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Understanding Individual Variability Among Older Adults with Hearing Loss, in partnership with American Auditory Society

Pamela Souza

Northwestern University

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Pamela Souza, PhD CCC-A

Pamela Souza is an audiologist, researcher, and teacher in the Department of Communication Sciences and Disorders at Northwestern University. As a researcher, she studies speech recognition, hearing aids, and the effects of aging and cognitive change on communication, and has published and presented widely on those topics. She is a Fellow of the American Speech Language Hearing Association and of the Acoustical Society of America. Her clinical interests include hearing aids, severe hearing loss, hearing assistive technology, and patient counseling. Although she has worked with patients of all ages, she most enjoys working with older adults. Her research and practice are also motivated by personal experiences with hearing loss and dementia within her own family.

Disclosures

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- 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.

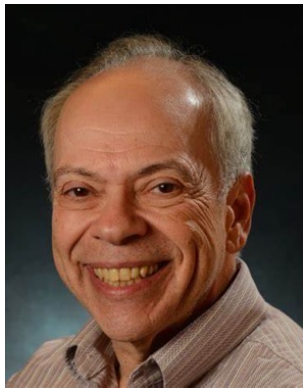
Learning Outcomes

After this course, participants will be able to:

- Describe the contribution of patient factors to speech recognition in noise.
- Describe how signal processing contributes to cumulative signal modification.
- Describe the relationship between listener abilities and the benefits of hearing aid processing.

Acknowledgments

Kathryn Arehart
Univ. of Colorado



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NIDCD
National Institute on Deafness and Other Communication Disorders

Northwestern University
NUCATS
Clinical and Translational Sciences Institute

Topics

- Individual variability and current clinical approaches
- What hearing aids do (and why benefits vary)
- What contributes to individual variability in response to hearing aids?
- A wish for precision hearing care

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Hearing evaluations emphasize audibility

- 100% obtain a pure-tone audiogram
- 98% test speech recognition in quiet
- 30% test speech recognition in noise
- 4% test noise tolerance
- 1% test dead regions

Bundesinnung Hörakustiker (bundesinnung_ha), CC BY-SA 2.0, via Wikimedia Commons

Hearing aids are prescribed (for the individual)

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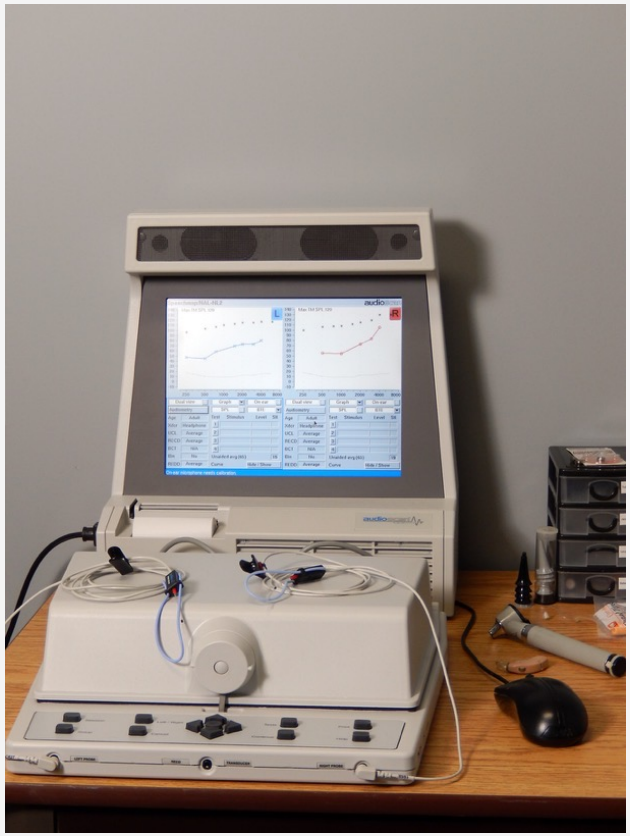
Selection. & Fit

How are hearing aids selected and fit?

- Prescribed gain is well-studied and validated.
- Signal processing is not.
- Signal processing may be changed if patient is dissatisfied. Clinician uses trial and error to find processing parameters that maximize hearing aid benefit - possibly suboptimal



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Although patients (and many audiologists) assume that advanced technology will result in better speech perception for each patient compared to basic technology, there is no evidence to support that view, and some evidence to the contrary

Cox, Johnson & Xu (2014)

We asked audiologists how they chose hearing aids…

FACTOR	AUDIOLOGISTS WHO SAID THAT FACTOR WAS VERY IMPORTANT	AUDIOLOGISTS WHO SAID THAT FACTOR WAS SOMEWHAT IMPORTANT
Patient listening environment	87%	12%
Hearing aid signal processing	81%	19%
Degree of hearing loss	78%	21%
Audiologist experience or comfort with that aid	73%	25%

Anderson et al. (2017)

…and where evidence-based guidance is needed

Initial Fit	Gain	WDRC Time Constants	Noise Suppression	Feedback	Directional Mic	Frequency Lowering
Prescriptive (NAL-NL1/2; DSL v 5/m[i/o])	44%	NA	NA	NA	NA	NA
Manufacturer's "first fit"	40%	80%	58%	69%	67%	40%
My own expertise	14%	18%	38%	25%	30%	36%
Other approach	1%	2%	3%	3%	3%	6%
Do not use at initial fit	0%	0%	2%	3%	0%	17%

