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From Ears to Brain: Physiologic and Cognitive Effects of Short-Term Hearing Aid Use in partnership with the American Academy of Audiology

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Disclosures

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- 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 changes in the acceptance of speech and noise levels after hearing aid use.
- List 3 relationships found across test results measures.
- Describe how hearing aid use impacts auditory gating.

Funding & Support

- Hearing Industry Research Consortium
- Clinical audiologists:
 - Katie Alsop, Cassie Thomas, Amanda Labue, & Amy Zahn
- Graduate student research assistants:
 - Molly Lohrey, Adelin Eason, Cassie Nedrud, Kailee Cairo, Graciela Olvera, Rudi Klarmann, Brittani Brooks, Brianna Cumiskey, Cassian Kruse, Danielle Johnson, Alyssa Laroi, & Meg Musselman

Existing Research



- Growing evidence showing pure-tone hearing thresholds relate to **cognitive decline** (Conceição Santos de Oliveira, 2023; Fu et al., 2022; Lau et al., 2022; Livingston et al., 2024; Loughrey et al., 2018; Yu et al. 2024)
 - Each 10-dB increase in hearing loss associated with a 16% increase in dementia risk.
- Lancet Report (2004) lists hearing loss as of the 14 modifiable risk factors for future dementia (Livingston et al., 2024)

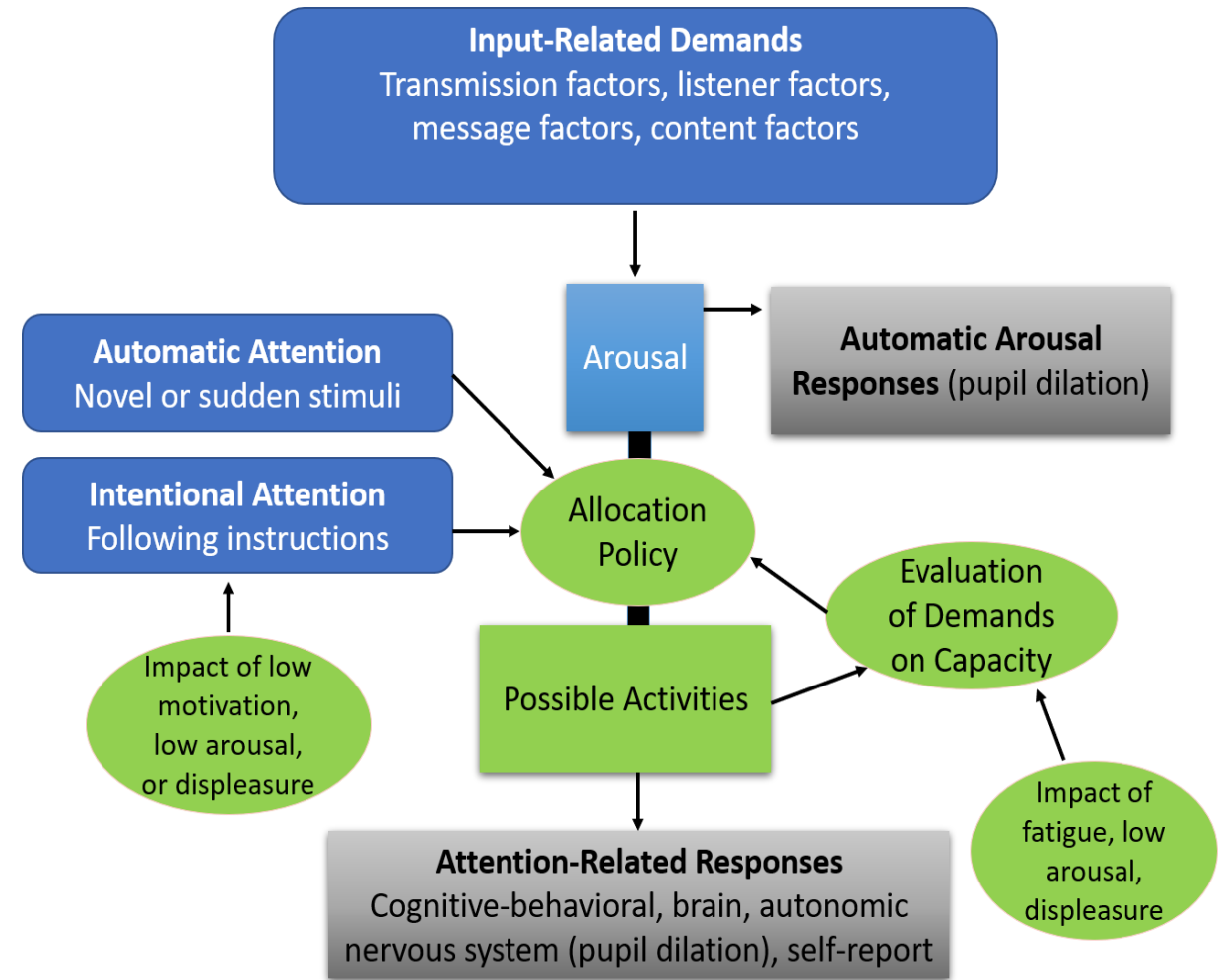
Existing Research



- Mixed findings regarding cognitive enhancement/maintenance with hearing aid (HA) use (e.g., Maharani et al., 2018; Sanders et al., 2021; Sarant et al., 2024; Yang et al., 2022; Yeo et al., 2022)
 - Maharani et al. (2018) and Sarant et al. (2024): Slower decline in immediate and delayed word recall (episodic memory) and more stable cognitive performance in HA versus non-HA users
 - Lin et al. (2023) report a 48% reduction in cognitive decline in one group of HA users who had lower baseline cognition scores and elevated risk for cognitive decline
 - However, the second group with higher baseline cognitive performance did not show a reduction in cognitive decline

Framework for Understanding Effortful Listening (FUEL)

- We believe the complex connection between cognition and HA use may be examined within the FUEL model
- Listeners overcome listening demands by allocating attentional resources with mental effort, which is influenced by cognition, motivation, emotion, and the perceived importance of success



Our Recent Research



Study Goals

Aim 1

- Examine potential changes in subjective listening abilities, acceptance of noise, cognition, emotion, and physiological measures after using bilateral HAs

Aim 2

- Explore relationships among test measures and the impact of hearing aid use on the cognitive, motivation, and emotion measures after HA use

