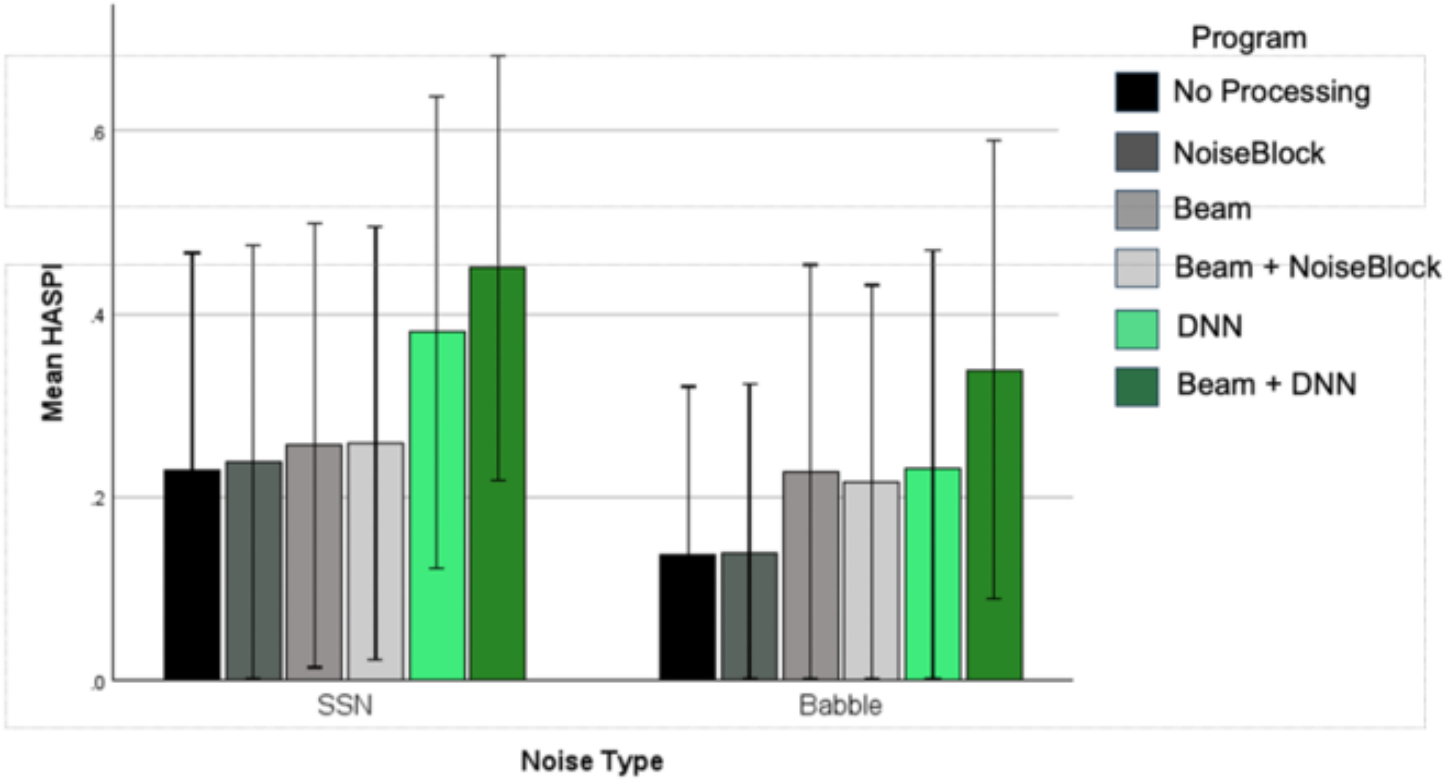


Key Findings:
Benefits with speech from the front or the side even at poorer SNRs



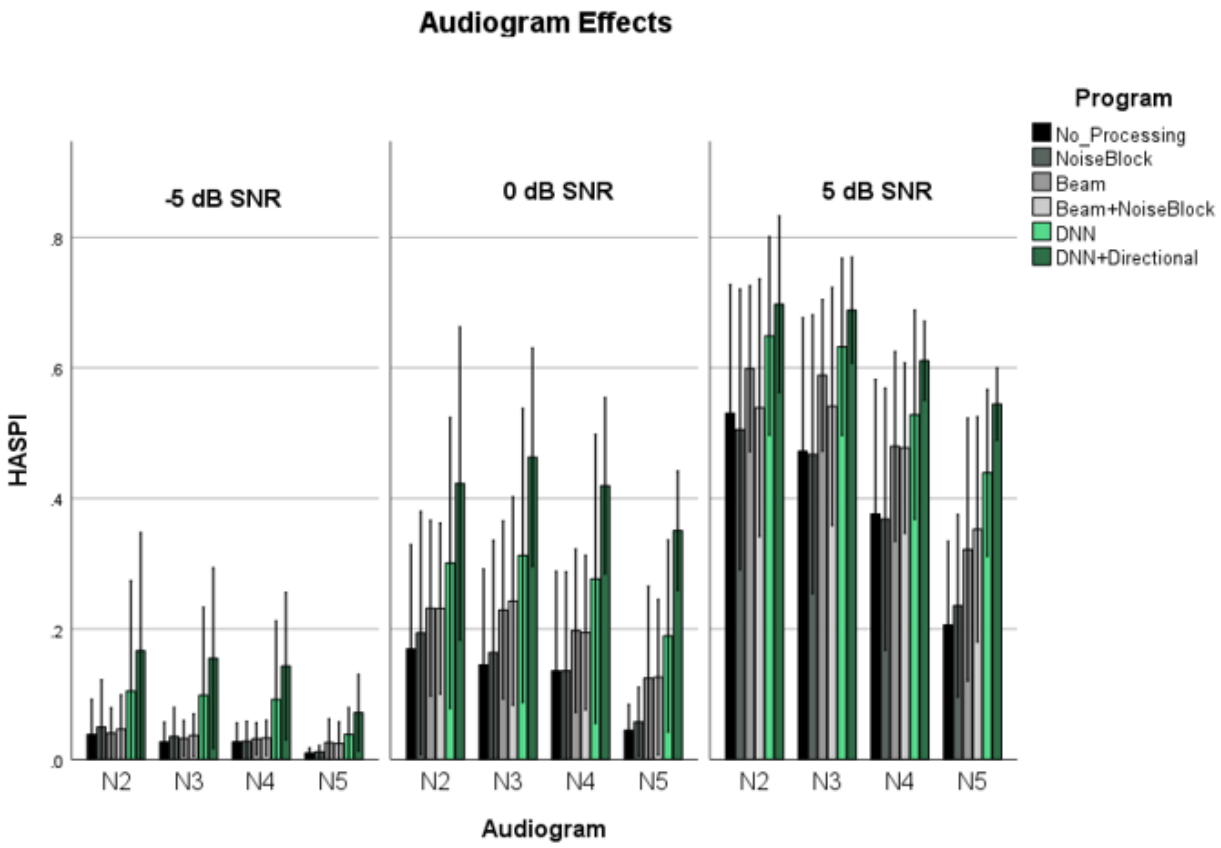
Ashkanichenarlogh et al., (2025)

Key Findings:
Noise management is most effective with SSN vs MTB but still provided significant benefit in babble when combined with directionality



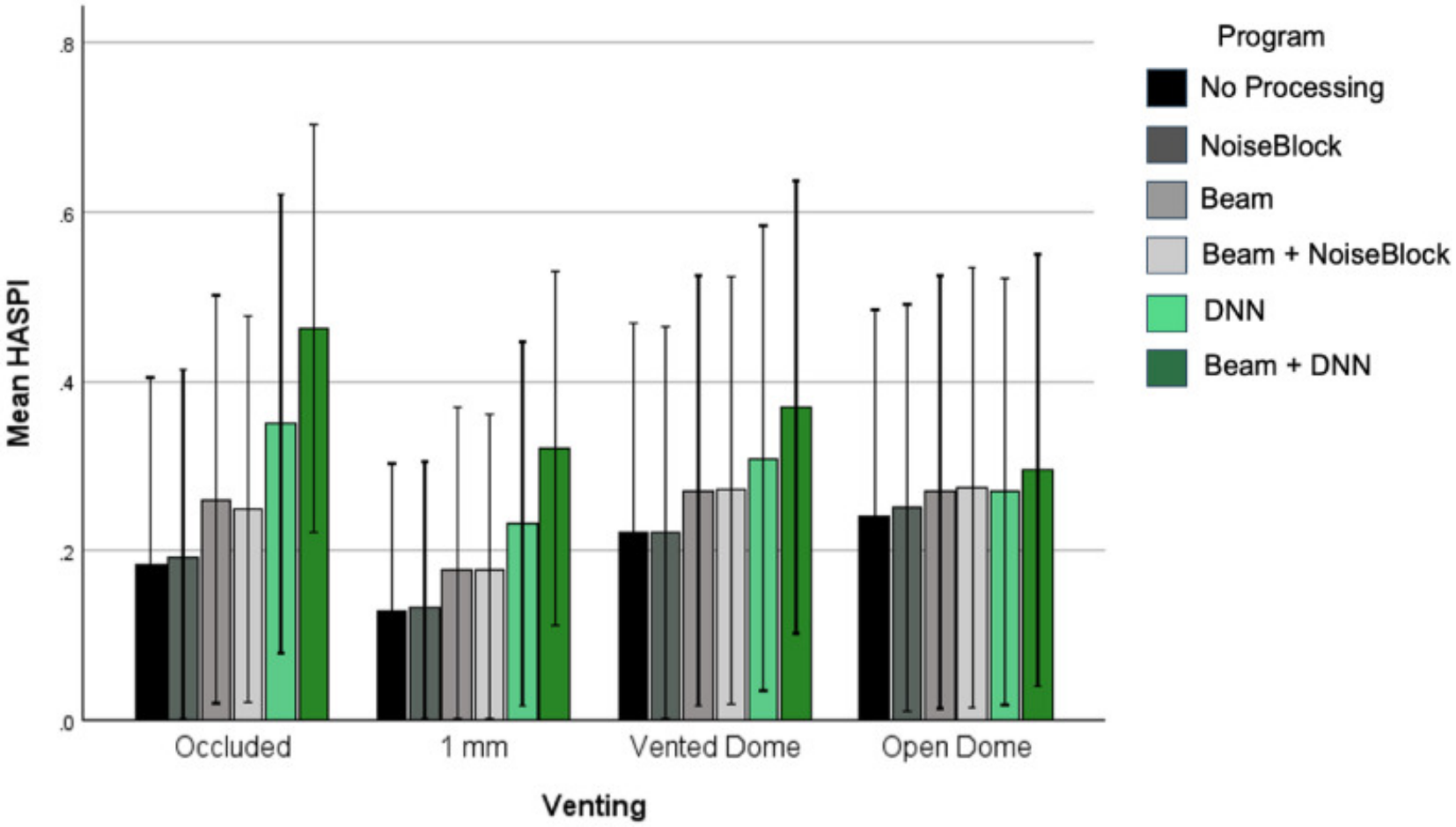
Ashkanichenarlogh et al., (2025)