Fine Tuning	Gain	WDRC Time Constant	Noise Suppression	Feedback	Directional Mic	Frequency Lowering
I do not use	NA	0%	0%	1%	0%	8%
I do not fine tune	NA	35%	1%	4%	5%	2%
Patient report	98%	48%	96%	81%	86%	82%
Manufacturer's software recommendation	42%	46%	55%	59%	50%	49%
My own expertise	95%	52%	91%	87%	87%	80%
Info: articles, conferences, colleagues	51%	27%	42%	27%	40%	37%
Info: manufacturer	37%	22%	36%	29%	35%	31%
Loudness measures	27%	7%	10%	5%	4%	4%
TEN test for dead regions	3%	1%	1%	1%	1%	0%
Cognitive Assessments/Screenings	3%	3%	3%	0%	1%	3%
Acceptable Noise Level (ANL) Tests	5%	3%	4%	2%	1%	2%

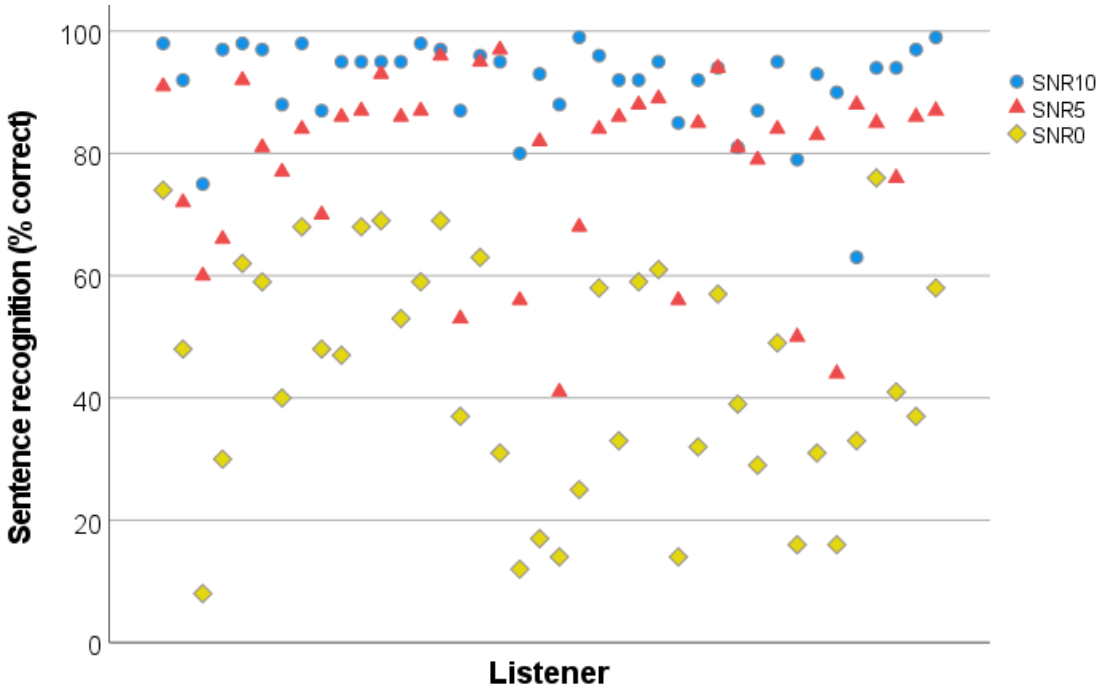
Green: majority (≥ 50%), Blue: some (11-49%), Gray: few (≤10%)

Anderson et al. (2017)

Could we better individualize hearing aids if..

- We understood more about individual variability in use suprathreshold information
- We chose hearing aid signal processing according to individual abilities
- We considered the interaction between hearing aid processing and listener abilities (in realistic listening environments)

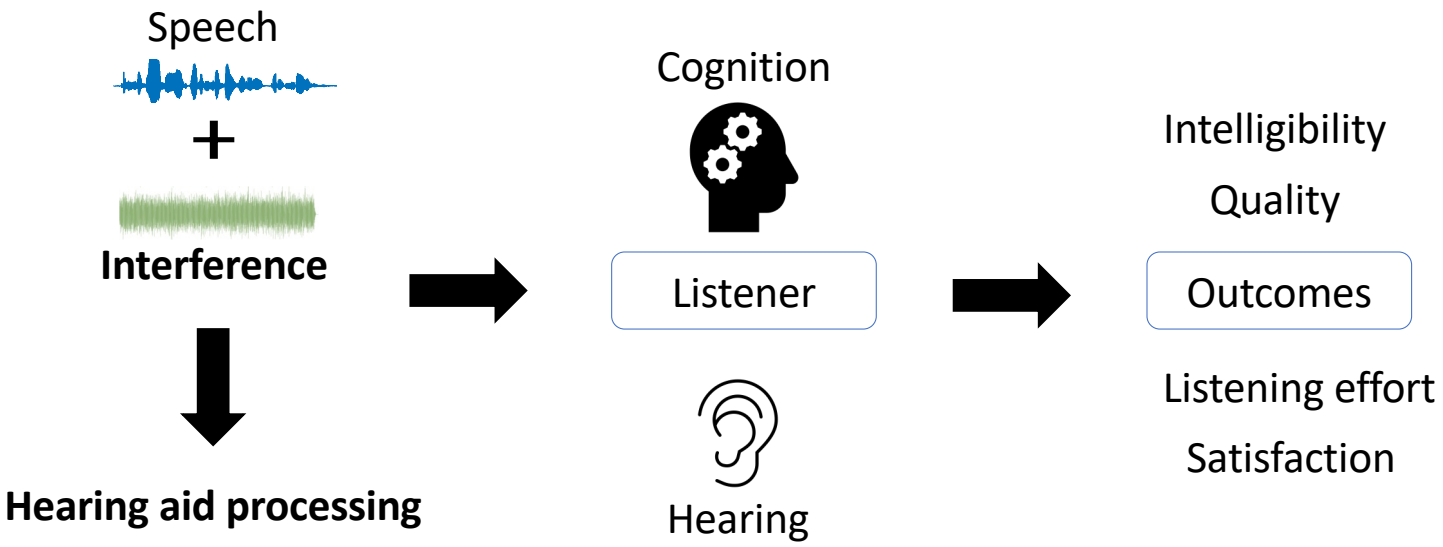
Large variability in performance with hearing aids