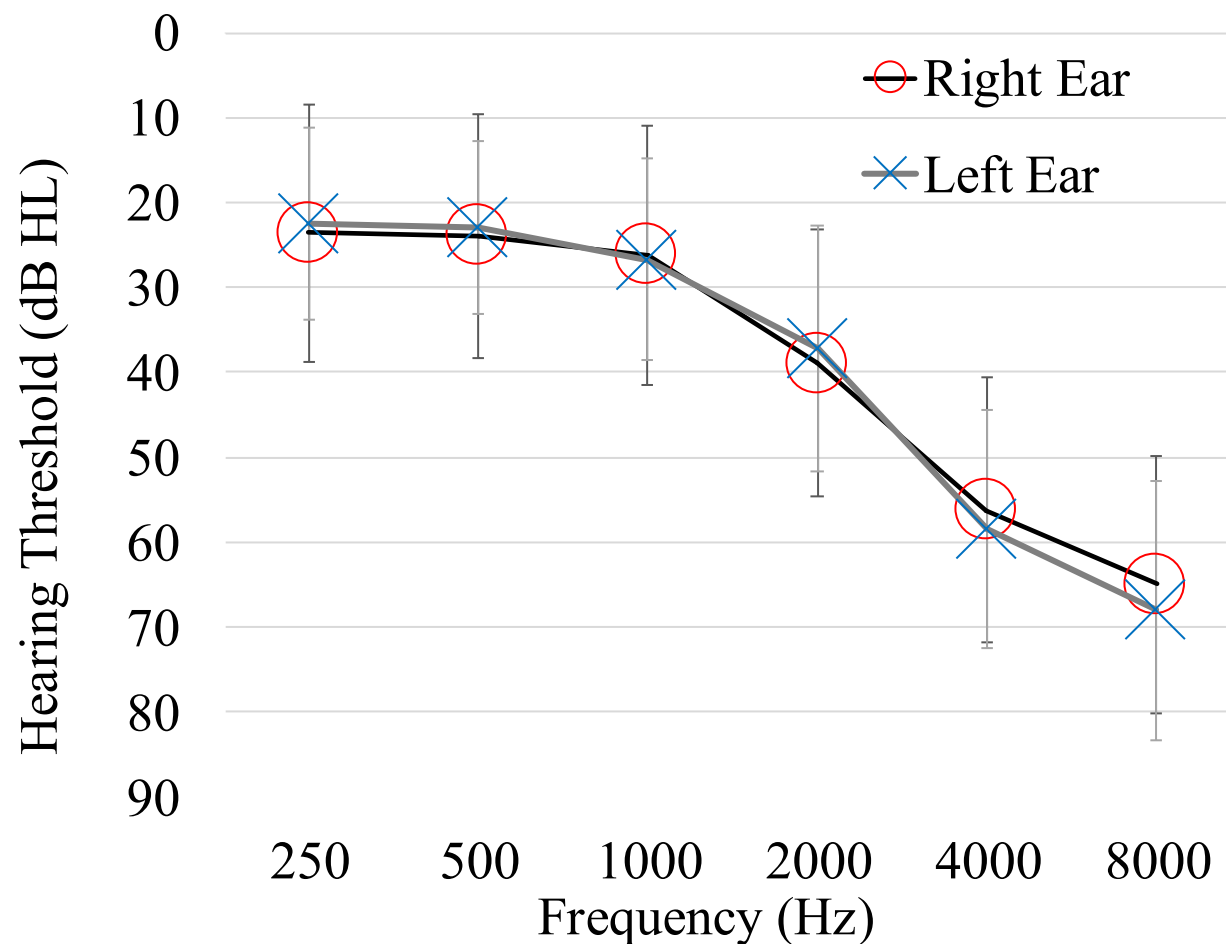
Study Timeline & Procedures

1. Audiological assessment in clinic; order and pay for bilateral hearing aids
2. Complete Study Session #1
3. Attended follow-up/fine-tuning appointment in clinic 2-3 weeks after fitting
4. Wear hearing aids for 2 months
5. Complete Study Session #2
6. Wear hearing aids for 2 more months
7. Complete Study Session #3

Participant Profiles

Subject Characteristics (N=29)

- Average age: 70 years (SD 10.6)
- 18 identified as male; 11 female
- 19 report tinnitus; 13 noise exposure; and 10 occasional vestibular issues
- No experience with hearing aids; fit with Phonak(n=11), Oticon (17), or Widex (n=1) HAs
- Session 2 Data Logging: Average of **10.1 hours/day** (SD=3.7)
- Session 3 Data Logging: Average of **9.8 hour/day** (SD=3.9)



Test Measures

Abbreviated Profile of Hearing Aid Benefit (APHAB)	Treatment Self-Regulation Questionnaire (TSRQ)
Acceptable noise level	
NIH Toolbox – Cognition & Emotion Battery	
Auditory sensory gating to speech and non-speech stimuli	

