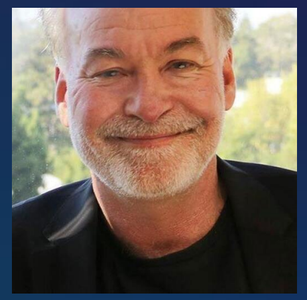
Redefining Human Hearing: From Research to Reality

What AI and wearable technology mean for the future of audiology



Thomas Lunner



Christi Miller

Canadian Academy of Audiology
October 2026

Meta

Thomas: background

- **Developed the** first digital hearing aid *[Oticon Digifocus 1995, PhD work, low -power multi -channel WDRC algorithms and prescription fitting methods, chipset specs]*
- **Industry:** Led research at Oticon Research Centre Eriksholm for 20 years
- **University:** Was professor at 2 universities in parallel *[Linkoping University and Danish Technical University]* until 2020
- Joined Meta Reality Labs Research 2020 to lead research in Augmented Hearing

Why I am here

- Putting hearing aids in glasses is an obvious idea
- The hearing aid industry chose to drop it
- So someone else picked it up

Who wants to solve speech-in-noise problems for their clients?

So do we.

What is changing, and what is getting bigger

Restoring audibility

for self-reported loss

Being automated, to a degree

Helping people make full use of better hearing

About to get considerably larger

01 The bar: what size of benefit actually matters

External literature.

Two numbers, one paper, the same listeners

3 dB

Just -noticeable difference

The smallest SNR change a listener can reliably detect (2.8–3.7 dB). The same for normal-hearing and hearing-impaired listeners.

6–8 dB

Just -meaningful difference

The change for which a listener would swap devices or make a trip to the clinic. Again regardless of hearing ability.

McShefferty, Whitmer & Akeroyd (2016). The just-meaningful difference in speech-to-noise ratio. Trends in Hearing 20:1–11. doi:10.1177/2331216515626570

“These latter, less arbitrary JMD [just-meaningful difference] values exceed what is currently possible with conventional hearing-aid technology.”

MCSHEFFERTY, WHITMER & AKEROYD (2016), TRENDS IN HEARING

Raising the bar

- The field’s conventional bar for clinically meaningful speech-in-noise benefit is 3 dB
- That bar sits at the threshold of mere detectability

Killion et al. (2004); Etymotic Research (2001); just-noticeable difference: McShefferty et al. (2016)

The same SNR is a very different task for different people

- Speech reception thresholds in noise vary widely between individuals
- The audiogram predicts only part of that spread
- So a fixed SNR improvement lands very differently from person to person

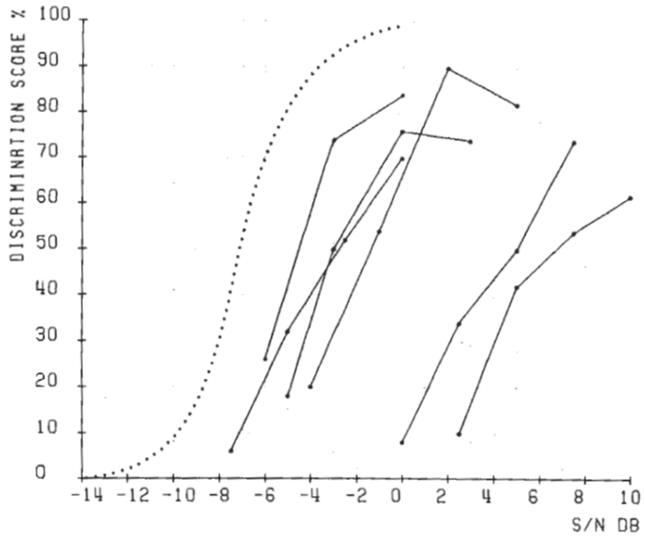


Fig. 4. Intelligibility curves for sentences in noise of 6 extra patients. Dotted line is the average curve for normals (Hagerman, 1982).

Hagerman, B. (1984). Clinical Measurements of Speech Reception Threshold in Noise. Scandinavian Audiology, 13(1), 57 –63.

Why SNR matters beyond words correct

- Adequate word scores, and still exhausted after the restaurant
- Listening effort keeps falling as SNR improves, even after intelligibility reaches ceiling (100% correct)
- Acceptable noise level: listeners want speech roughly 5 –10 dB above the noise
- FUEL and ELU explain why: better SNR frees cognitive capacity

Rennies et al. (2014) JASA; Krueger et al. (2017); Nabelek et al. (1991, 2006) JAAA; Pichora -Fuller et al. (2016) Ear & Hearing (FUEL); Rönnberg et al. (2013) (ELU).

Why noise reduction matters even when word scores don't move

Ease of Language Understanding (ELU)

When the signal matches what we know, understanding is fast and implicit.

Noise and distortion cause mismatch, and understanding shifts to slow, explicit processing that draws on working memory.

Framework for Understanding Effortful Listening (FUEL)

Listening effort is the deliberate allocation of limited cognitive resources,

shaped by how demanding the task is and how motivated the listener is.

Better SNR restores the match and frees working memory: less effort for the same words understood.