Key Findings:
Benefits across the different audiogram - even at poorer SNRs



Ashkanichenarlogh et al., (2025)

Key Finding:
DNN is most effective with less open fittings



Ashkanichenarlogh et al., (2025)

Key Conclusions

- **DNN combined with beamforming yielded the highest predicted speech intelligibility across conditions.**
- **DNN + beamforming had consistently high performance, even when the fittings were vented, when in reverberation, and even with more severe losses.**
- **Beamforming remains an important technology.**

What about in hearing aid users?

Would we see similar benefits?



Behavioural Assessment of Phonak's Infinio Sphere DNN

Trends in Hearing
Volume 30, 2026
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https://doi.org/10.1177/23312165261449983

Sage Journals

Research Article

The Effect of Deep Neural Network Implementation on Speech Recognition, Listening Effort, and Sound Quality in Older Adults With Mild to Moderately Severe Hearing Loss

Paula Folkeard [1,2], Vahid Ashkanichenarlogh [1,3], Mohamed Rahme [1,2], Vijay Parsa [1,2,3], Volker Kühnel [4], Bilal Sheikh [5], Jinyu Qian [5], Yu-Ying Sung [1,2], and Susan Scollie [1,2]

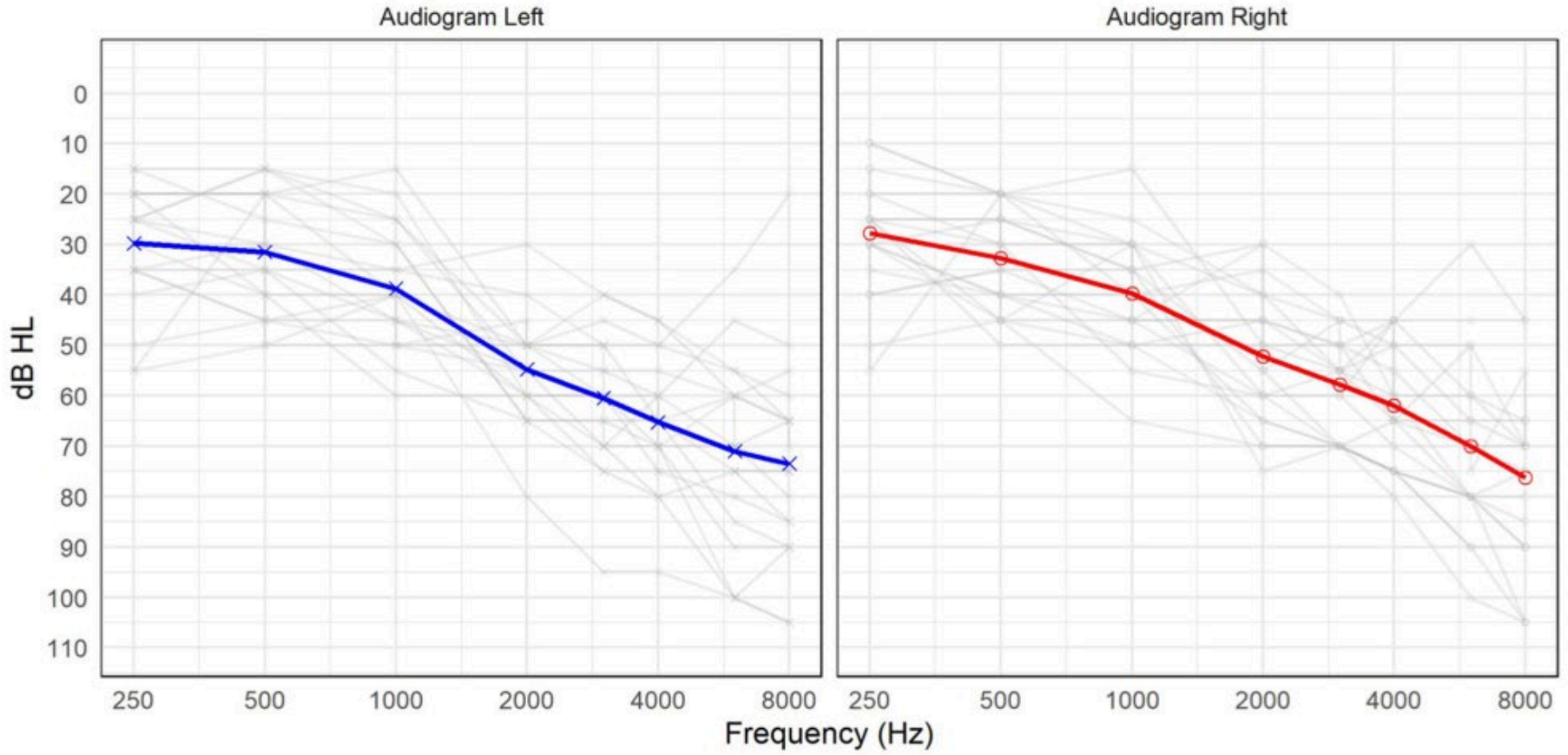
Abstract

Deep neural network (DNN)-based noise reduction has emerged as a promising advancement in hearing aid signal processing as a means to improve speech intelligibility in noisy environments for hearing aid wearers. The aim of this study was to investigate the impact of the DNN on speech intelligibility in speech-shaped noise (SSN) and multitalker babble (MTB) when the target speech was coming from the front and from the side. Subjective ratings of clarity, total impression, listening effort, and background noise awareness were also collected. Twenty adult participants with mild to moderately severe sensorineural hearing loss were fitted with hearing aids from a single manufacturer, programmed with four different settings that varied across combinations of microphone directionality (omnidirectional and directional beamforming) and noise reduction (off, traditional, DNN). Results showed that DNN, when combined with beamforming, consistently outperformed the other programs across all metrics. Outcomes were influenced by both noise type and spatial configuration. DNN was more effective in SSN than MTB. Beamforming was especially beneficial when the target speech came from the front. Listening in programs that included both DNN and beamforming together resulted in additional benefits shown in the outcome measures, most likely due to the beamforming improving the signal-to-noise ratio and providing a cleaner signal for the DNN to work with.

Keywords

deep neural networks, machine learning, denoising, speech-in-noise, listening effort, sound quality

Behavioural Assessment of Phonak's Infinio Sphere DNN



Folkeard et al., (2026)

Hearing aid settings for manual programs

Test Program Type	Microphone	Noise Reduction Strategy
No Processing	Omni	Off
Beam + Noise Block	Binaural beamforming	Traditional
DNN-only	Omni	DNN
Beam + DNN	Fixed monaural beamforming	DNN

Folkeard et al., (2026)

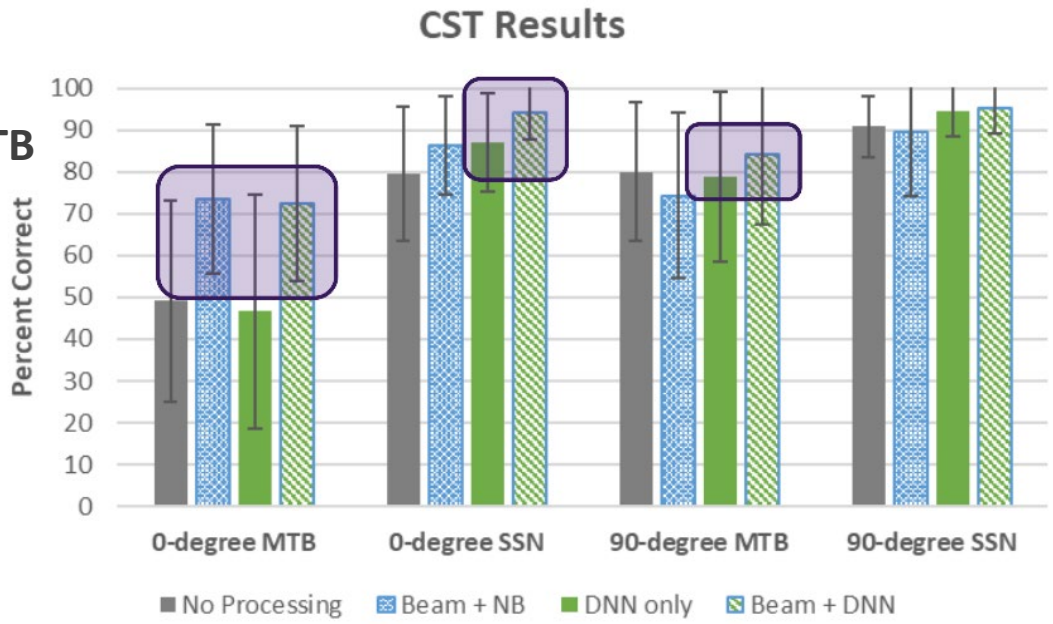
Test Conditions
Objective Measures of Speech Perception