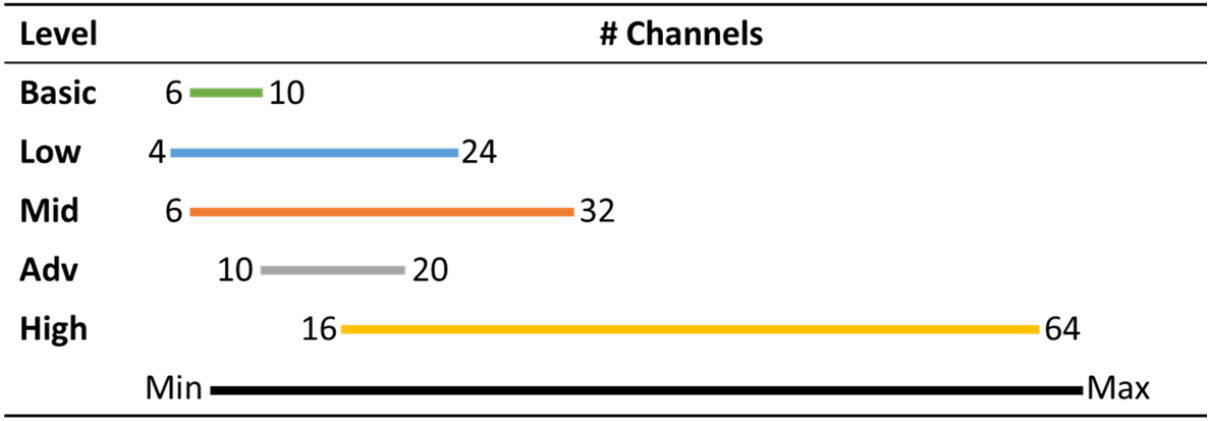
Aided speech recognition varies even among adults with similar age, audiogram, hearing aid technology and match-to-target

Souza et al., 2019

Conceptual framework



Hearing aid signal processing: spectral



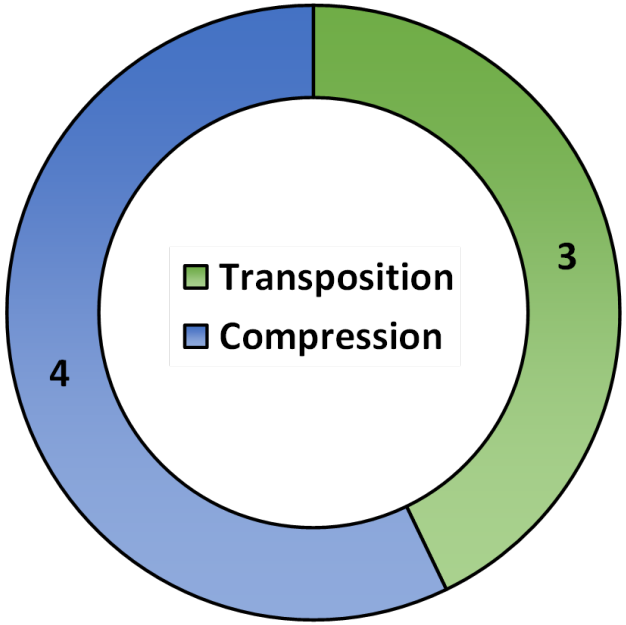
More compression channels can more closely control hearing aid response across frequency, but may reduce the spectral peak-to-valley relationship (spectral contrast) for some sounds