Rönnberg et al. (2008) Int J Audiol; Rönnberg et al. (2013) Front. Syst. Neurosci. (ELU) · Pichora-Fuller et al. (2016) Ear & Hearing (FUEL)

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ELU: Why is good sensing representation important for cognition? => Keeping effort low

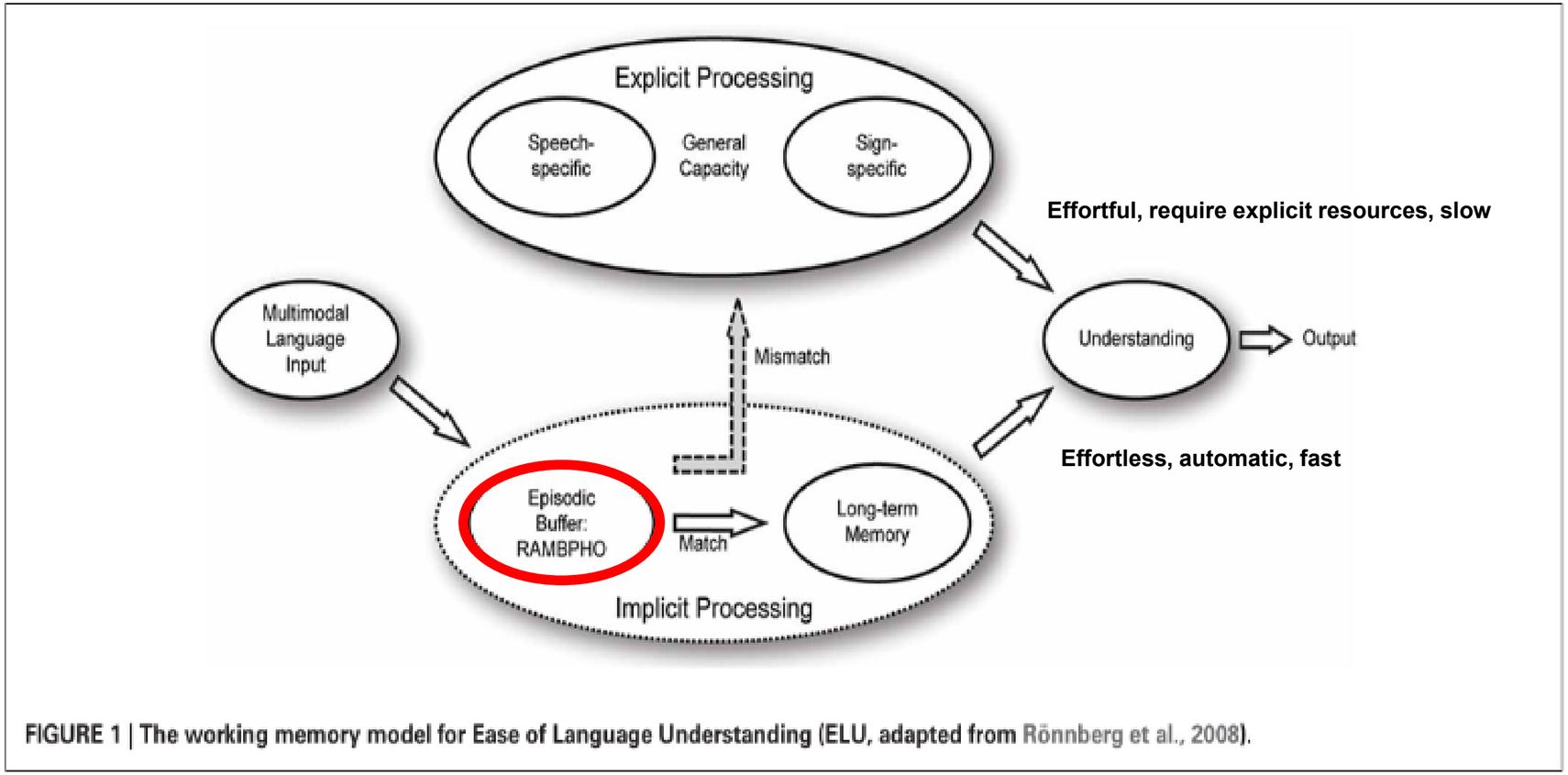


FIGURE 1 | The working memory model for Ease of Language Understanding (ELU, adapted from Rönnberg et al., 2008).

For example, Lunner et al (2016) showed that Noise Reduction (NR, better SNR) improved working memory recall even if speech intelligibility was 100%

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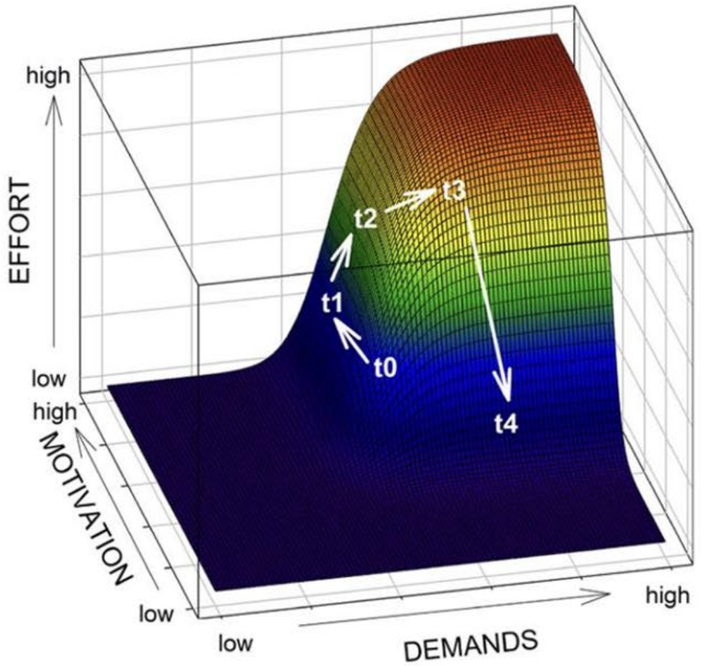
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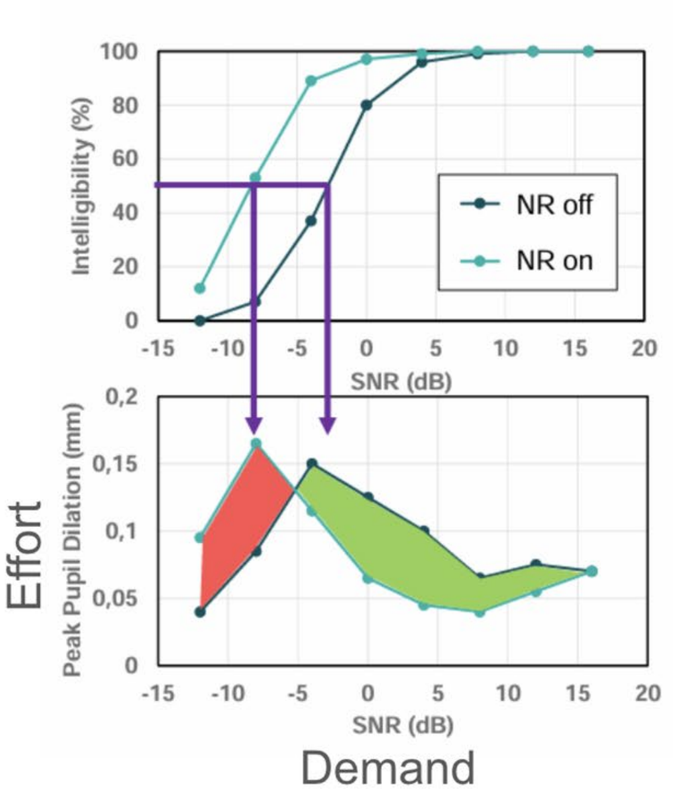
Rönnberg et al. (2008) Int J Audiol; Rönnberg et al. (2013) Front. Syst. Neurosci. (ELU) · Pichora-Fuller et al. (2016) Ear & Hearing (FUEL)