Speech-in-Noise Test	Speech Direction	Noise Type	CST Presentation Level	Signal-to-Noise Ratio (SNR)
Connected Speech Test	Front	Multi Talker Babble (MTB)	70 dB SPL	0 dB
	Side of Better Ear	Speech Shaped Noise (SSN)		

Folkeard et al., (2026)

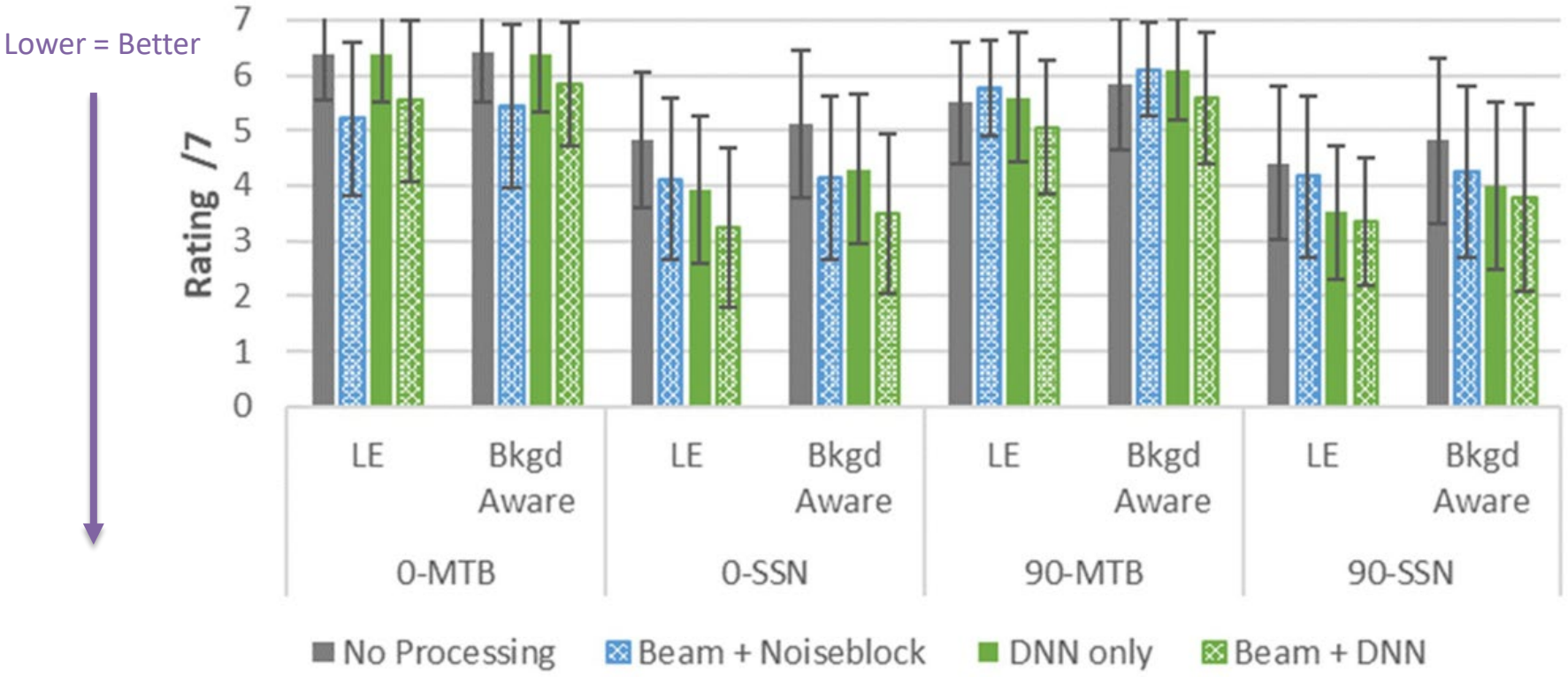
Speech Perception Results

- On average, DNN+Beam significantly outperformed all other conditions.
- SSN with speech from the front and MTB with speech from the side: DNN+Beam outperformed all other programs.
- MTB with speech in front: any program with directionality outperformed omni conditions.



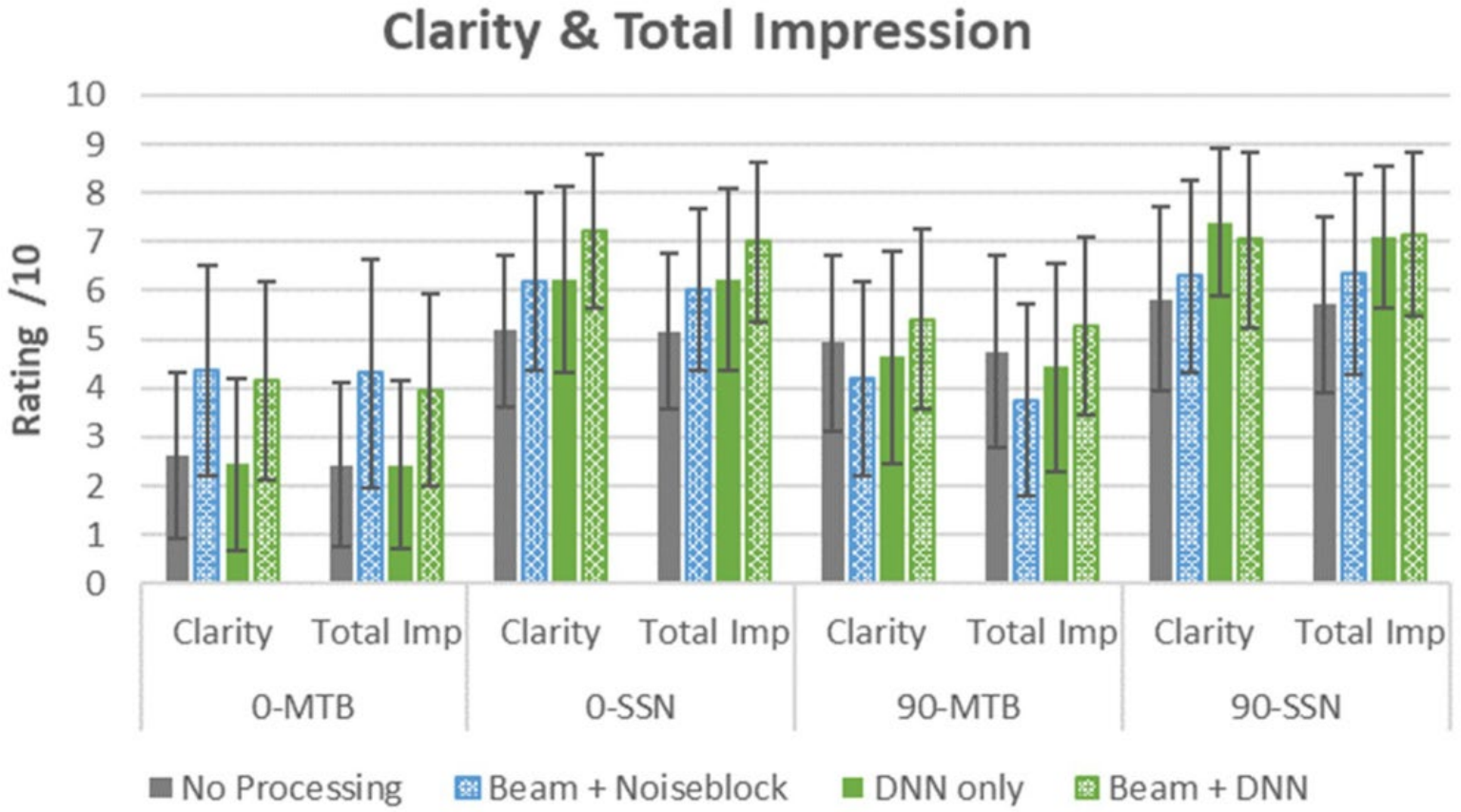
Folkeard et al., (2026)

Listening Effort & Background Noise Awareness Results



Folkeard et al., (2026)