Results



✓ Results

APHAB

1. When I am in a crowded grocery store, talking with the cashier, I can follow the conversation.

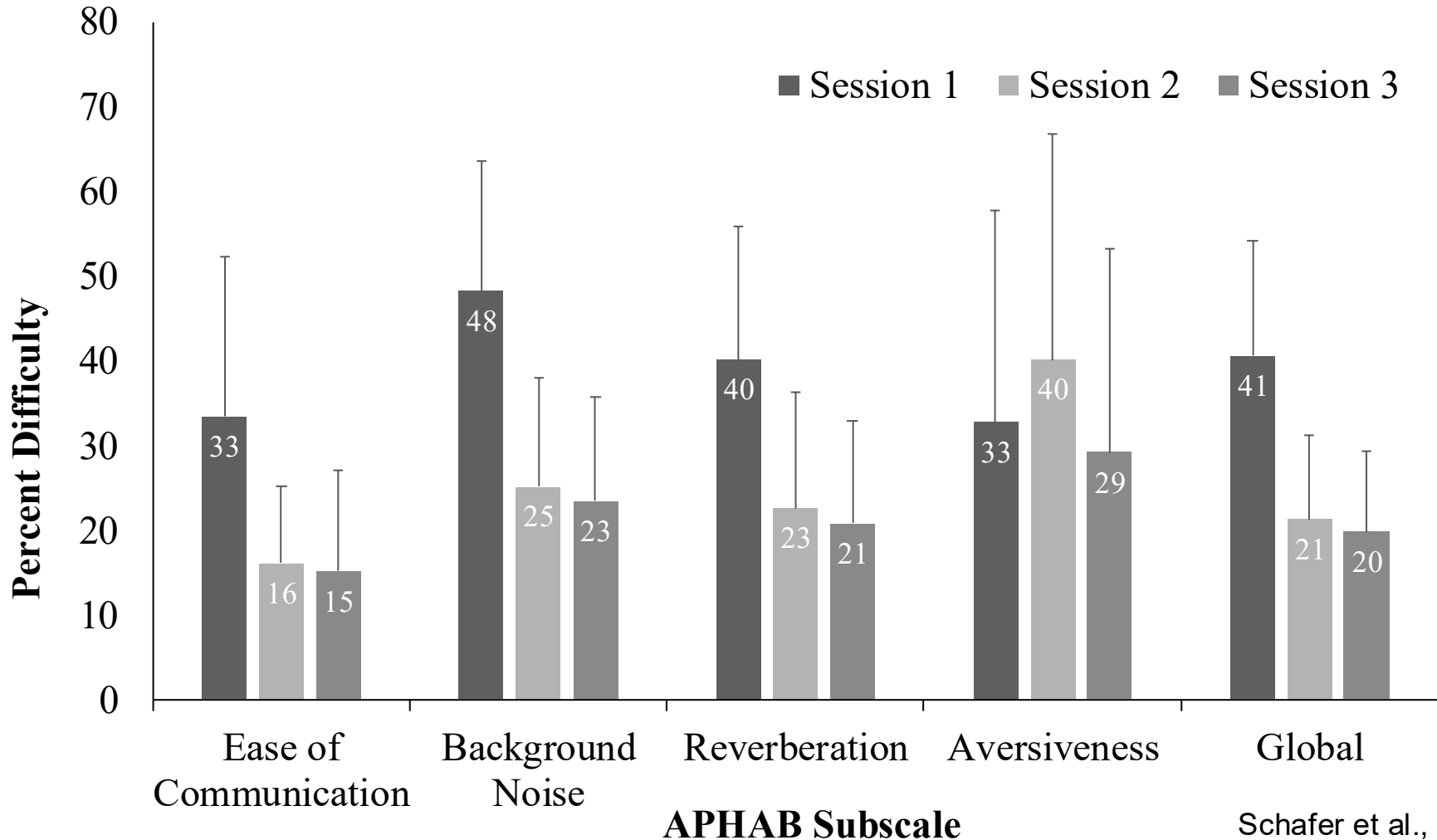
Without Hearing Aid

With Hearing Aid

A B C D E F G

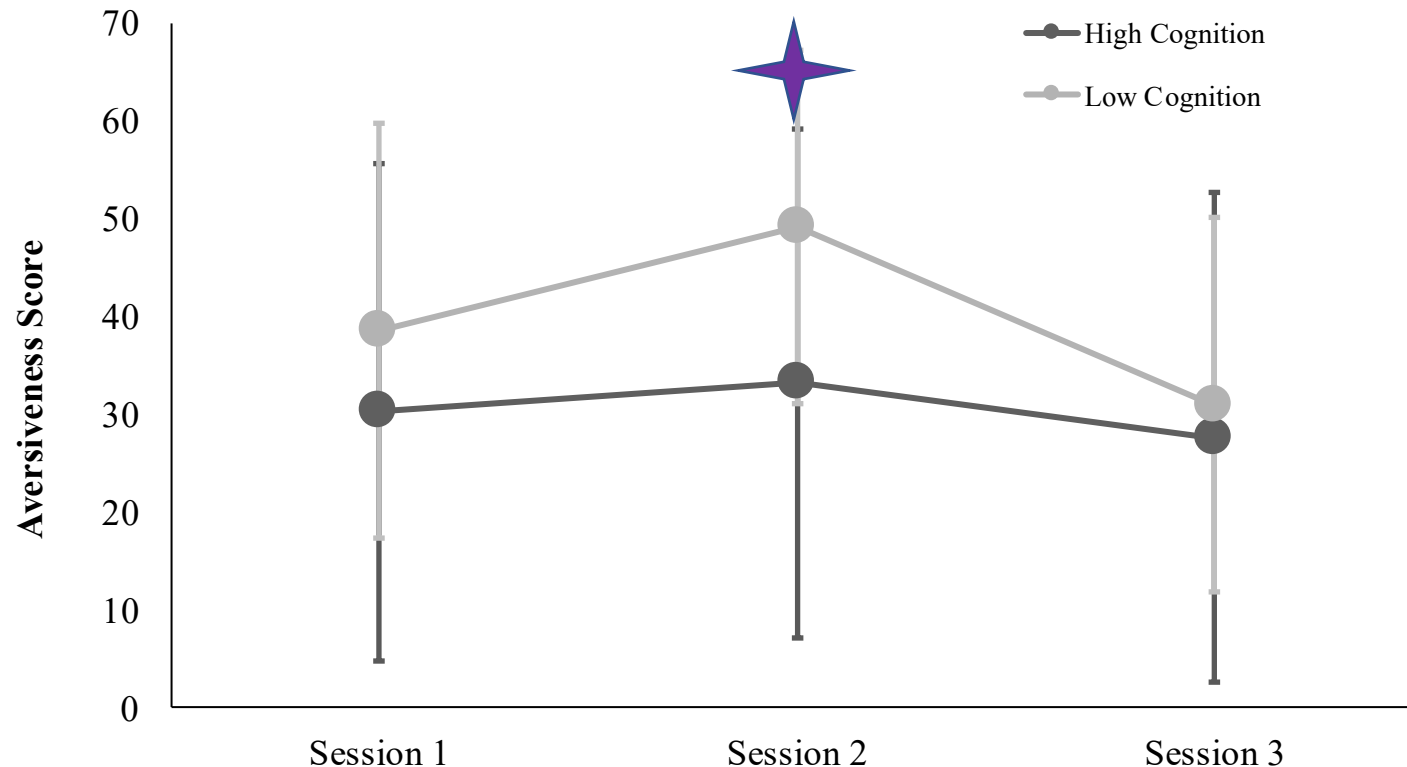
A B C D E F G

- A Always (99%)
- B Almost Always (87%)
- C Generally (75%)
- D Half-the-time (50%)
- E Occasionally (25%)
- F Seldom (12%)
- G Never (1%)



- Significantly less listening difficulty in S2 and S3 vs. S1:
 - Ease of communication
 - Background noise
 - Reverberation
 - Global
- Significantly lower Aversiveness in S3 vs S2