Rallapalli et al. (2018) surveyed 137 products across 7 manufacturers

Quiz Hint

Q1

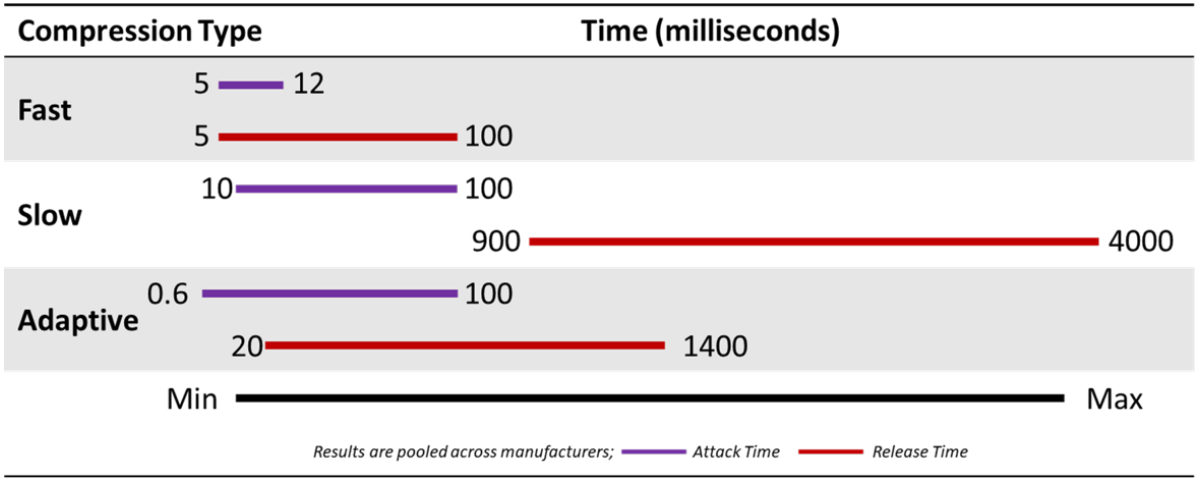
Hearing aid signal processing: spectral



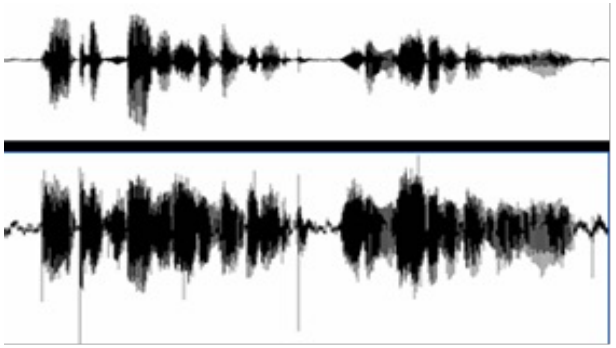
Frequency lowering may improve audibility of high-frequency speech cues, but also alters spectral cues in the processing region

Rallapalli et al. (2018) surveyed 137 products across 7 manufacturers

Hearing aid signal processing: temporal

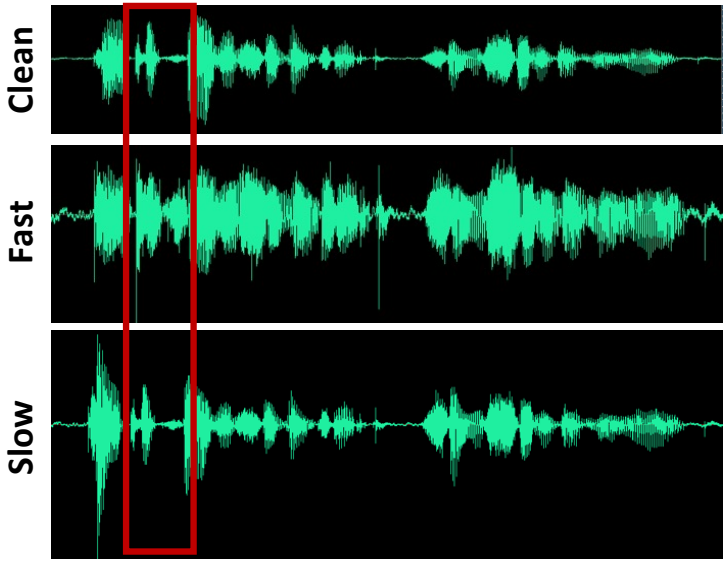


Fast-acting WDRC may improve audibility of low-intensity speech cues, but also alters temporal cues



Rallapalli et al. (2018) surveyed 137 products across 7 manufacturers

Wide dynamic range compression (WDRC)



Goal

- Improve audibility of soft sounds and provide comfort for loud sounds
- Apply level-dependent & time-varying gain

Tradeoff

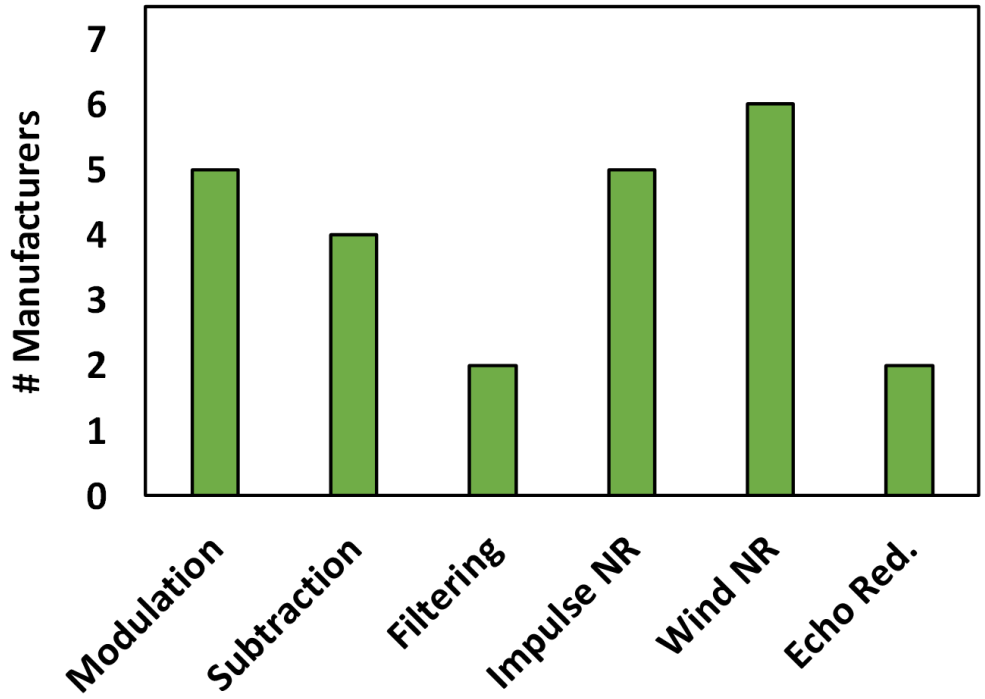
- Fast compression (<200-250 ms): better audibility of brief, low-intensity phonemes, more temporal distortion
- Slow compression (> 200-250 ms): less audibility, maintains intensity variations across phonemes, less temporal distortion

Jenstad & Souza (2005)