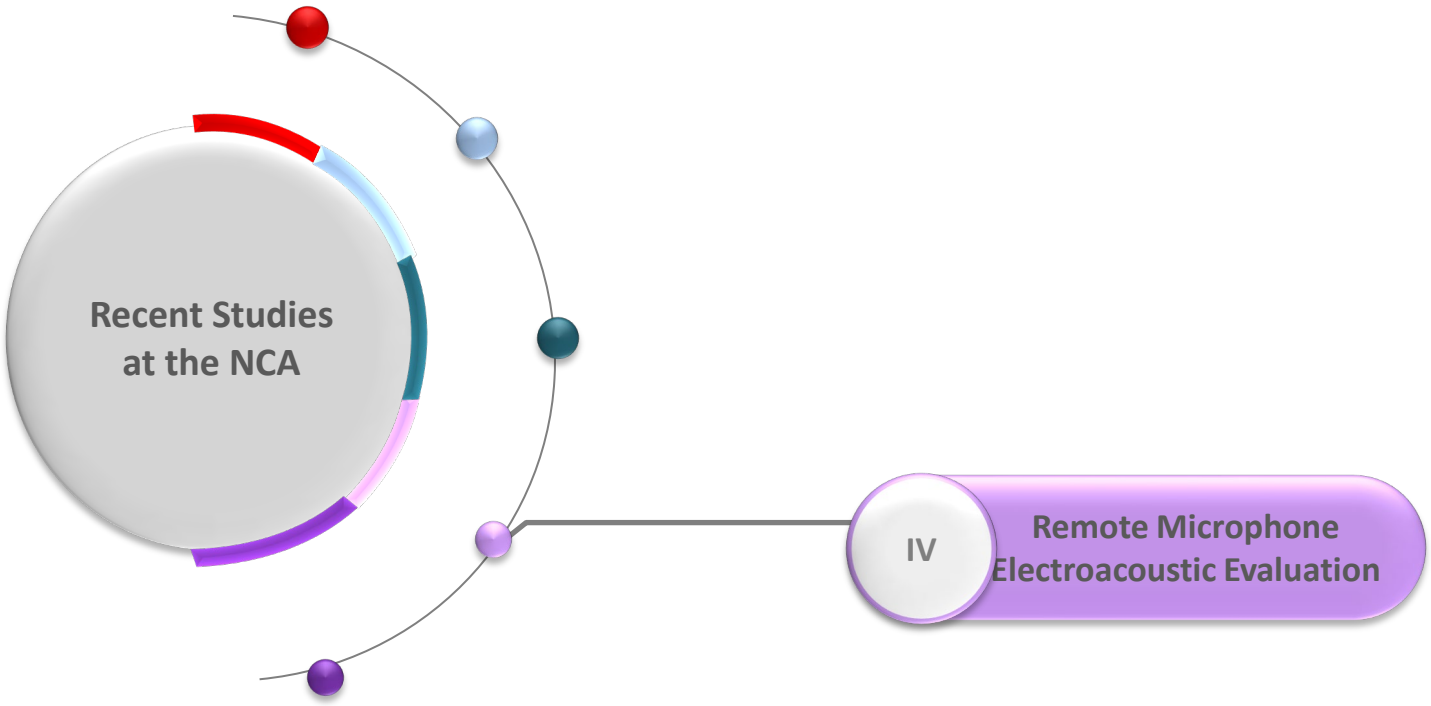
Subjective Measures of Sound Quality



Folkeard et al., (2026)

Take Home

- Directionality is a driver of performance and preference
- New generations of tech that enhance directional systems or combine directionality with AI-driven technology are continuing to improve performance
- Benefits are not uniform across all tasks or environments and can be affected by clinical fitting decisions such as venting choice


Recent Studies
at the NCA
IV
Remote Microphone
Electroacoustic Evaluation

Hearing Aids Even When Fit to Minimum Standard of Practice

Optimal benefits in situations when:

1. Listener is near the talker
2. Listener is facing the talker



Outcomes vary when the listener is positioned:

1. To the side of talker
2. Behind the talker
3. Far from talker
4. In unpredictable locations

Ricketts & Picou (2013)

Why is the Group-Based Exercise Scenario so Interesting?

1. Adherence and re-enrollment rates as high as 75%
2. Improved social experiences
3. Improved feelings of well-being and belonginess
4. Broader implication on healthy aging



Farrance et al., (2016); Gilbert et al., (2017); Molloy et al., (2010)

Exercisers Value Listening to:

Fellow Exercise Members

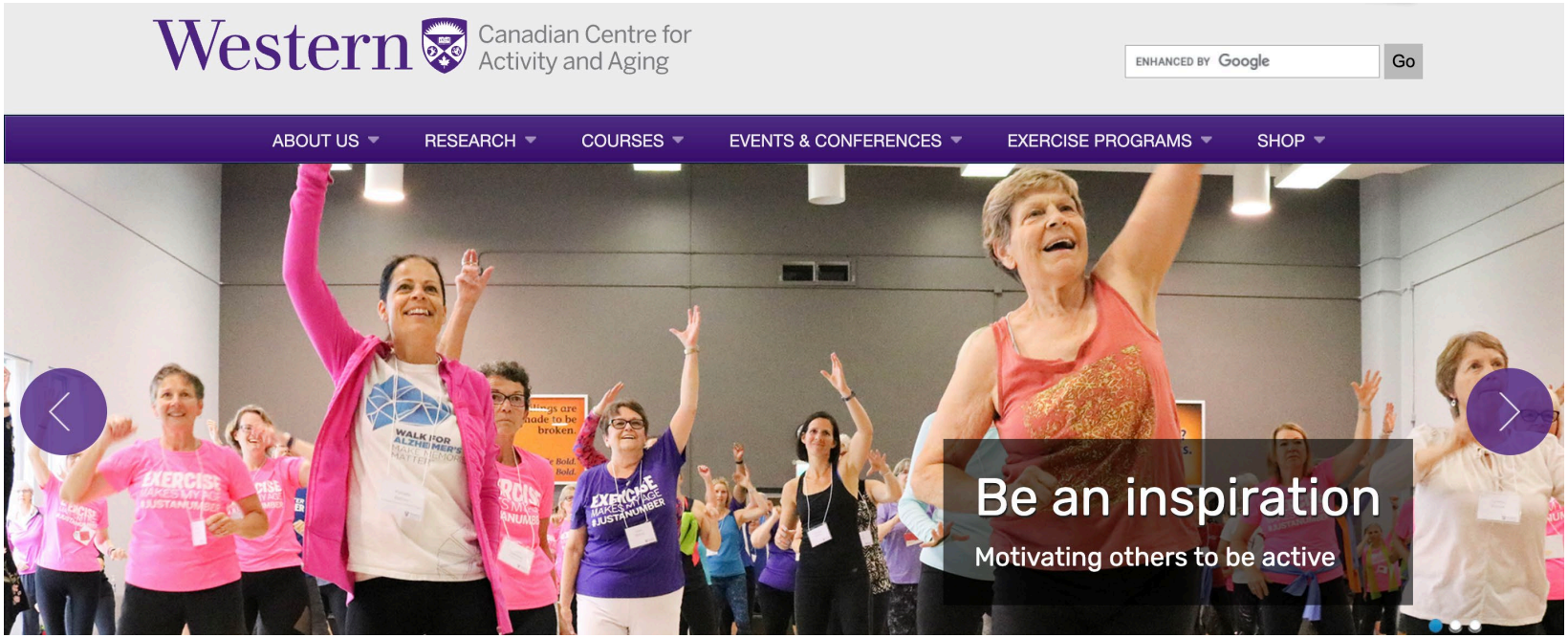


Senior Fitness Instructor



Farrance et al., (2016); Gilbert et al., (2017); Molloy et al., (2010)

We Collaborated with the CCAA to Learn More about Barriers to Hearing Accessibility



Barriers to Understanding Exercise Instructions

Rahme et al., 2022



Would Hearing Aids Fit To Best Practices Address These Barriers?



Would Hearing Aids Fit To

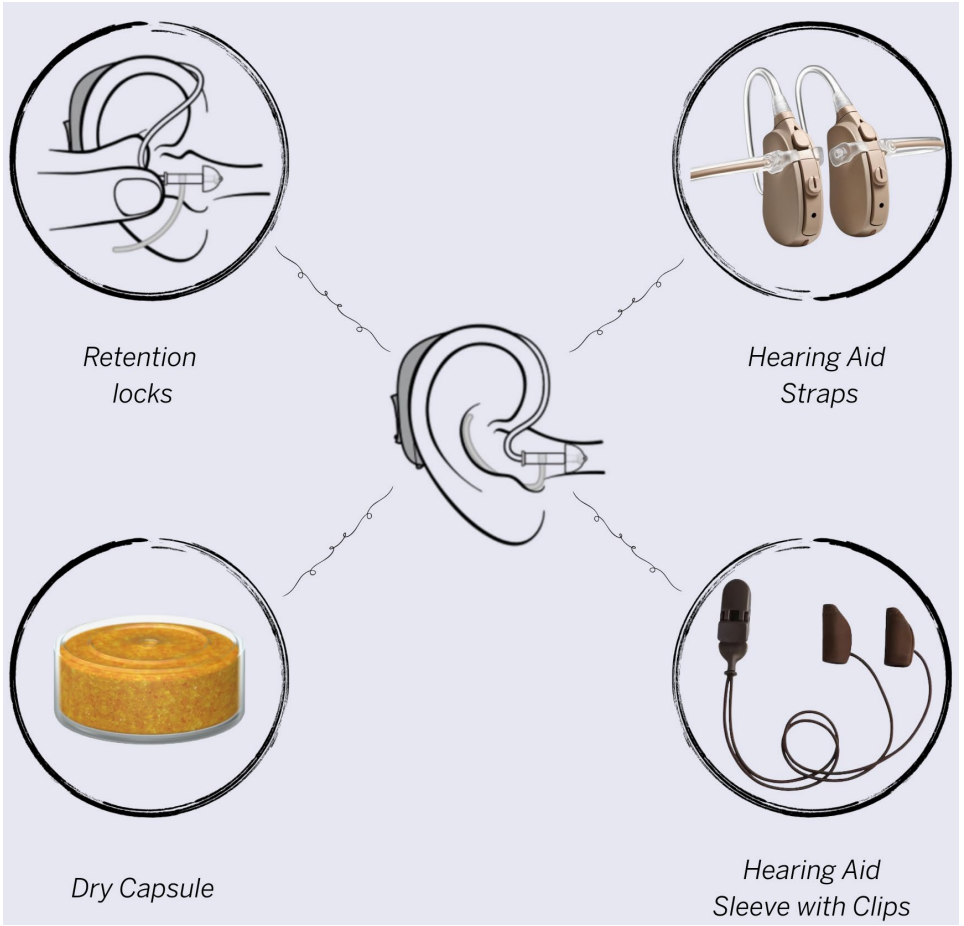
~~**Best Practices**~~

Minimum Standard of Care

Address These Barriers?