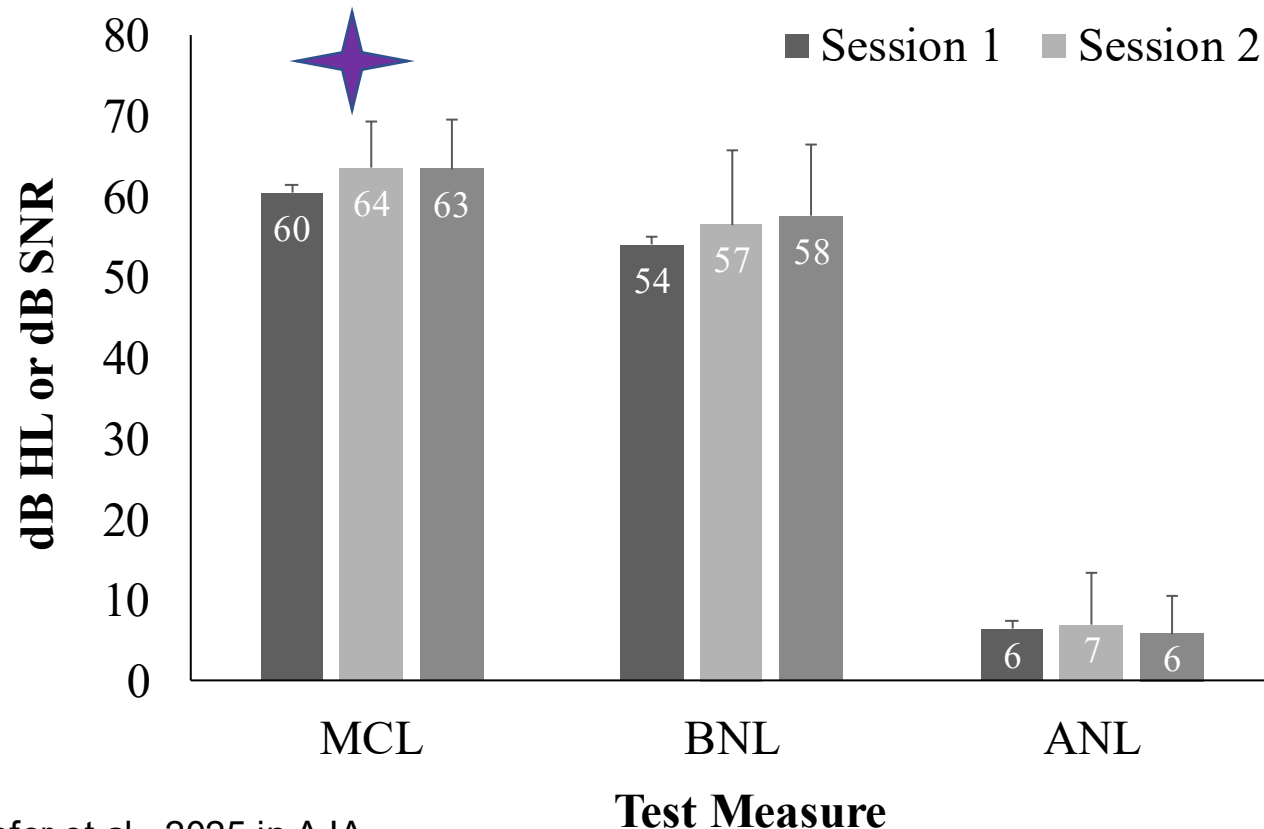
APHAB Aversiveness



- Decrease in aversiveness occurred in both cognition groups, but was more prominent in those with lower baseline cognition

Acceptable Noise Level (ANL)

Most Comfortable Level (MCL) – Background Noise Level (BNL) = ANL

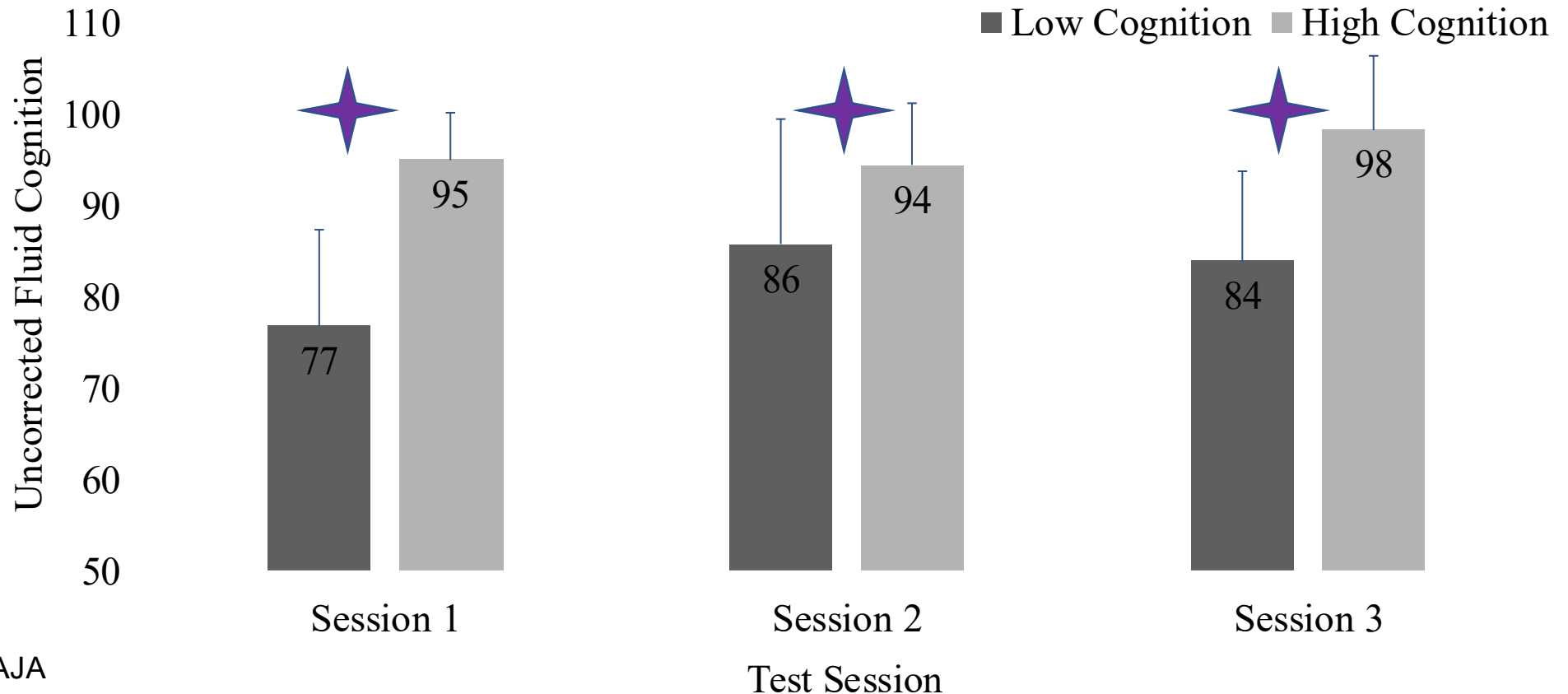


- MCL: Sessions 2 and 3 > 1
- BNL: Increase approached significance ($p=.07$)
- ANL: No differences