The pupil shows the effort, and the moment people give up

- Effort, measured by pupil dilation, is highest around 50% intelligibility
- When the task gets too hard, dilation falls: listeners disengage
- Noise reduction lowered pupil dilation at SNRs where intelligibility was already high



Framework for Understanding Effortful Listening (FUEL, Pichora-Fuller et al, 2016)



Ohlenforst et al (2018)

The perceptual targets are high.

The glasses platform is the vehicle.

Why glasses: what the platform affords

More microphones, wider spacing

Larger arrays than an ear-level device can carry, so narrower beams. Multichannel Machine-Learning (ML) speech enhancement can reach 10–20 dB in favourable conditions.

Egocentric sensors

Head motion, cameras and eye tracking: the inputs for inferring what the wearer is trying to hear.

Room for compute and power

Ear-level devices are tightly constrained by battery and processing budget.

Worn anyway

A socially accepted form factor. Nobody reads a pair of glasses as a medical device.

Mehra, Brimijoin, Robinson & Lunner (2020). Potential of augmented reality platforms to improve individual hearing aids and to support more ecologically valid research. Ear & Hearing 41(Suppl 1). doi:10.1097/AUD.0000000000000961

And what it costs

- Open-ear speakers sit close to the microphones, which limits how much gain is stable
- Every millisecond of processing has to fit a latency budget
- Glasses are not in the ear canal: audibility for greater losses still needs an ear-level device

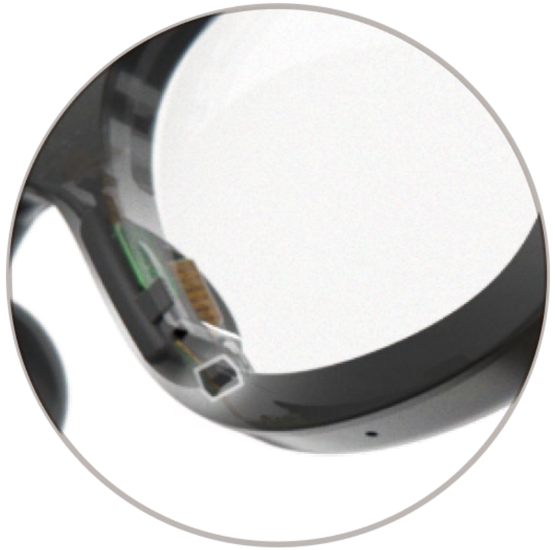
Front-end role for hearing aids and cochlear implants: proposed in Mehra et al. (2020).



Aria Gen 2



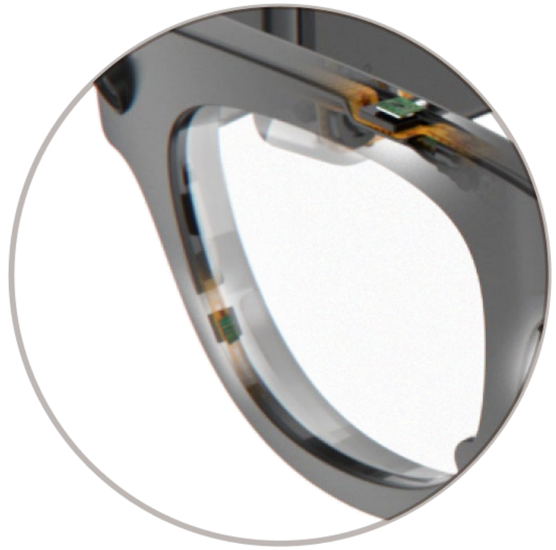
4x SLAM Cameras
12 MP RGB cameras
2x IMU