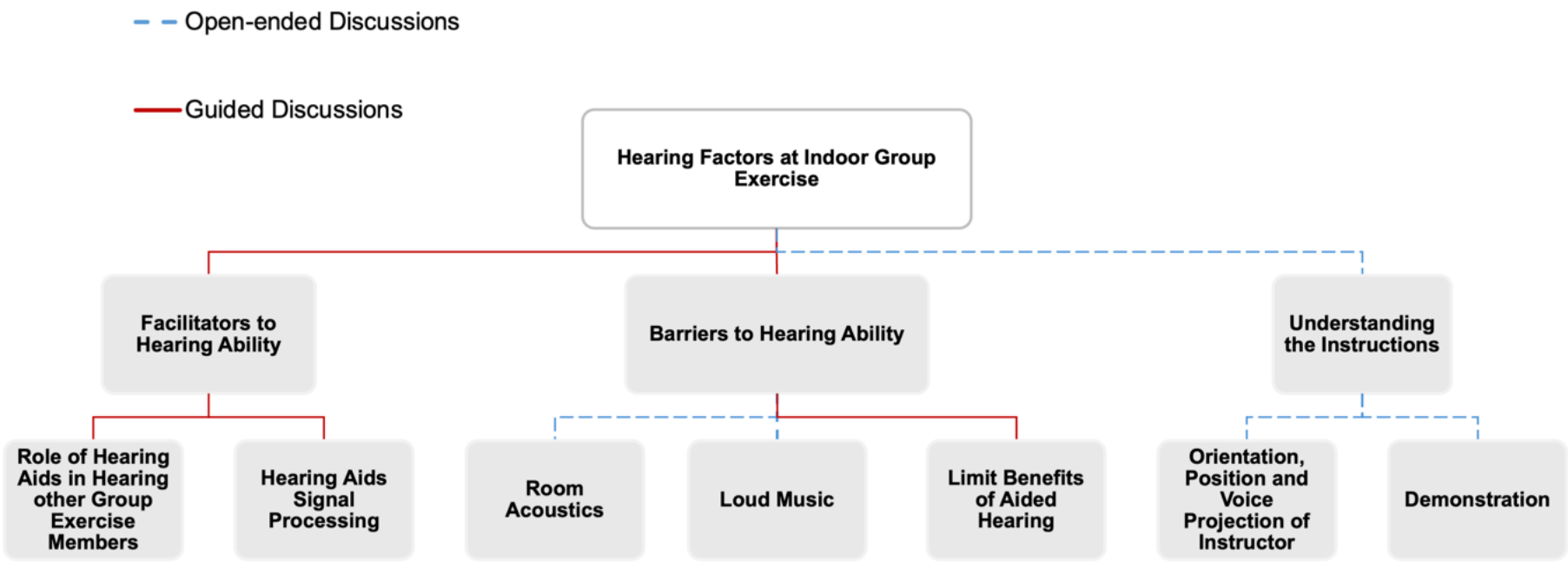
We Provided Physical Fit Accessories

- **Retention**:
  - Retention lock, stick'n stay tape, hearing aid-glasses connector, and retention cord.
- **Comfort**:
  - Hearing aid sleeves with and without corded alligator clips.
- **Moisture**:
  - Capsule-based dehumidifier and hearing aid sleeves.



Rahme et al., 2025

Hearing Factors at Indoor Group Exercise



Rahme et al., 2025

Electroacoustic Assessment of Remote Microphone



“When I was warming up, you talk to other members, and I did hear them better than when I didn’t have aids.”



“She had her back to me and all of us couldn't hear. It wasn't just me. The entire class almost, you know, people would say, well, what did she say, you know, and if she turned around, then obviously, we all heard her.”

“It was clear with the instructor depending on where she was located in the room. But overall, it [hearing aid] definitely did help with exercise.”

Rahme et al., 2025

Would Remote Microphones Connected to Hearing Aids Address the Barriers to Hearing the Fitness Instructor?





Things We Already Know About Hearing Aid Remote Microphones

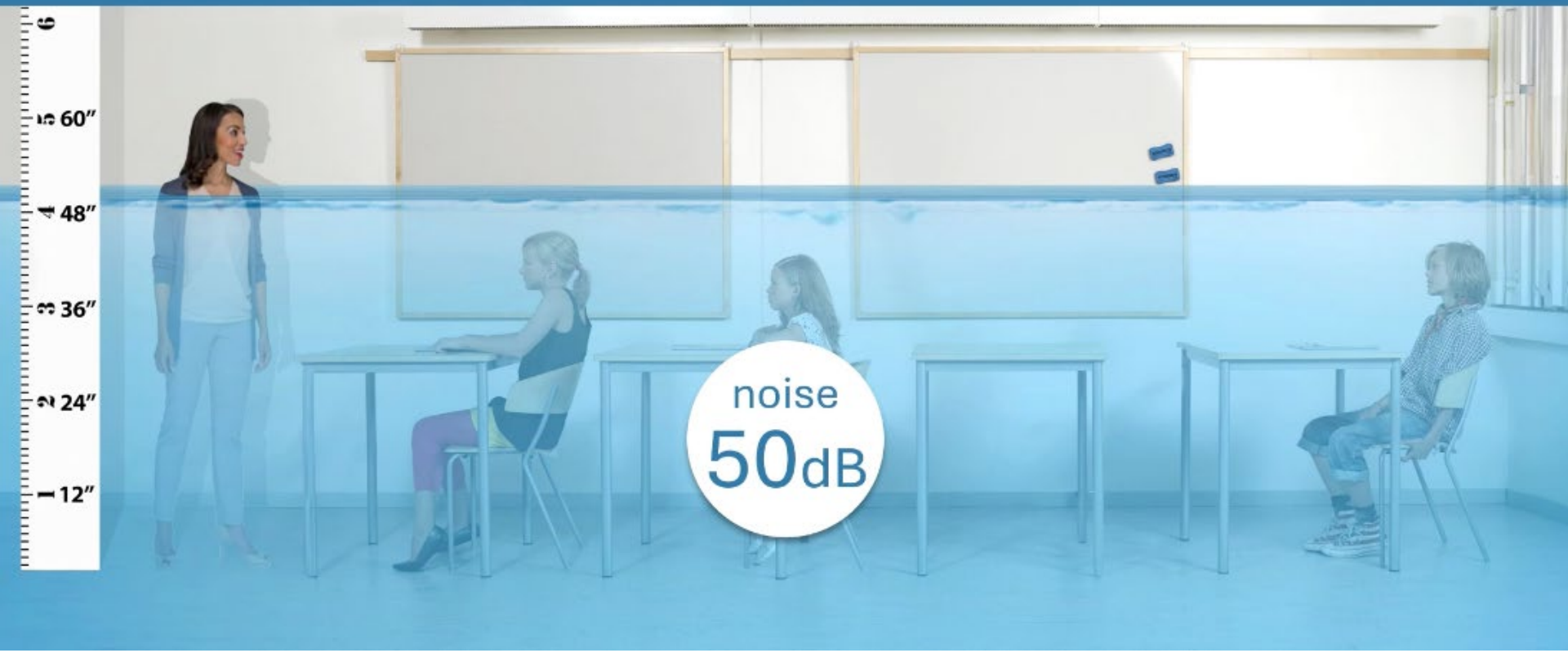
- Hearing aid remote microphone technologies have been shown to be effective in overcoming the barriers of complex listening environments, distance, and location of the target talker compared to hearing aids alone. (Lewis et al., 2022; Picou et al., 2020; Tharpe et al., 2017; Thibodeau, 2014, 2020; Wolfe et al., 2015, 2020; & Zanin et al., 2024)
- Promising outcomes in real-world classrooms and aquariums.
- Lower fatigue, improved safety and awareness, reduced repetitions and confusions (Gabova et al., 2022; Gabova, et al., 2024; Gabova, et al., 2024)