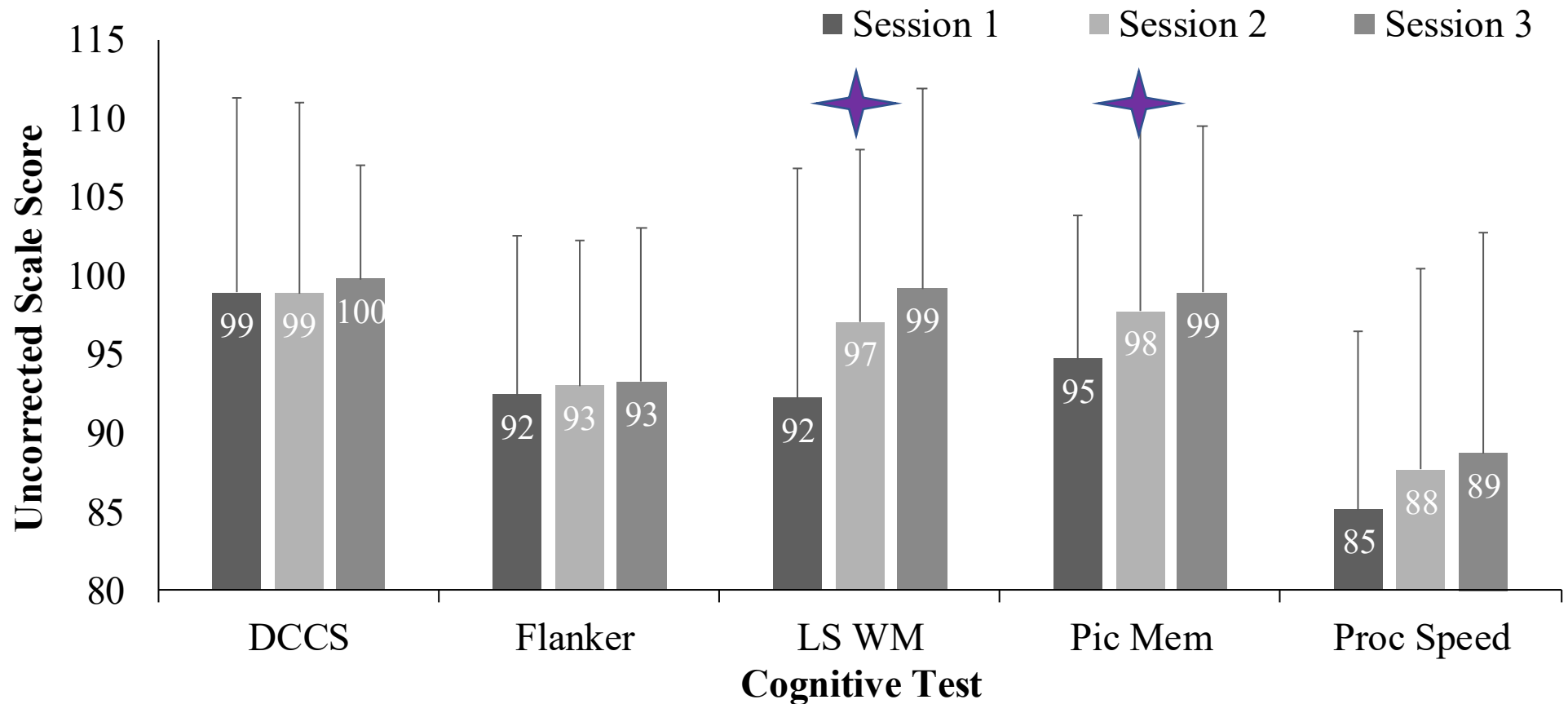
NIH Toolbox Tests & Fluid Cognition Composite Score

Dimensional Change Card Sort	Sort visual stimuli based on color or shape and flexibly switch between dimensions
Flanker Inhibitory Control and Attention	Selectively attend to visual targets and suppress distracting information
List Sorting Working Memory	Recall, sort, and sequence of visual and auditory stimuli
Picture Sequence Memory	Recall increasingly lengthy series of illustrated objects and activities with corresponding audio
Pattern Comparison Processing Speed	Measures processing speed by asking participants to discern whether two simple pictures are the same or different.

NIH Toolbox: Fluid Cognition Grouped by Baseline Cognition



NIH Toolbox: Individual Cognitive Tests



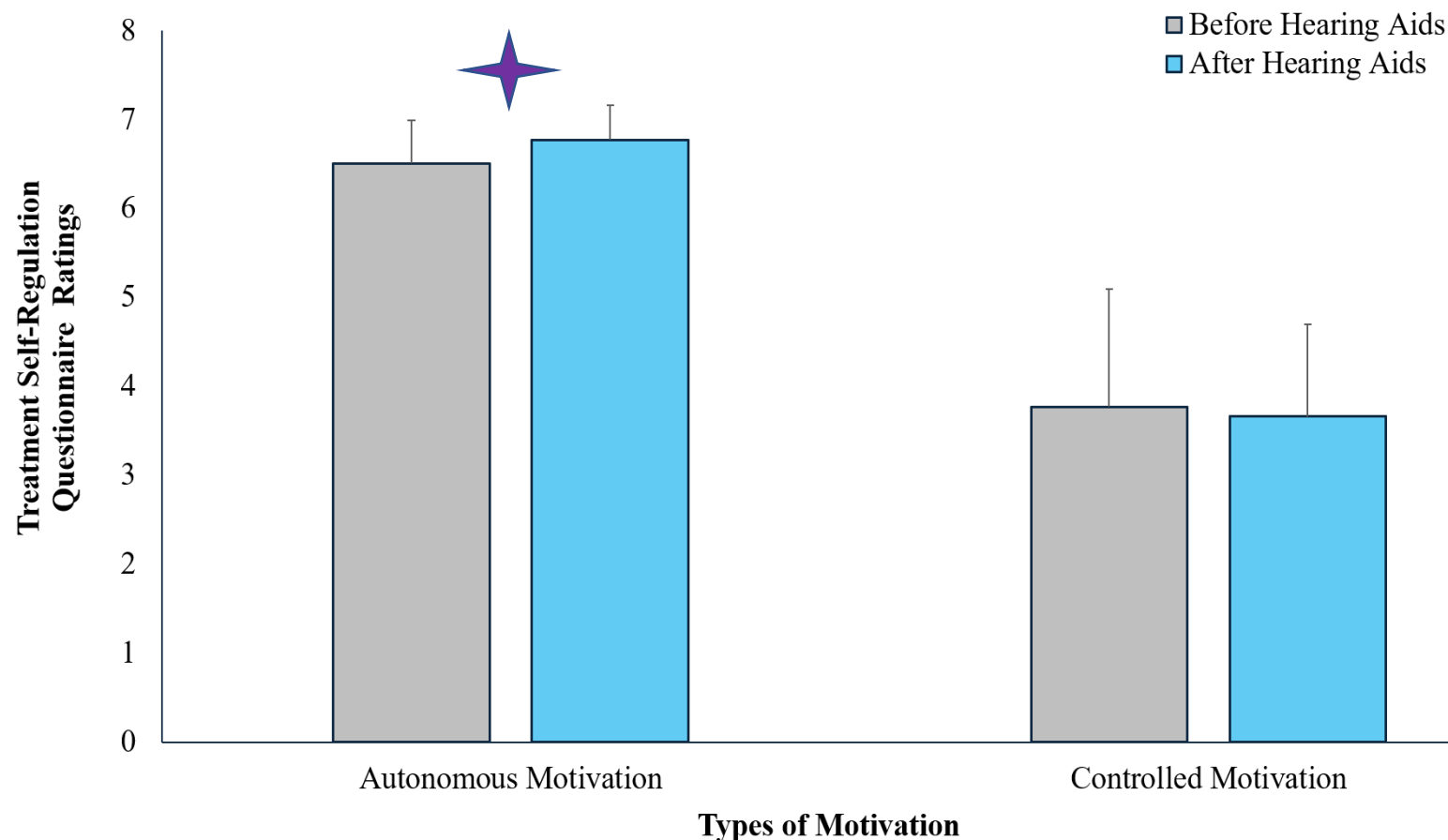
NIH Toolbox Emotion Tests

Psychological Well-Being	Positive Affect Survey	Happiness, joy, serenity, peace
	General Life Satisfaction Survey	Global feelings and attitudes about life
Social Relationships	Emotional Support Survey	Have empathy, caring, & understanding in social network
	Loneliness Survey	Perceived level of loneliness
Stress and Self-Efficacy	Perceived Stress Survey	Perceived experiences and coping
	Self-Efficacy Survey	Ability to manage functioning and have control over meaningful events
Negative Affect	Fear-Affect Survey	Perceived fear and anxious misery
	Fear-Somatic Arousal Survey	Somatic symptoms related to arousal
	Sadness Survey	Perceived poor mood; cognitive indicators of depression