Eye tracking cameras
7x spatial mic



Health (PPG)
Contact microphone



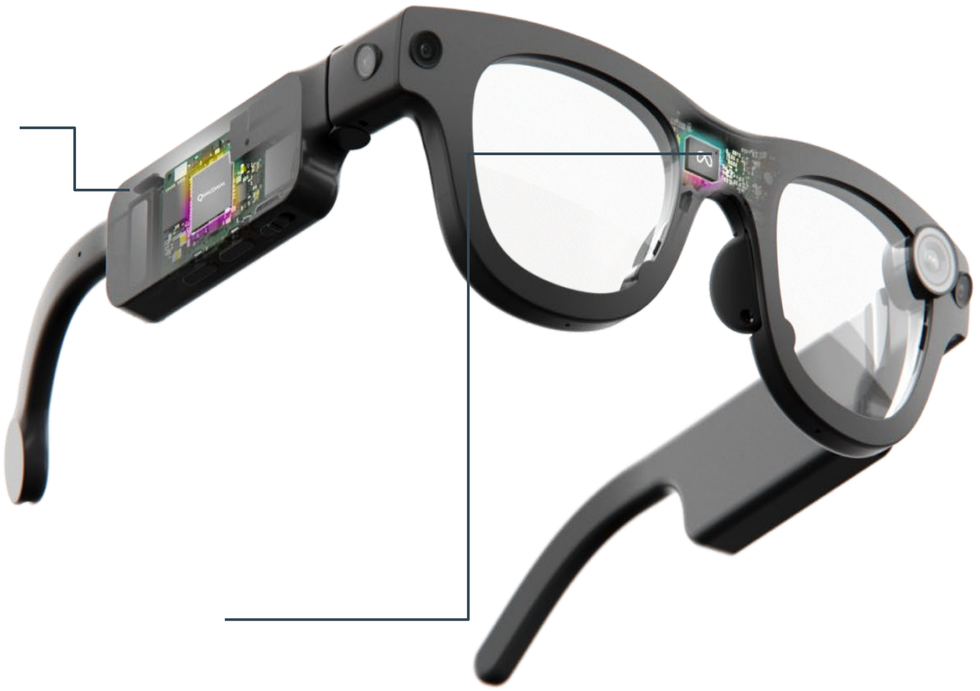
Magnetometer
Barometer

Advanced Sensors

On-device Machine Perception

Qualcomm AR1Gen1 Chipset

Meta's Custom Co - processor



SLAM Tracking

Hand Tracking

Eye Tracking

Automatic speech recognition

Our Partners

The Ohio State University

UC San Diego

IOWA

Università di Catania

IMPERIAL

Penn

Princeton University

SFU Simon Fraser University

Stanford University

Technical University of Munich

The University of North Carolina at Chapel Hill

UCD Dublin University College Dublin

University of Bristol

240

research partners in 27 countries

340

Citations of Aria / Aria data

02 The research, measured against the bar

Speech enhancement research on Glasses

Improve the user's ability to hear and understand speech or other audio targets in various environments

Uses a number of mics and a suite of several capture and rendering processing algorithms to provide an enhanced acoustic scene.

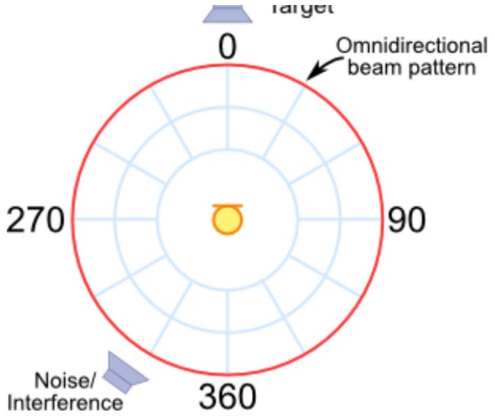
For those with mild-to-moderate hearing loss, the same pipeline can also compensate for the loss.



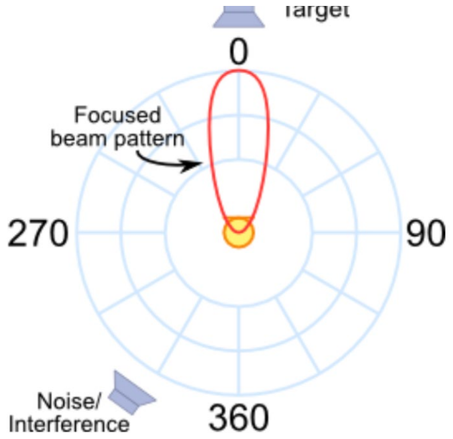
Far-Field Enhancement using Beamforming (Spatial Filtering)

Imagine being on a cocktail party (different talkers, noises all around you)
Background noise and many different conversations happening at once