Let's say inches = decibels



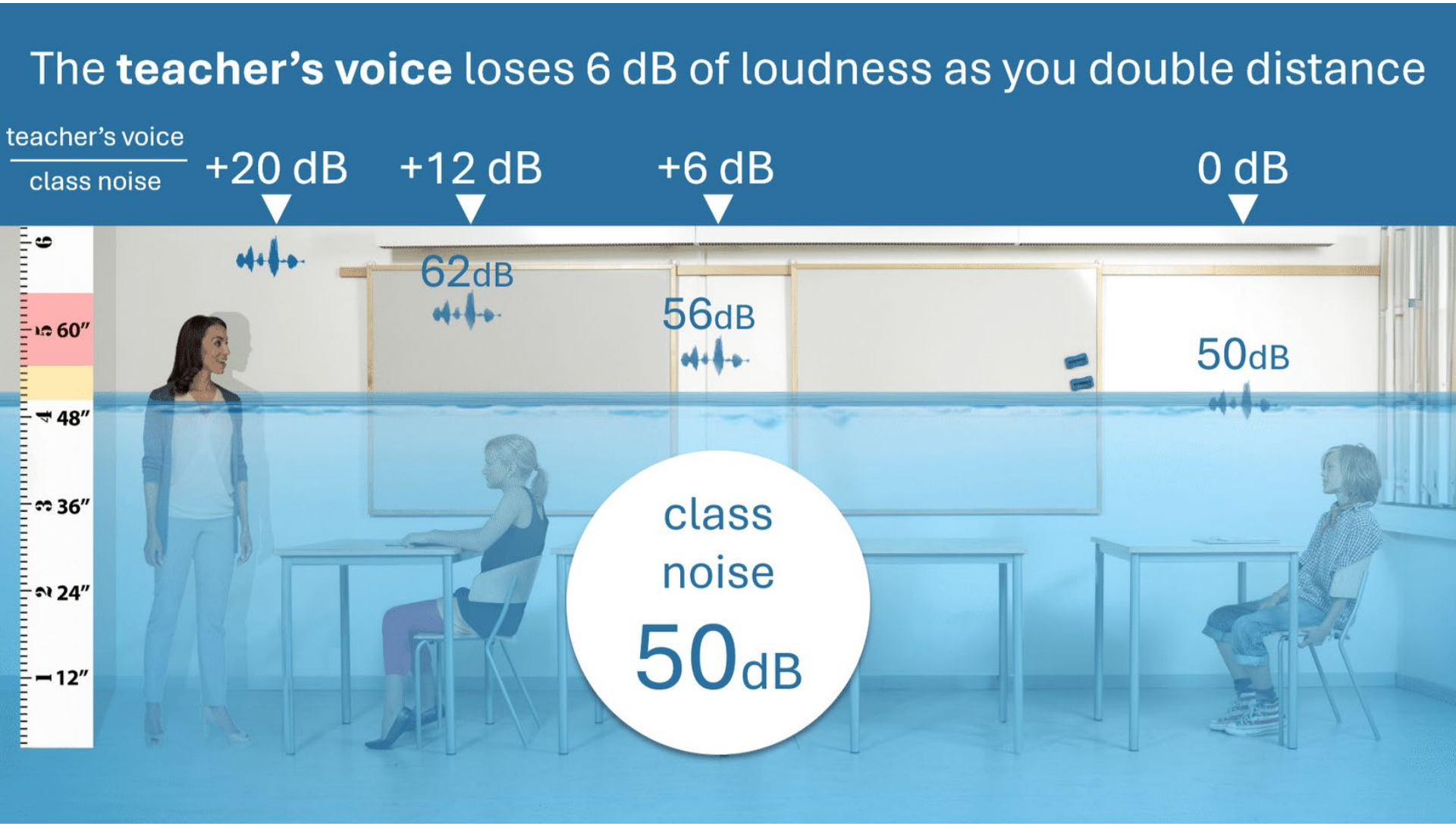
Sindrey et al., 2025

With people it's around 50 dB

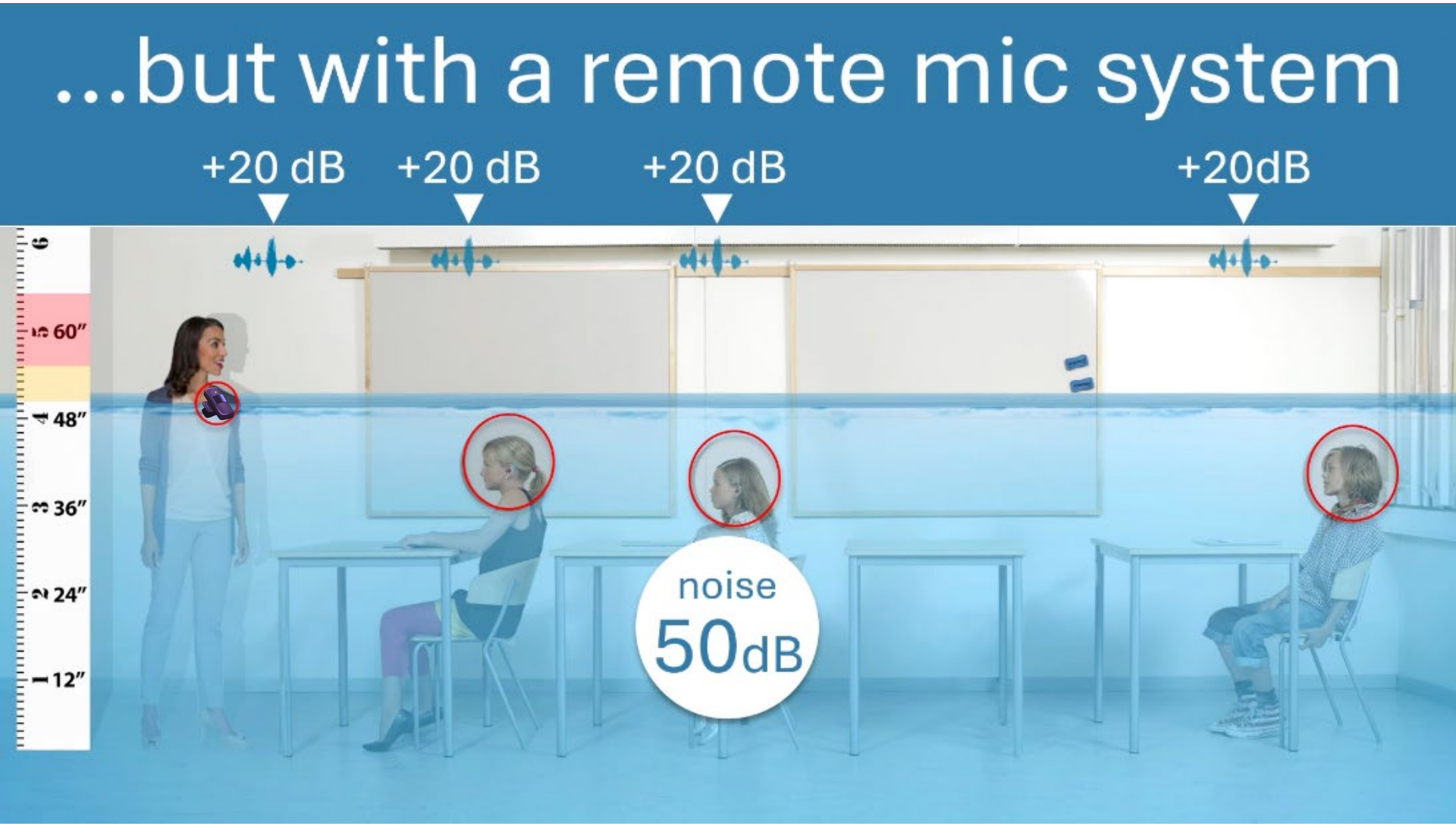


Sindrey et al., 2025

Electroacoustic Assessment of Remote Microphone



Sindrey et al., 2025



Sindrey et al., 2025

Let’s go on a Road Trip!!





In Gym Manikin Set-Up

Audiograms (Bisgaard et al., 2010)

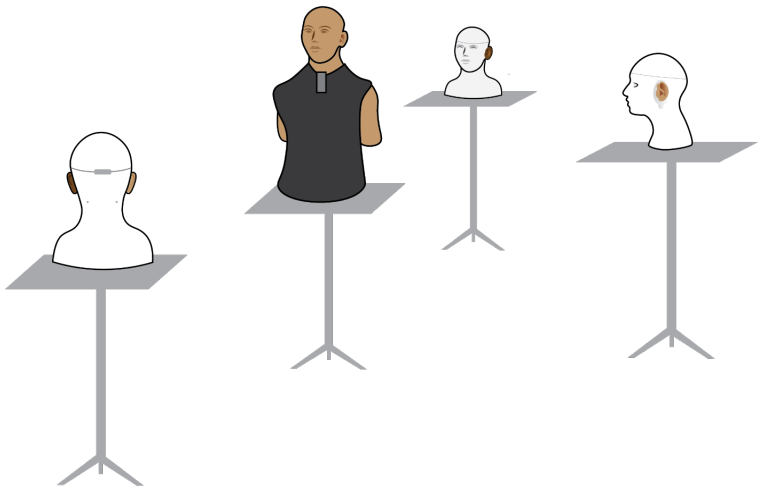
- Mild sloping hearing loss (N2)
- Moderate sloping hearing loss (N3)

Distances

- 2 meters
- 4 meters

Azimuths Relative to Simulated taker

- Facing
- Side
- Behind



Made Recordings in 2 Exercise Environments

Fitness Studio: moderate reverberation

(RT = .35 s)



Gymnasium: high reverberation

(RT = 1.95 s)