- No significant differences across test sessions for any of the emotion measures
- However, positive affect ($p = 0.09$) and self-efficacy ($= 0.09$) approached significance

TSRQ Motivation

- **Autonomous:**
 - Doing something because it is personally meaningful or aligns with your values and goals
- **Controlled:**
 - Doing something because of external pressure, rewards, or to avoid guilt/shame



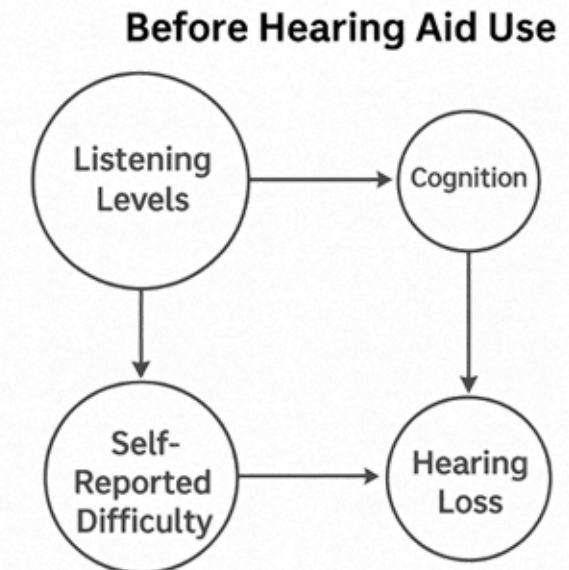
Principal Component Analysis

- --PCA transforms a set of correlated variables into a smaller set of principal components.
- --More simply groups performance data and patient variables into meaningful constructs
- --Does not imply causation, but identify notable associations among variables



PCA #1: APHAB, ANL, PTA, Fluid Cognition, HA Use

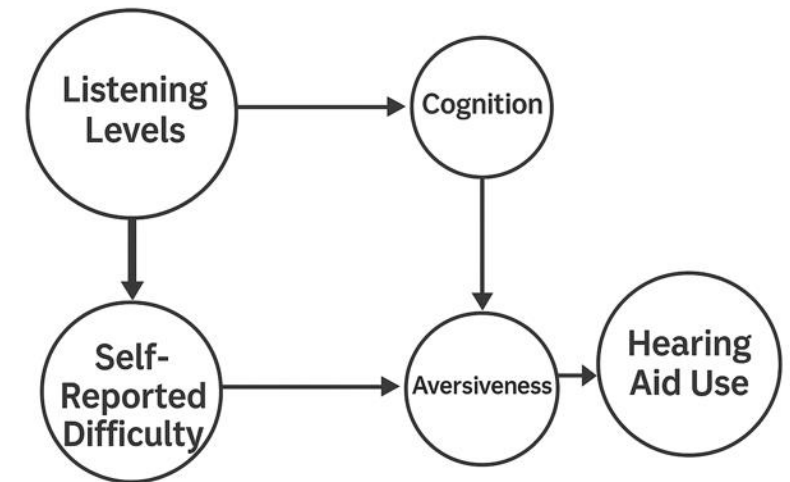
- Before hearing aid use:
 - Preferred listening levels (MCL, BNL) clustered together, separate from self-reported difficulty and aversiveness
 - Self-perceived hearing difficulty was driven primarily by hearing loss severity (PTA) and noise tolerance (ANL)
 - Cognition loaded with future hearing aid use



PCA #1: APHAB, ANL, PTA, Fluid Cognition, HA Use

- After four months of hearing aid use:
 - Preferred listening levels still clustered
 - Self-reported difficulty is now clustered with aversiveness, not audiometric loss
 - Cognition shifted to align with actual hearing aid use, not just future intentions

After Four Months of Hearing Aid Use



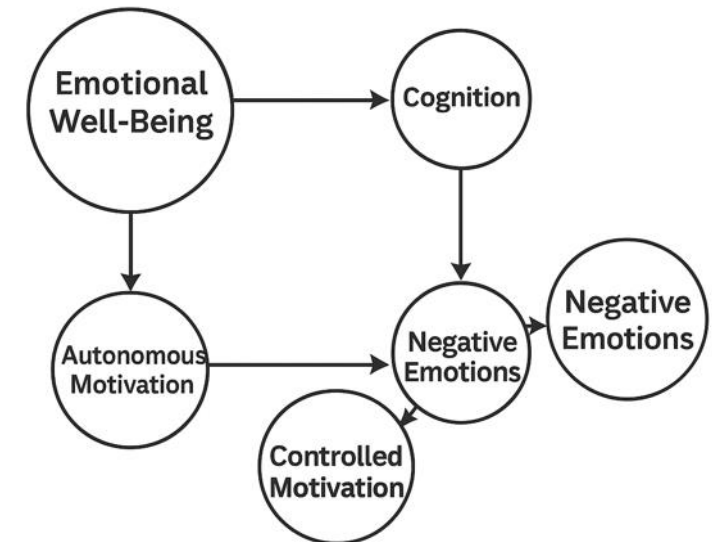
PCA #1: Clinical Takeaways

- At baseline, ANL predicted listening difficulties in real-life situations on the APHAB
 - ANL is easy and quick to incorporate
- Baseline cognition predicted actual HA use
 - Possibly better decision-making about HA use
 - Highlights the importance of HA use prior to cognitive decline
- After 4 months, HA use aligns with higher cognition
 - Hearing aids support cognition, particularly working memory
- Aversiveness on the APHAB predicted future HA use
 - Consider different compression settings or additional technologies (e.g., remote microphones) to address sound aversion

PCA #2: Emotion, Motivation, Working Memory, & HA Use

- After 4 months of HA use:
 - Emotional well-being forms a dominant, unified dimension (all positive & all negative load)
 - Autonomous motivation clusters with working memory, emotional support, & life satisfaction
 - Sustained hearing aid use relates to working memory as well as lower fear and sadness
 - Social support improves quality of life, but does not automatically translate into greater hearing aid use.