Omni-directional



Directional



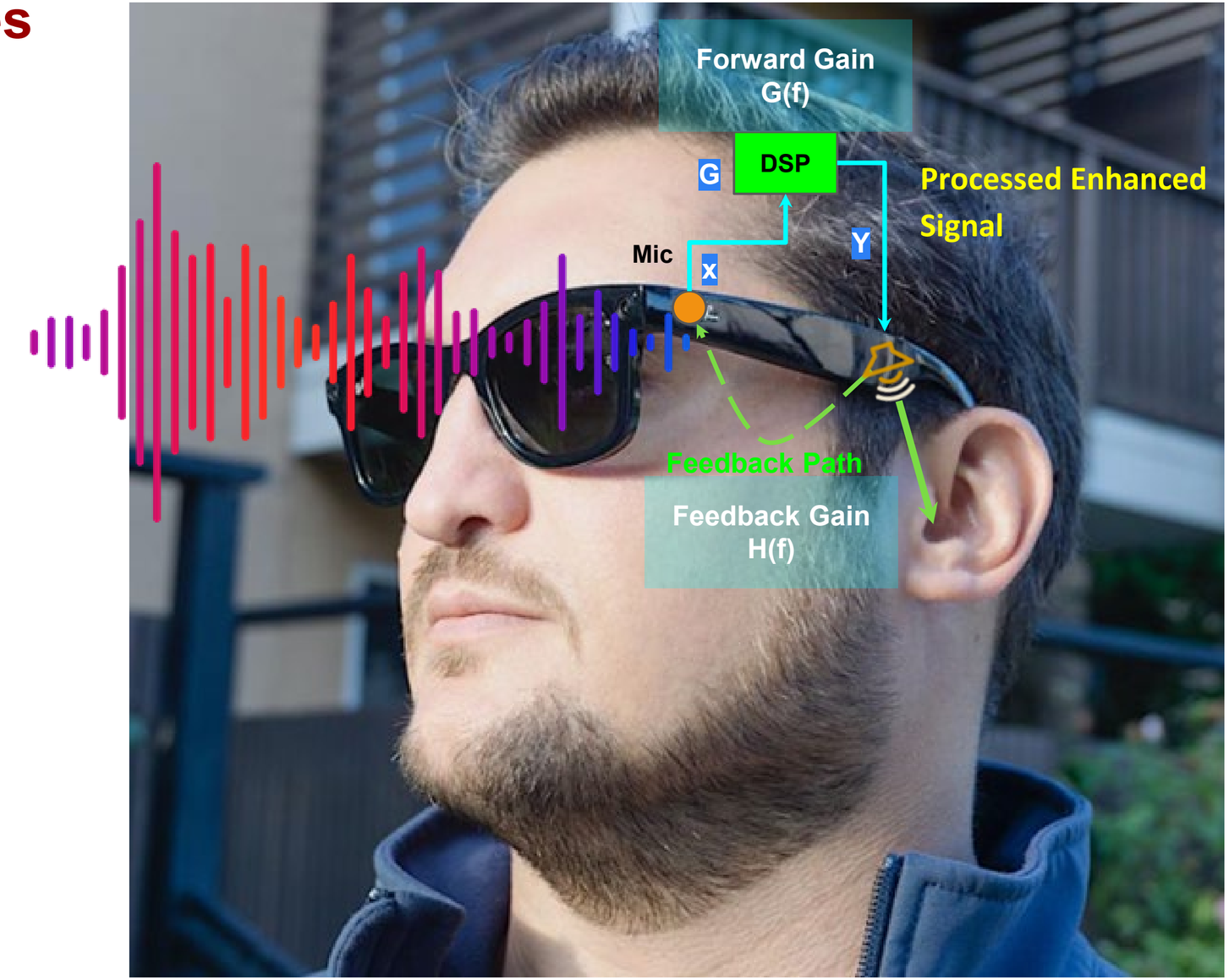


Speech enhancement on Glasses

Feedback path

Adaptive filtering used to model & remove the feedback

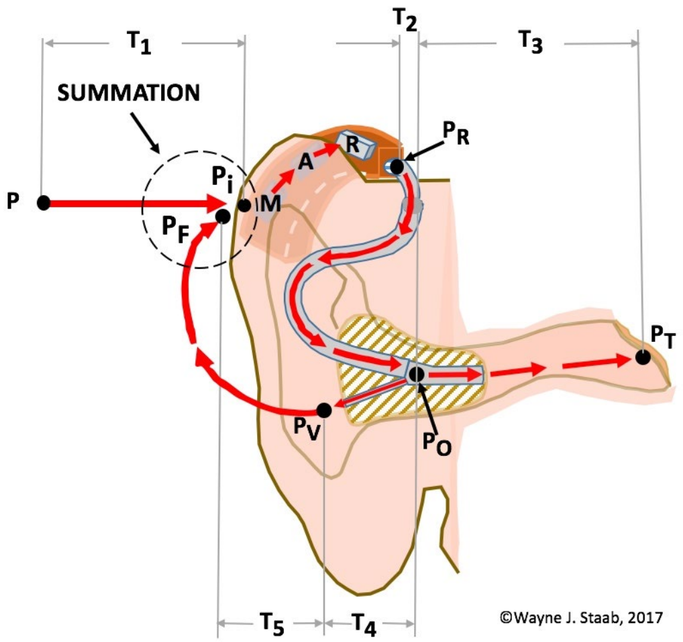
The output of the adaptive filter is subtracted from the microphone signal to cancel the feedback picked up by the microphone, thus allowing more stable gain in the hearing aid.



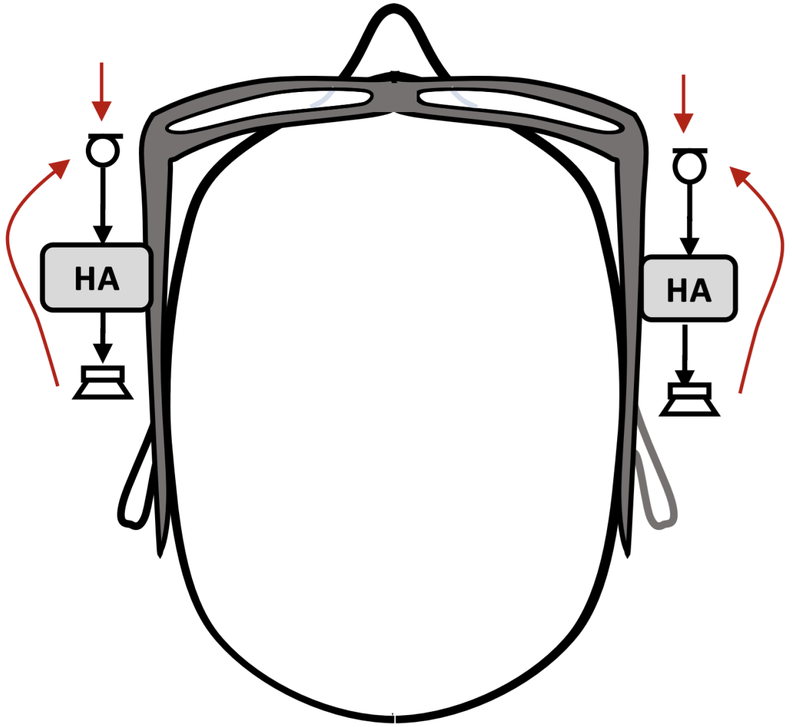
Feedback can occur if Loop Gain > 0 dB

Loop Gain = G(f)*H(f)