Quiz Hint

Q2

Hearing aid signal processing: DNR



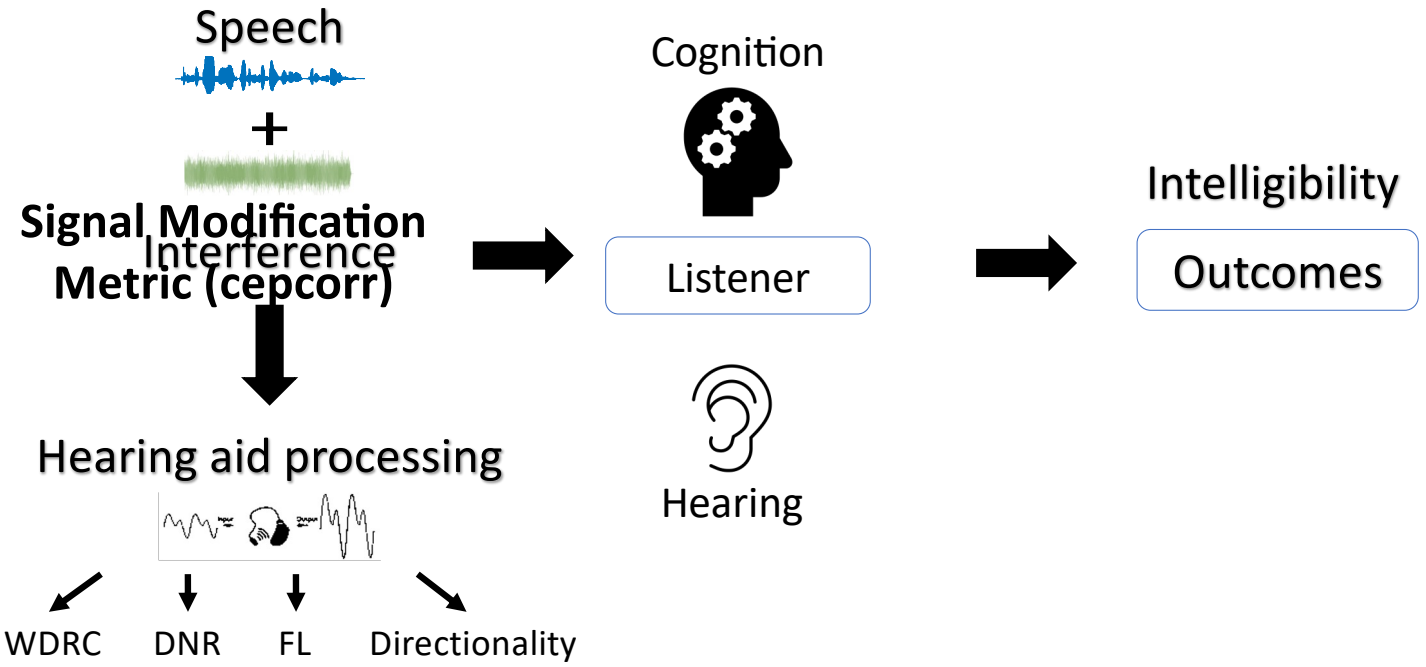
Digital noise reduction can improve signal-to-noise ratio, but errors in classification may remove speech components or retain noise components

Rallapalli et al. (2018) surveyed 137 products across 7 manufacturers. Max gain reduction range 3-24 dB. Max gain enhancement range 0-6 dB.

Hearing aid signal processing tradeoffs

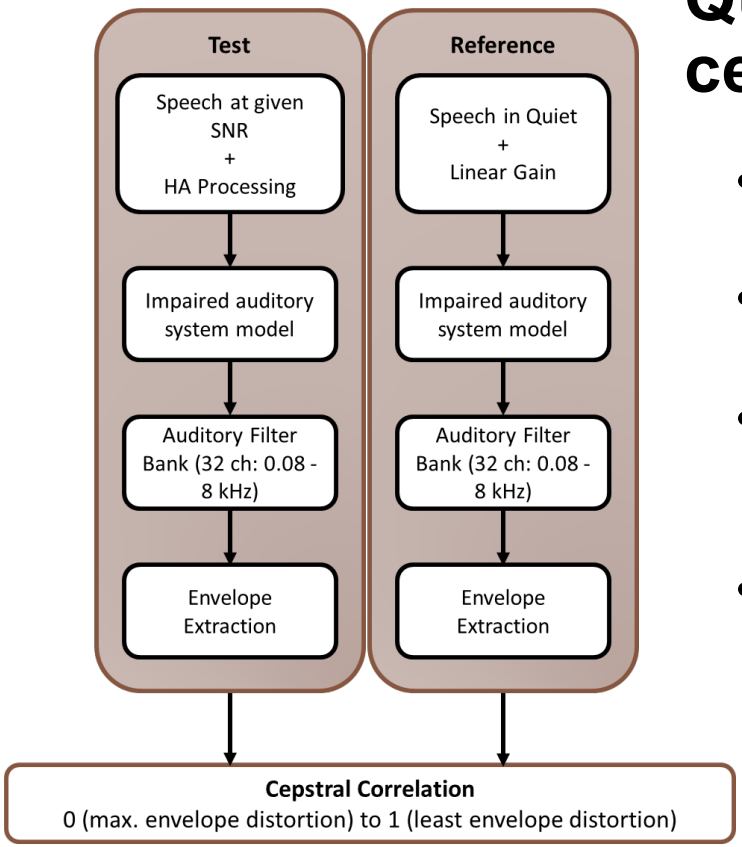
Signal Processing	Enhancement	Distortion
Wide dynamic range compression	Audibility	Temporal envelope
Digital noise reduction	Noise reduction	Incidental removal of speech information
Frequency lowering	High-frequency speech audibility	Vowel formants, overlap in some fricative spectra
Mic. directionality	Signal to noise	Spatial cues