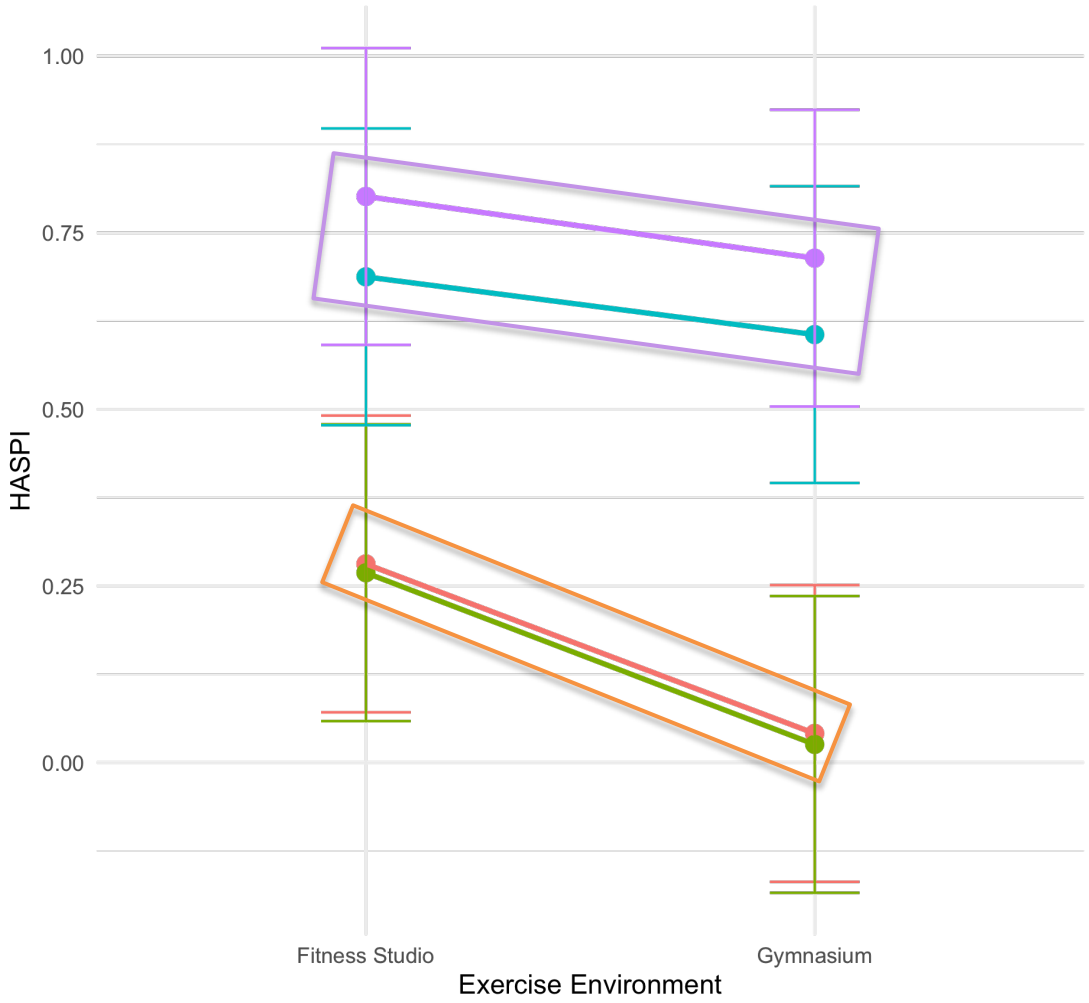
We Compared 3 Brands with the Following Hearing Device Conditions

Hearing Aids Alone *Fitted and verified to DSL v5 prescription formula*		Remote Microphones *Electroacoustically transparent*	
Signal Processing Off Program	Automatic Program *(default)*	Low Technology ○ Non-adaptive ○ Low-cost ○ Entry-level	High Technology ○ Adaptive ○ Advanced ○ Educational-level systems

Rahme et al., 2025 & 2026

Improved Speech Perception Scores For Remote Microphones

Higher = Better



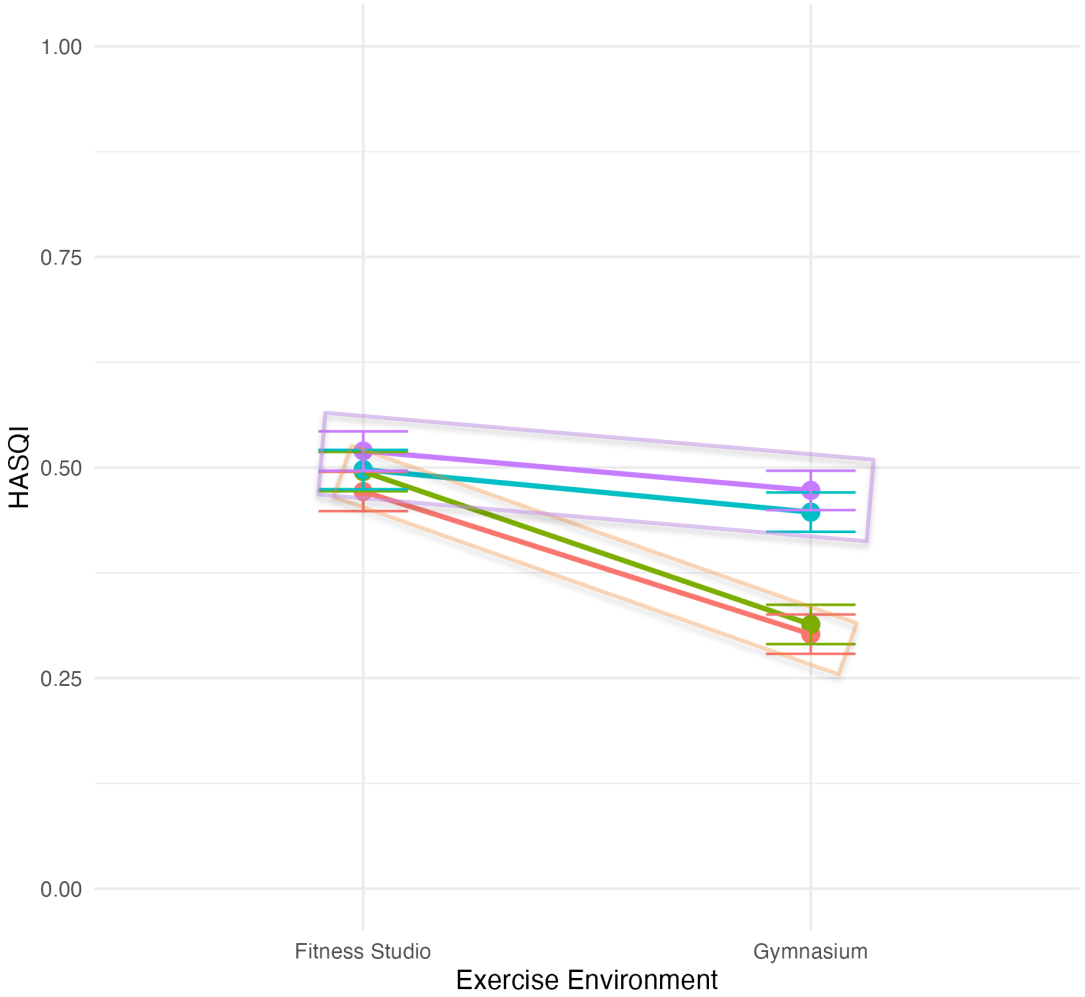
Hearing aids alone

Hearing Aid Condition
Signal Processing Off
Automatic Program
Low Mic
High Mic

Remote Microphones

Sound Quality Scores Were Less Robust

Higher = Better



Hearing aids alone

Remote Microphones

Rahme et al., 2025 & 2026

Remote microphones were feasible in the gym

- Remote microphones consistently outperformed hearing aids alone regardless or audiogram, reverberation levels, distance, and orientation relative to the listeners.
- Test apparatus was feasible in measuring differences between conditions.

What about in hearing aid users?

Would we see similar benefits?