Acoustic Feedback Paths in Open-Ear Smart Glasses



Going from Monaural to Binaural FBC resulted in 4dB less Maximum Stable Gain



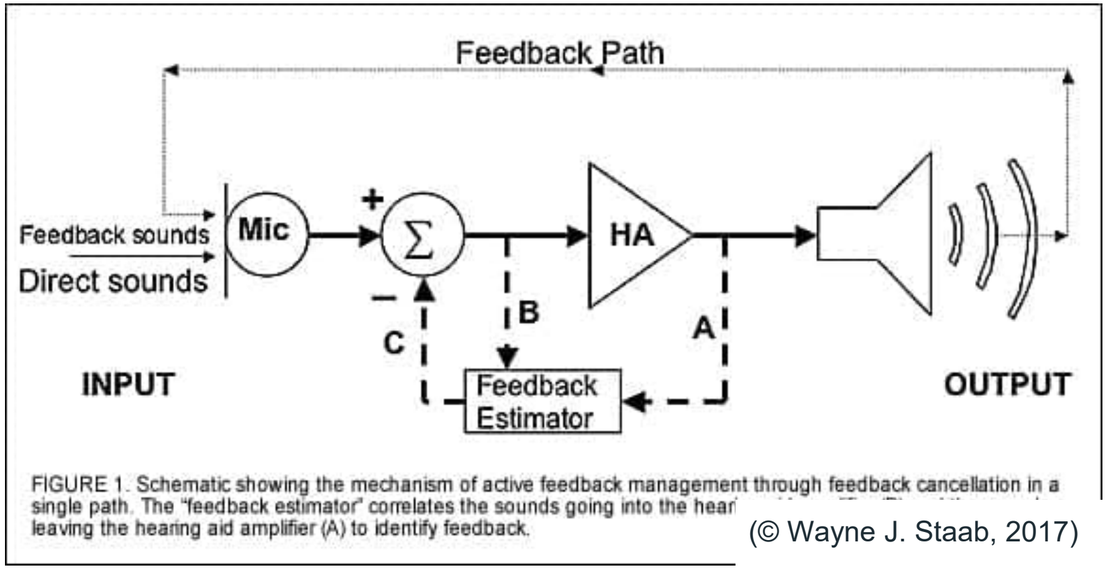
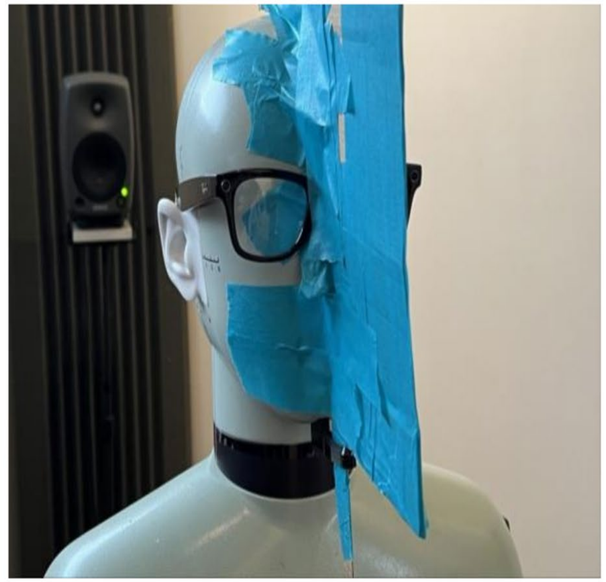
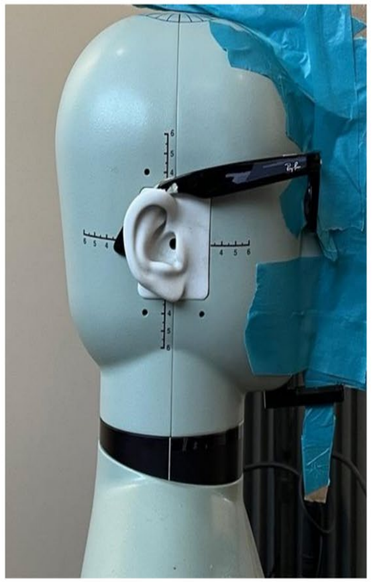


FIGURE 1. Schematic showing the mechanism of active feedback management through feedback cancellation in a single path. The "feedback estimator" correlates the sounds going into the hear leaving the hearing aid amplifier (A) to identify feedback.

(© Wayne J. Staab, 2017)