Overall signal modification view



Quiz Hint

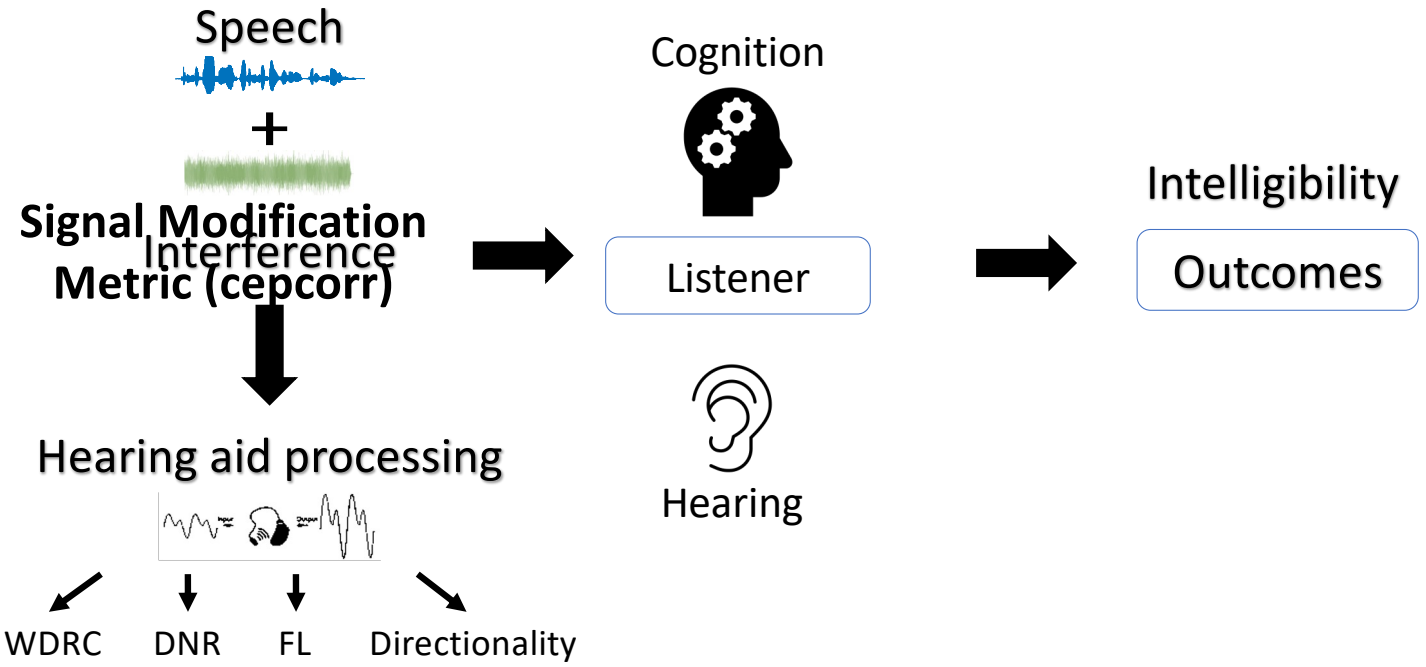
Q5



Quantifying signal modification - cepstral correlation

- Acoustic metric to capture cumulative hearing aid processing
- Based on the envelope of speech received by the listener
- Incorporates speech level, noise level, hearing thresholds (audibility), suprathreshold distortions
- Background noise and/or stronger hearing aid processing results in more speech envelope distortion

Are some listeners more susceptible to distortion?



Quiz Hint

Q4

Working memory plays a role in speech recognition

Ease of Language Understanding (ELU) model

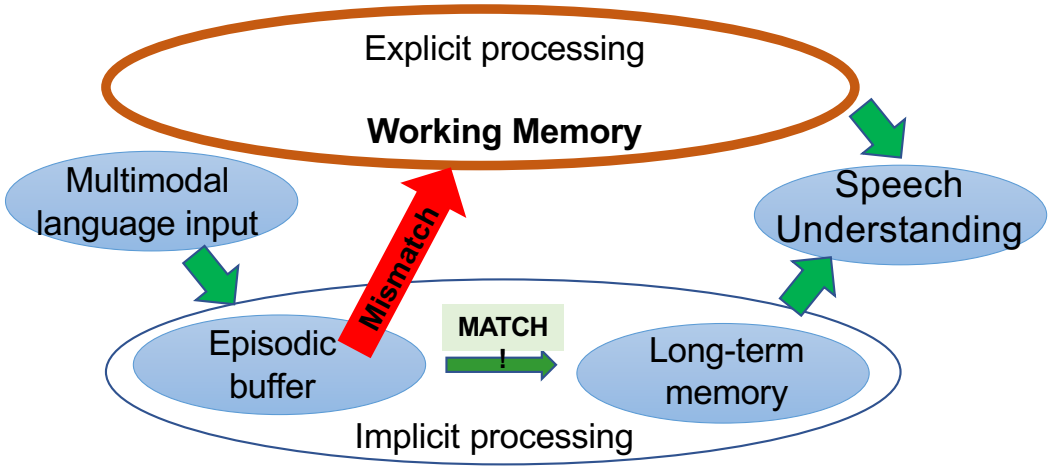


Image credit: Mark Warner, CC BY-SA 2.0, via Wikimedia Commons

Ronnberg et al., 2008, 2013

Measures	Test	Format	Availability
Working memory	Reading Span Test (RST)	Executable file. Visual (reading)	ehon@oticon.com

Sentences appear in segments

After each sentence, does it make sense? (processing)

After a block of sentences, prompted to recall first or last words

Overview of methods

Study	Hearing aid processing	Sound location	Signal to noise (dB)	Processing
Arehart et al. (2012)	Frequency compression	Earphones	-10 to +10	Simulated
Souza et al. (2015)	WDRC + frequency compression	Earphones	0, +10	Simulated
Arehart et al. (2015)	Digital noise reduction	Earphones	-18 to +12	Simulated
Souza et al. (2019)	WDRC + frequency compression	Speech and noise from front	0, +5, +10	Wearable
Rallapalli et al. (2020)	WDRC + directional	Speech from front in surrounding noise	0, +5, +10	Wearable

A tale of two patients

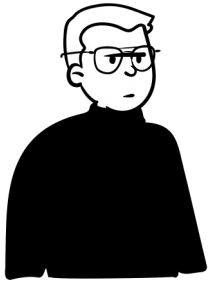
Lydia
72 years old
Mild-moderate sloping hearing loss
High working memory, 50% reading span (1 SD above mean for her age)

John
72 years old
Mild-moderate sloping hearing loss
Low working memory, 30% reading span (1 SD below mean for his age)

Should we adjust hearing aid processing for cognitive ability?