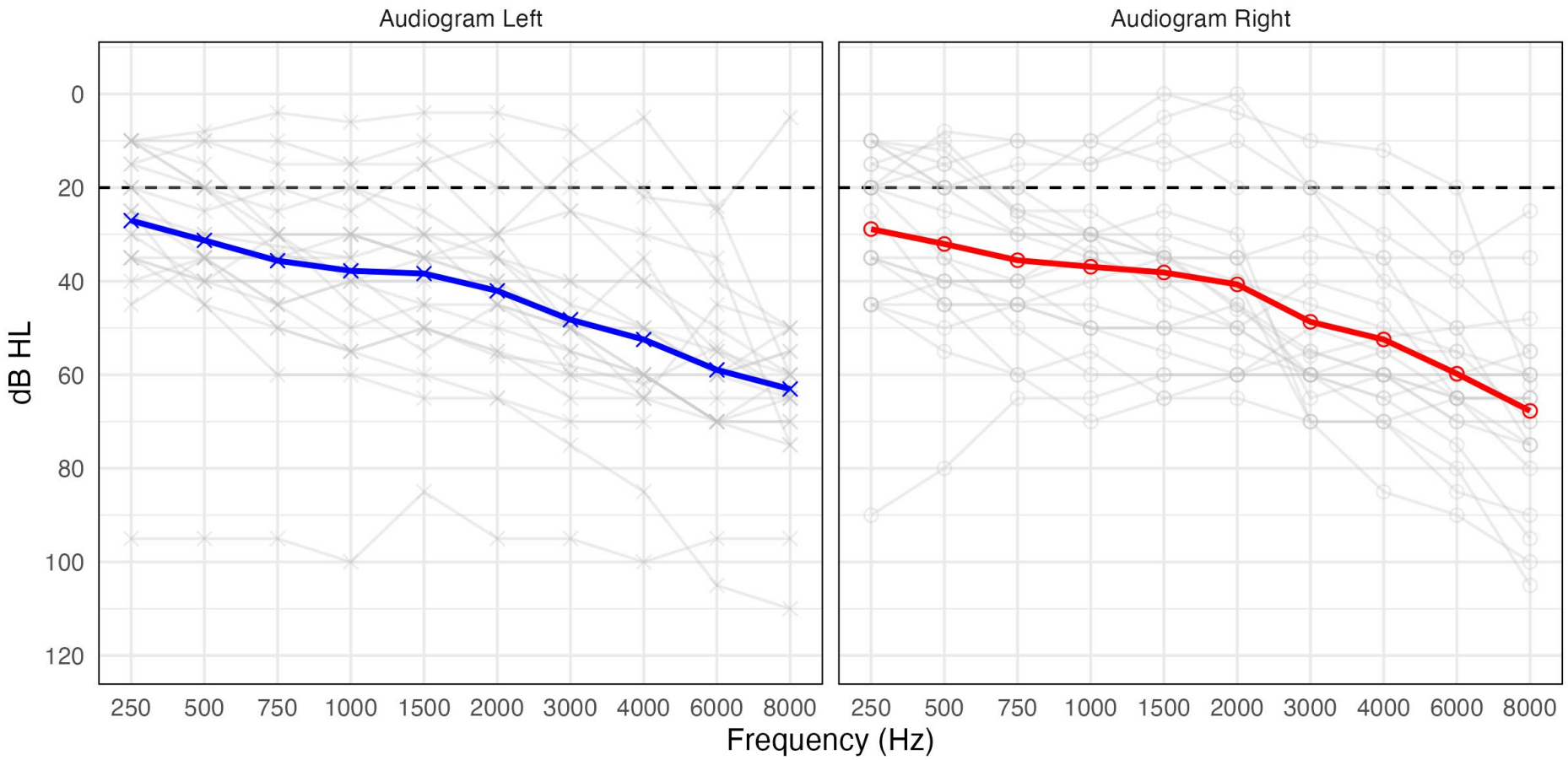


V

Behavioral
Remote Microphone

CANADIAN HEARING SERVICES | GLOBAL PARTNERSHIPS FOR RESEARCH & INNOVATION

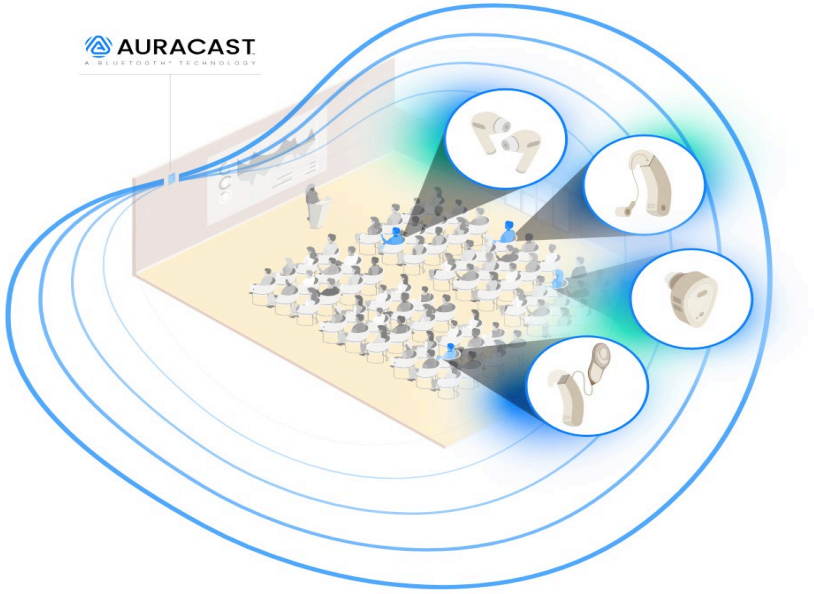
22 Participants with Age Range: 62 – 87 Years



Rahme et al., in-prep

Hearing aids alone vs. Remote microphone in hearing exercise instructor

Hearing Device Conditions	
Hearing Aids Alone	Remote Microphone with Auracast
**Fitted and verified to DSL v5 prescription formula (Scollie et al., 2005)*	**Electroacoustically transparent (EUHA, 2017)*



AURACAST™
A BLUETOOTH® TECHNOLOGY

Rahme et al., in-prep

We Hosted Exercise Classes



Music Sound Level
62.5 dBA

Reverberation Time
1.95 s

Noise Floor Level LAeq
46 dBA

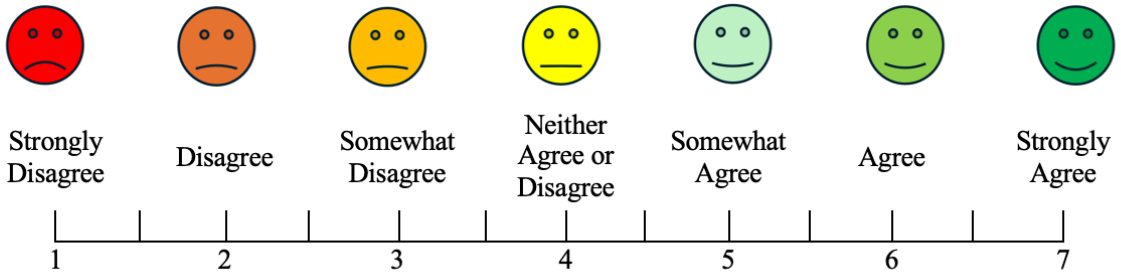
Rahme et al., in-prep

Instruction Script Example

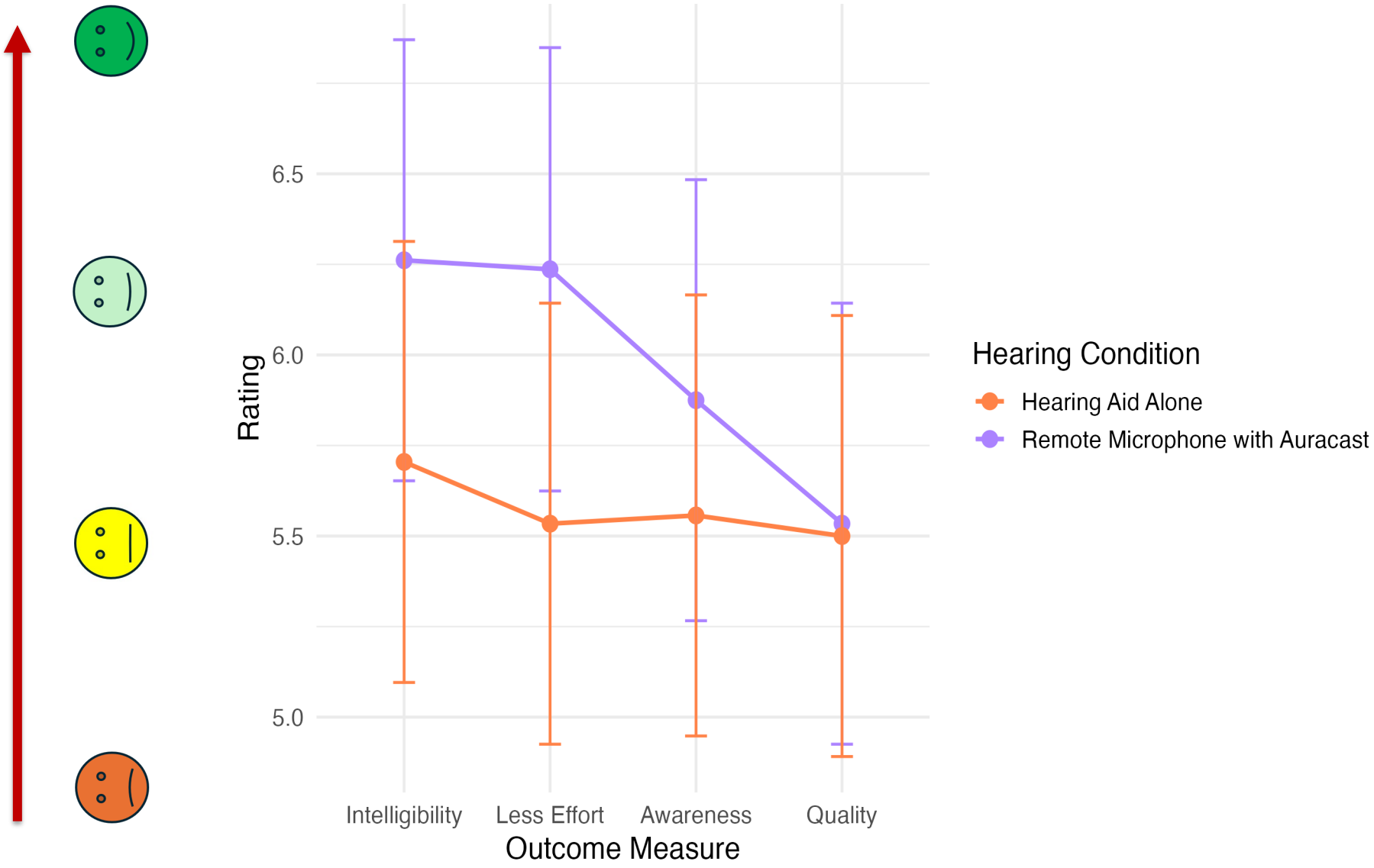


- “Let’s start off by marching in a spot. Follow me!
- Raise your knees to a comfortable position.
- Focus on breathing as we warm up.
- Try to use the opposite arm and leg.
- Get those arms going!
- Well done.
- Let’s do another 10.
- Keep moving!
- 5-4-3-2-1”

Participants Rated 4 Outcome Measures

Condition:	
Speech Intelligibility I can **understand** what was being said by the instructor.	
Listening Effort I did not have **to work hard** to follow the instructions.	
Background Sound Awareness I was **aware** of the background sounds while hearing the instructions.	
Sound Quality I found the **quality** of the instructor's voice to be good.	

Behavioral Assessment of Remote Microphones



Rahme et al., in-prep

Remote Microphones Improved Hearing Access During Group Exercise

- Remote Microphone with Auracast condition was significantly better than hearing aids alone ($p < .05$) and across all outcome measures.
- Similar trend in rating regardless of the factors of trial or outcome measure.

Predictive metrics underestimate performance compared to behavioral data

To Sum Up

1. Recent studies at the National Centre for Audiology showed positive electroacoustic and patient reported outcomes of signal processing features (directionality, DNN based denoising) as well remote microphones.
2. Electroacoustic studies may underestimate remote microphone performance in very challenging listening environments compared to behavioral assessment.
3. Optimal device outcomes are expected when these strategies are used together.

Thank you for your time!

Questions?