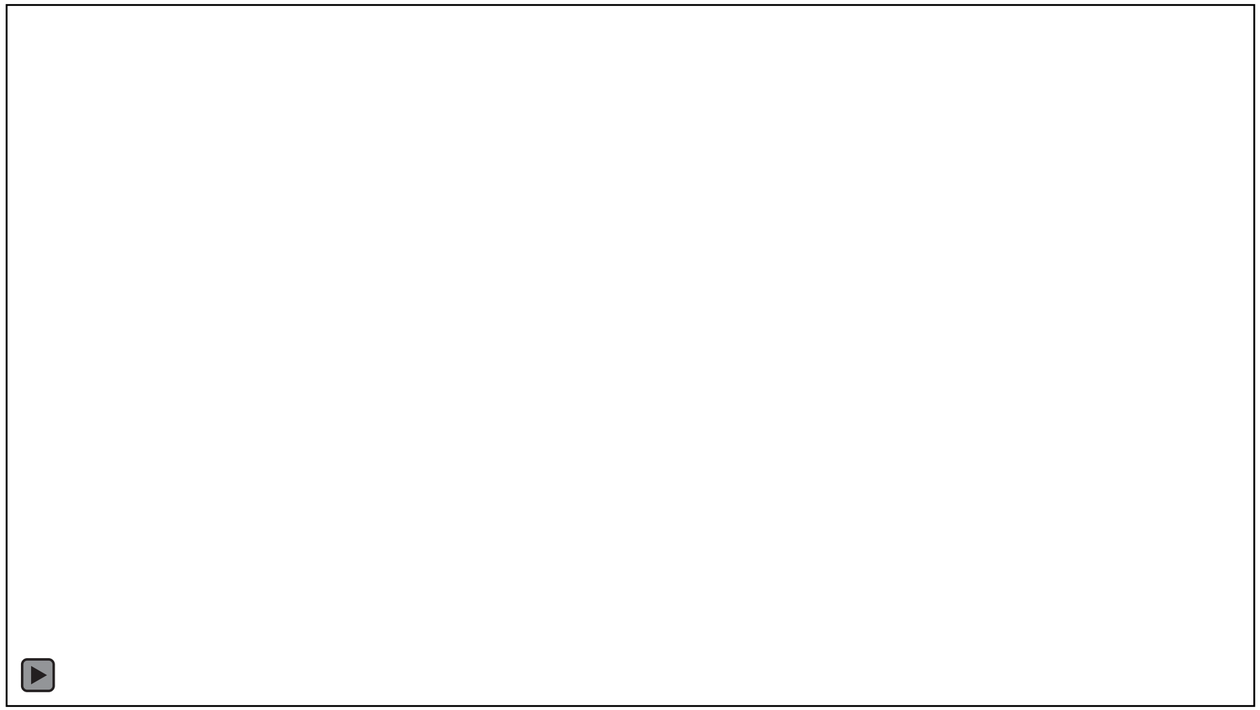


Amplifying the person you're talking to

1. Beamforming: point the microphone array at the talker

2. Speech cleaning: remove what the beam lets through

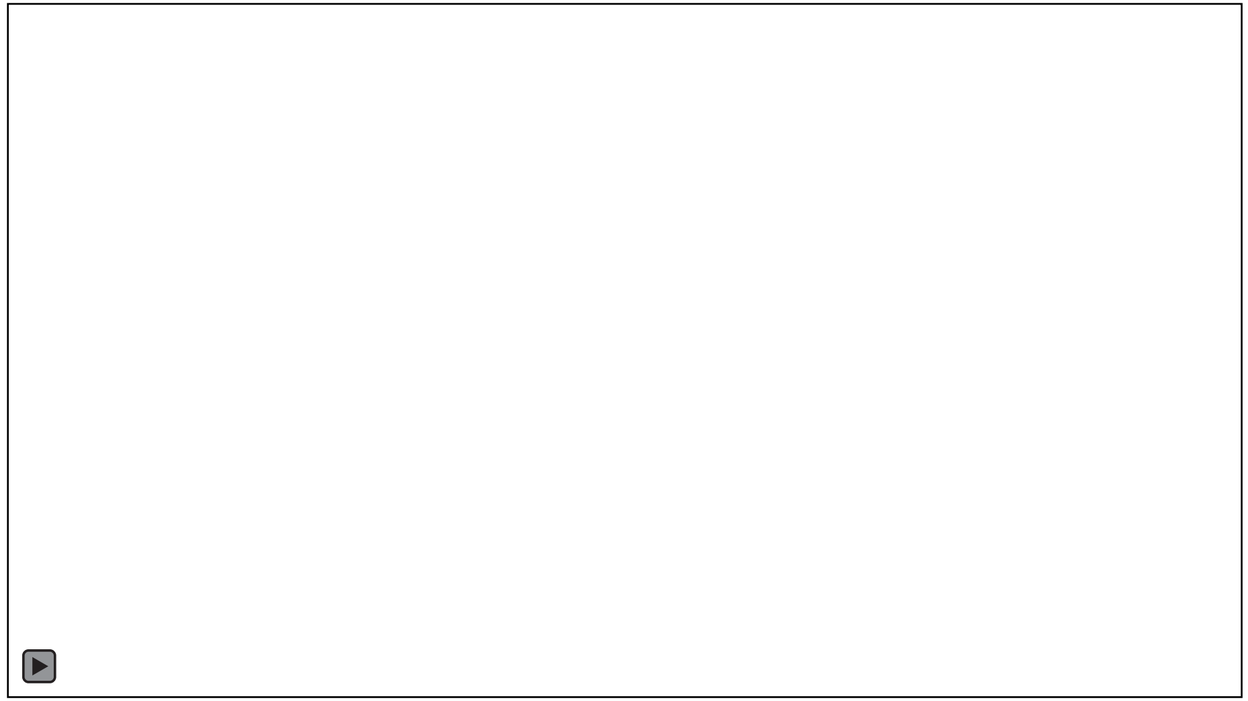
3. Amplify the talker's voice (around 15 dB of gain)