- Working memory determined listeners' responses to sentences presented in babble and amplified with frequency compression
- As signal distortion increased (more aggressive FC), listeners with low working memory were more impacted by signal distortions than listeners with high working memory
- Working memory (controlling for age and hearing loss) accounted for 29% of the variance in intelligibility

Lydia
With mild FC (1.5:1 CR) speech recognition is 100%
With moderate FC to improve consonant audibility (3:1 CR) speech recognition is 96%



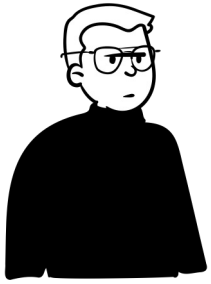
John
With mild FC (1.5:1 CR) speech recognition is 96%
With moderate FC (3:1 CR) speech recognition is 84%

Arehart et al. (2012)	**Frequency compression**	**Earphones**	**-10 to +10**	**Simulated**

Should we adjust hearing aid processing for cognitive ability?

- Listeners with low working memory performed more poorly for a given amount of signal modification (FC x WDRC) compared to individuals with high working memory capacity.
- As signal modification increased, scores for high working memory listeners decreased at a slower rate compared to scores for low working memory listeners
- Working memory (controlling for age and hearing loss) accounted for 33% of the variance in intelligibility

Lydia
With mild FC x slow WDRC, sentence recognition in noise is 90%
With moderate FC x fast WDRC, sentence recognition is 55%



John
With mild FC x slow WDRC, sentence recognition in noise is 90%
With moderate FC x fast WDRC, sentence recognition is 45%

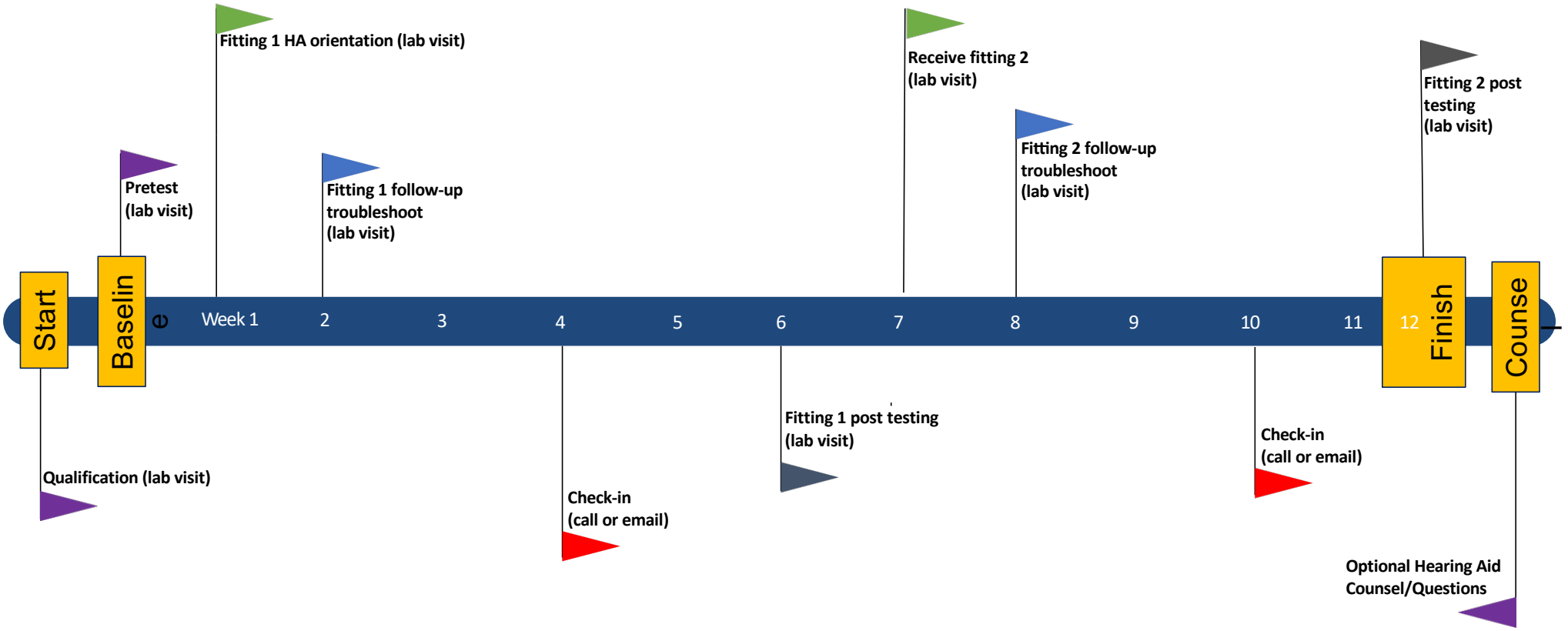
Souza et al. (2015)	**WDRC + FC**	**Earphones**	**0 , +10**	**Simulated**

Aided recognition depends on audiogram + working memory + age

- Individuals with poorer WM are disadvantaged with:
  - Fast-acting WDRC
  - More background noise (or lower SNRs)
  - When other signal processing is combined with WDRC (e.g., frequency compression)

But:

- **Simulated rather than wearable hearing aids**
- **Not matched to a clinical hearing aid target**
- **Patient was not acclimatized to the processing**

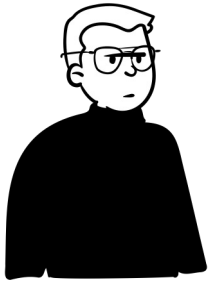


Souza et al. (2019)	**WDRC + FC**	**Speech + noise front**	**0 , +5, +10**	**Wearable**

Should we adjust hearing aid processing for cognitive ability?