After Four Months of Hearing Aid Use



PCA #2: Clinical Takeaways

- **When counseling patients about the benefits of hearing aids, consistent use will result in:**
 - Higher working memory
 - Self-driven commitment to wearing HAs
 - Auditory experiences
 - Reduced feelings of fear and sadness
 - Alignment of positive emotions, increased quality of life, and decreased negative emotions
- **Autonomous motivation is important** - Doing something because it aligns with your values/goals
 - Associated with higher working memory, general life satisfaction, and emotional support

Behavioral Conclusions

- HA use increases working memory performance
- Baseline fluid cognition and aversiveness may impact actual HA use
- HA use may align positive emotions, increase quality of life, and decrease negative emotions
- Autonomous motivation may increase with HA use and is associated with higher working memory and life satisfaction

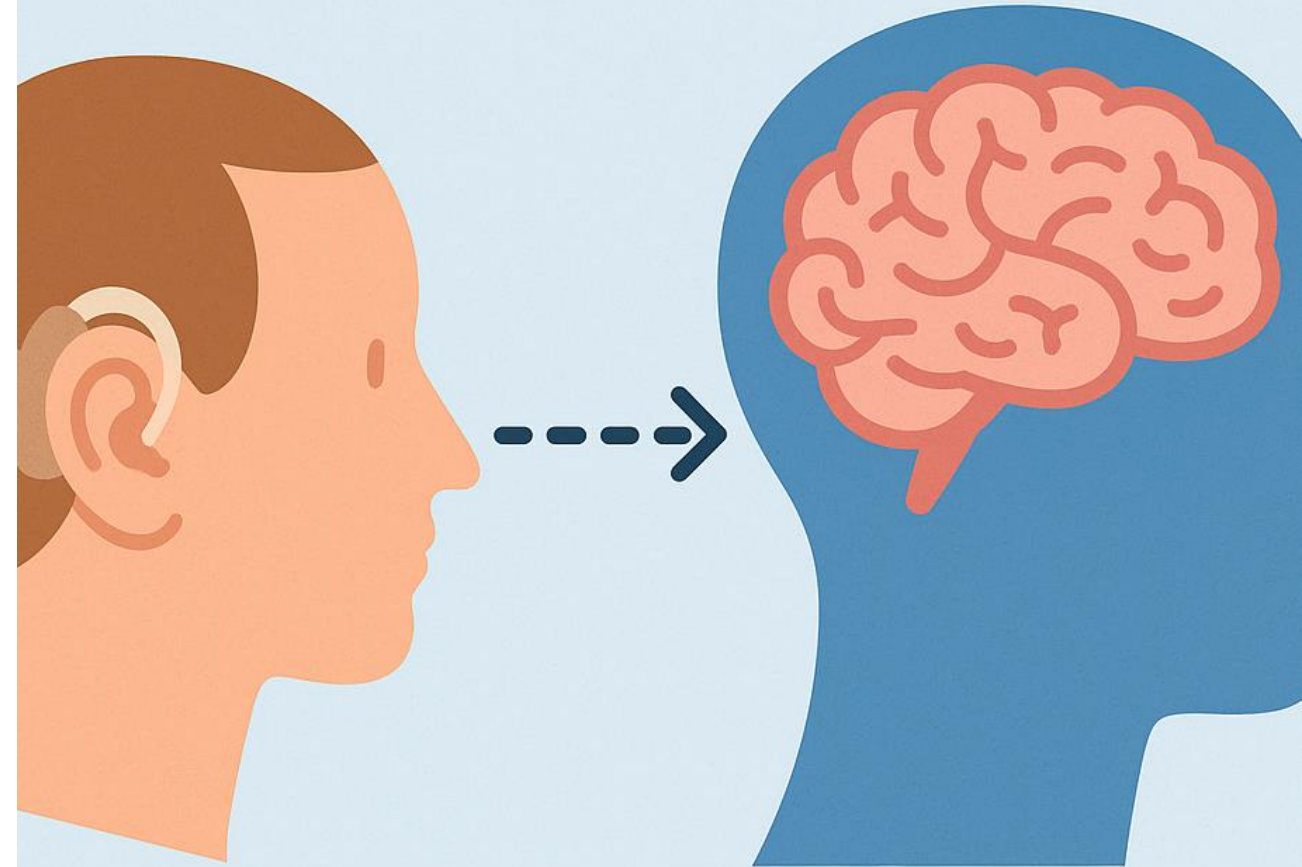




Neural Correlates of Behavioral Outcomes

- Strong behavioral improvements with 8 weeks of hearing aid usage
- What are the neural mechanisms that support these changes?
 - Aversiveness to sound
 - Noise Acceptance

HEARING AIDS AND THE BRAIN



Auditory Acclimatization and New Hearing Aid Users

- New hearing aid users often report being overwhelmed by newly audible sounds at first fit.
- With time, many users often become less sensitive to irrelevant sounds
 - Acclimatization or a refocusing of attention likely occurs (e.g. Dawes and Munro, 2016)
 - Acclimatization refers to the “systematic change in auditory performance over time due to the change in the type and amount of acoustic information available to the listener (Arlinger et al., 1996).
- Consistent hearing aid use is vital for acclimatization



Sensory Gating

- Sensory gating is the brain's ability to filter out redundant or unnecessary stimuli (Korzyukov et al., 2007).
 - Occurs in the auditory, visual, and somatosensory domains
- Auditory sensory gating prevents the sensory system from being overwhelmed by sound (Venables, 1964)
 - Objective marker of inhibition and auditory filtering (Hetrick et al. 2012)