Animation: RL Research Audio, Fall 2023 Symposium

Challenge: feedback

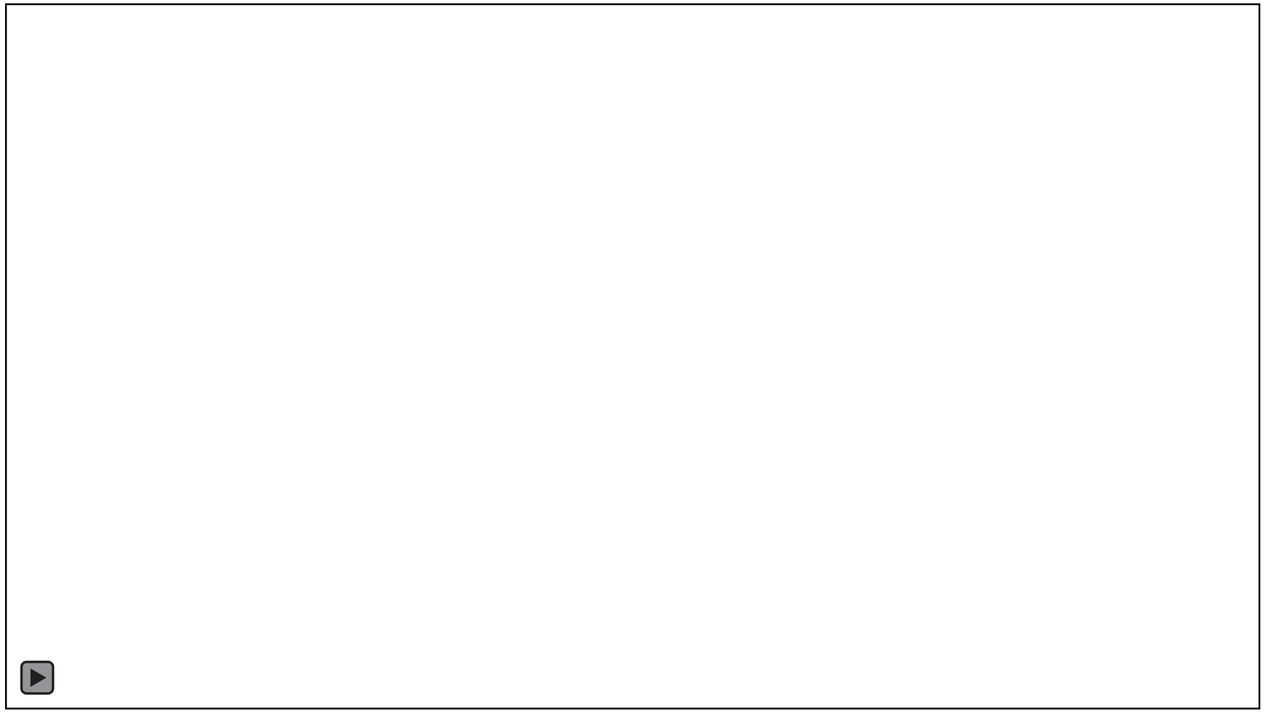
- Speaker and microphones sit centimetres apart
- The louder we play, the closer we get to feedback
- Feedback sets the ceiling on usable gain



Animation: RL Research Audio, Fall 2023 Symposium

Adaptive feedback control

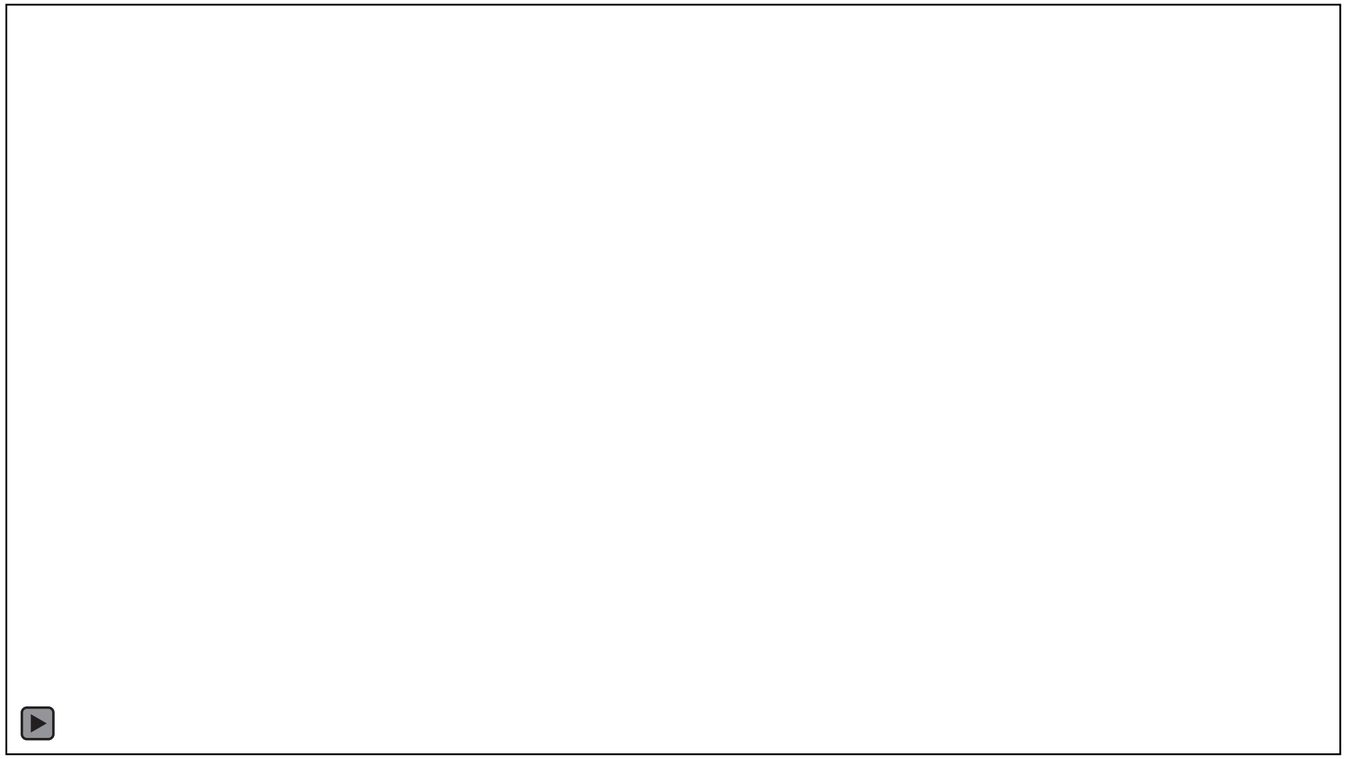
- Continuously learns the speaker -to- microphone path, on any head, even under a hat
- Predicts feedback and filters it out before it starts
- This is what made the needed gain possible



Animation: RL Research Audio, Fall 2023 Symposium

Challenge: your own voice

- Your mouth is much closer to the microphones than your partner's
- Amplified with a small delay, it's like hearing your echo on a call
- The most common complaint in early open ear demos -



Animation: RL Research Audio, Fall 2023 Symposium