- Listeners with higher working memory benefit more from improved signal fidelity
  - With well-fit wearable aids
  - After acclimatization
- Compared to previous studies, there was very little effect of amount of hearing loss (good target match, no listeners with severe loss)
- Working memory (controlling for age and hearing loss) accounted for 33% of the variance in intelligibility

Lydia
With no FC x slow WDRC, sentence recognition in noise is 90%
With moderate FC x fast WDRC, sentence recognition is 80%
Improved ~10% with low modification



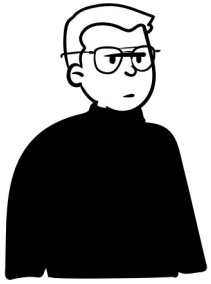
John
With no FC x slow WDRC, sentence recognition in noise is 80%
With moderate FC x fast WDRC, sentence recognition is 75%
Improved ~5% with low modification

Souza et al. (2019)	**WDRC + FC**	**Speech + noise front**	**0 , +5, +10**	**Wearable**

Should we adjust hearing aid processing for cognitive ability?

- Listeners with higher working memory benefit more from improved signal fidelity
  - With well-fit directional wearable aids
  - With beamforming aids
- Better noise management using directionality improves the signal, reducing the consequence of low working memory
- Significant interaction between working memory and distortion, suggesting that individual working memory affects sensitivity to envelope distortions (from noise, hearing aid processing)

Lydia
With beam x slow WDRC, sentence recognition in noise is 80%
With omni x fast WDRC, sentence recognition is 20%
Improved ~60% with low modification



John
With beam x slow WDRC, sentence recognition in noise is 65%
With omni x fast WDRC, sentence recognition is 20%
Improved ~45% with low modification

Rallapalli et al. (2020, 2024)	**WDRC directional**	**Speech + noise surround**	**0 , +5, +10**	**Wearable**

Summary

Study	Hearing aid processing	Sound location	Signal to noise (dB)	Processing
Arehart et al. (2012)	Frequency compression	Earphones	-10 to +10	Simulated
Souza et al. (2015)	WDRC + frequency compression	Earphones	0, +10	Simulated
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Rallapalli et al. (2020)	WDRC + directional	Speech from front in surrounding noise	0, +5, +10	Wearable

Susceptibility to signal distortions (combined effects of noise, hearing aid processing) in older adults depends on working memory ability

Quiz Hint

Q3

What do we know?

- Individual variability in aided speech recognition is affected by age and working memory ability
- Cumulative signal modification (cepcor) is a strong predictor of these relationships
  - With single or combined hearing aid processing
  - When directional processing is used
  - In simulations and wearable hearing aids
  - Under clinically realistic conditions
  - In clinical practice (early data from our lab)
    - Audiologist-fit signal processing choices
    - Wider range of patient abilities
    - Wider range of hearing aids and processing

Can we use these ideas to improve clinical care?

- Precision testing beyond the audiogram
- Intentional selection of hearing aid processing
- Patient counseling that acknowledges multiple patient (and listening environment) factors

Can we use these ideas to improve clinical care?

- Some signs of this, including:
  - Practice innovations to individualize diagnosis and hearing aid selection (Entheos)
  - Match processing to measures of hearing etiology or genetic profile
  - Integrated suprathreshold tests (Audible Contrast threshold)
  - Auditory profile-based hearing aid fitting
  - “Clinic-ready” working memory measures

Measures	Test	Format	Availability
Working memory	Reading Span Test (RST)	Executable file. Visual (reading)	ehon@oticon.com

Sentences appear in segments

After each sentence, does it make sense? (processing)

After a block of sentences, prompted to recall first or last words

Measures	Test	Format	Availability
Working memory	Word Auditory Recognition & Recall Measure (WARRM)	Auditory, American English sentences	sherri.smith@duke.edu

100 monosyllabic words presented in recall set sizes of 2, 3, 4, 5, and 6 items

1. Repeat
2. Process: after each word, is first letter 1st or 2nd half of alphabet?
3. Recall

You will cite **flip** [letter judgment]
You will cite **boost** [letter judgment]

You will cite **say** [letter judgment]

Tone prompt [recall]

Measures	Test	Format	Availability
Working memory	Repeat Recall Test (RRT)	Auditory, American English sentences	https://www.orca-us.info/

24 sentences in noise presented in recall set sizes of 6 sentences. Varies in noise level and context

1. Repeat
2. Recall
3. Rate listening effort
4. Rate noise tolerance

She **studied** the **film** at her **story**
His **memories** told him an **aunt role**
Five books auditioned for the **screen**
The **funny** was **projected** on the **journal**
Write your **bedtime** in the **movie**
He **watched** the **happy actor's library**

Prompt [recall]

A wish for precision hearing (aid) care

- Evaluation that tests relevant listener abilities
  - We have (some of) the tools
  - Efficient and integrated in clinical care
- Individualized processing technology
  - Self-fit?
  - AI-based?
  - Audiologist knowledge and intention

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Understanding Individual Variability Among Older Adults with Hearing Loss, in partnership with American Auditory Society

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