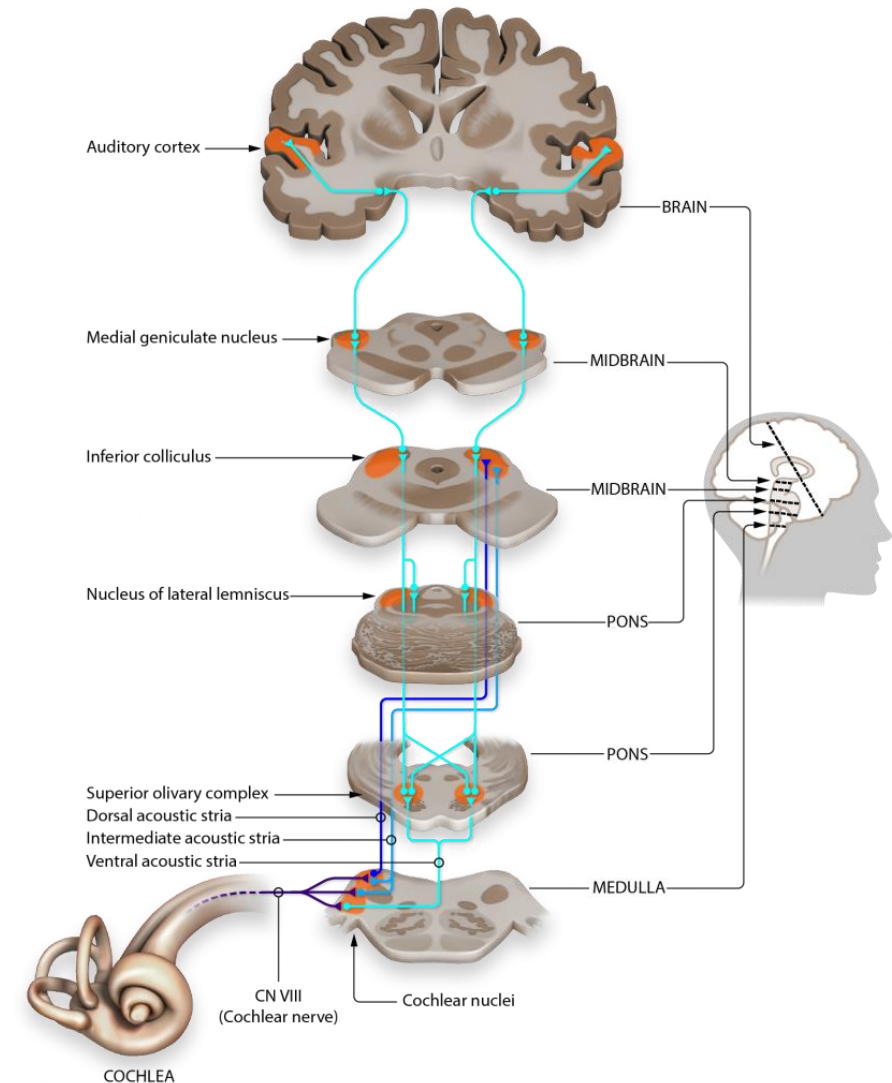
Auditory Sensory Gating

- Gating reflects the capacity of the nervous system to differentially respond to identical, redundant acoustic stimuli.
- Auditory filtering of irrelevant inputs serves to protect higher-order cognitive functions (Jones et al. 2016, Lijffijt et al, 2009).



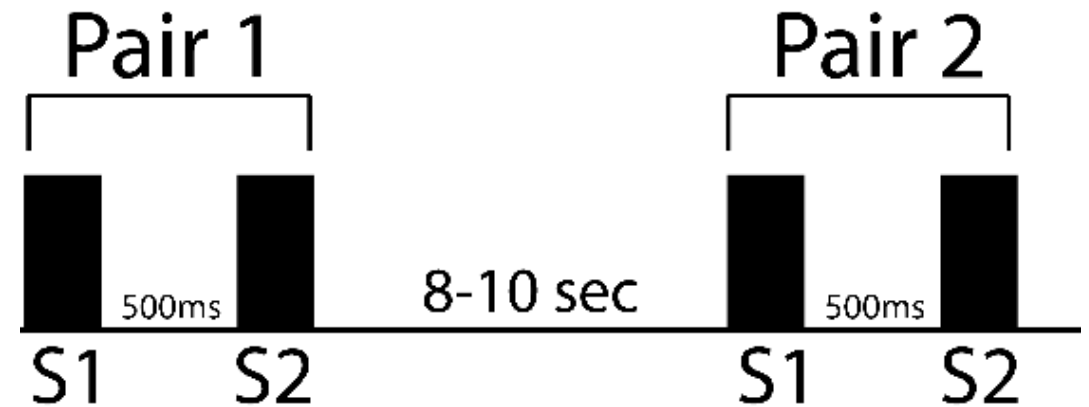
Mechanisms of Auditory Sensory Gating

- Elicited using pairs of identical stimuli
 - Stimulus 1 and Stimulus 2
- Stimulus 1 evokes excitatory and inhibitory neurons in the hippocampus
- When Stimulus 2 carries no new information, it is gated out because inhibitory neurons are still active (Korzyukov et al., 2007; Rauschecker et al. 2010).

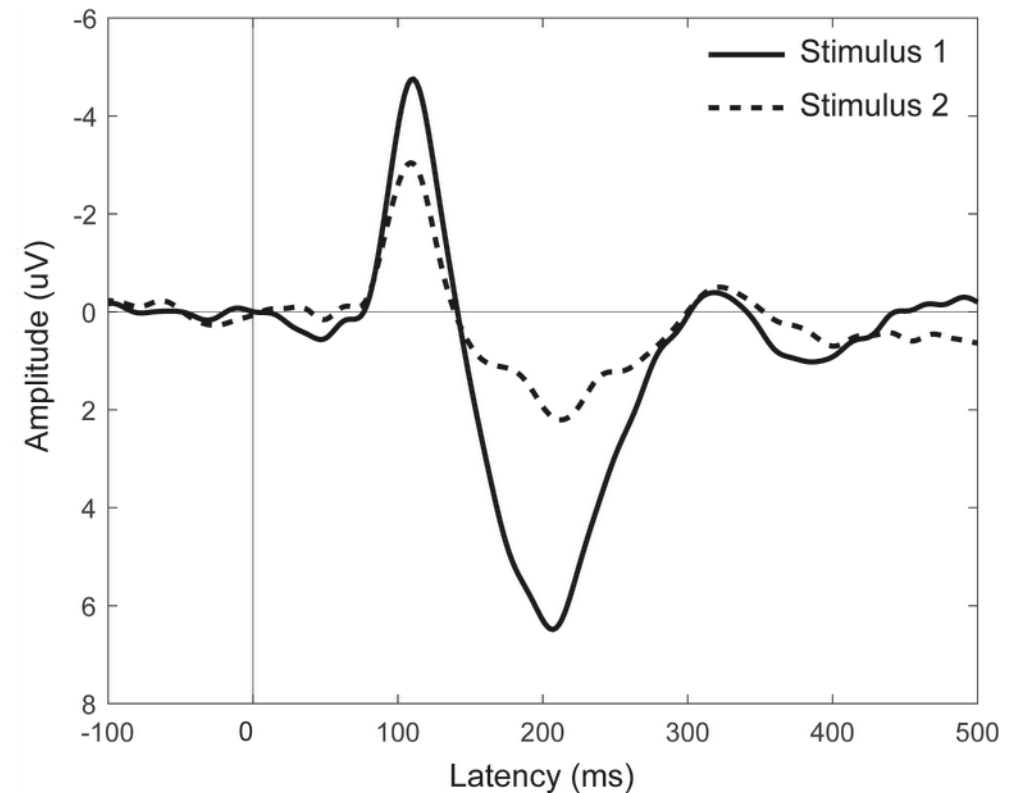
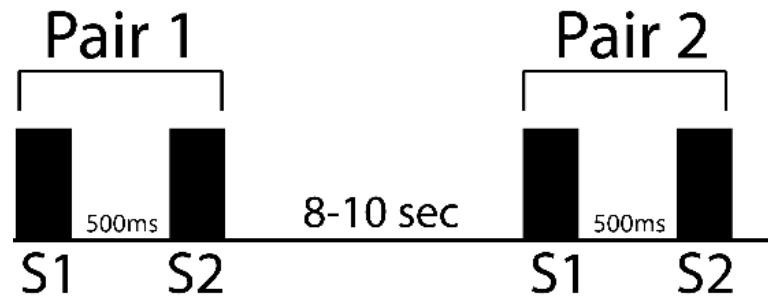


Auditory Sensory Gating

- The **paired-pulse paradigm** is a common technique used to measure sensory gating
 - Type of event-related potential (ERP)
 - Auditory evoked response
- Subject is presented with a pair of duplicate, identical stimuli of the same intensity
 - “Pulse 1” (conditioning stimulus) and “Pulse 2” (test stimulus)
 - 500 ms interval between the two stimuli

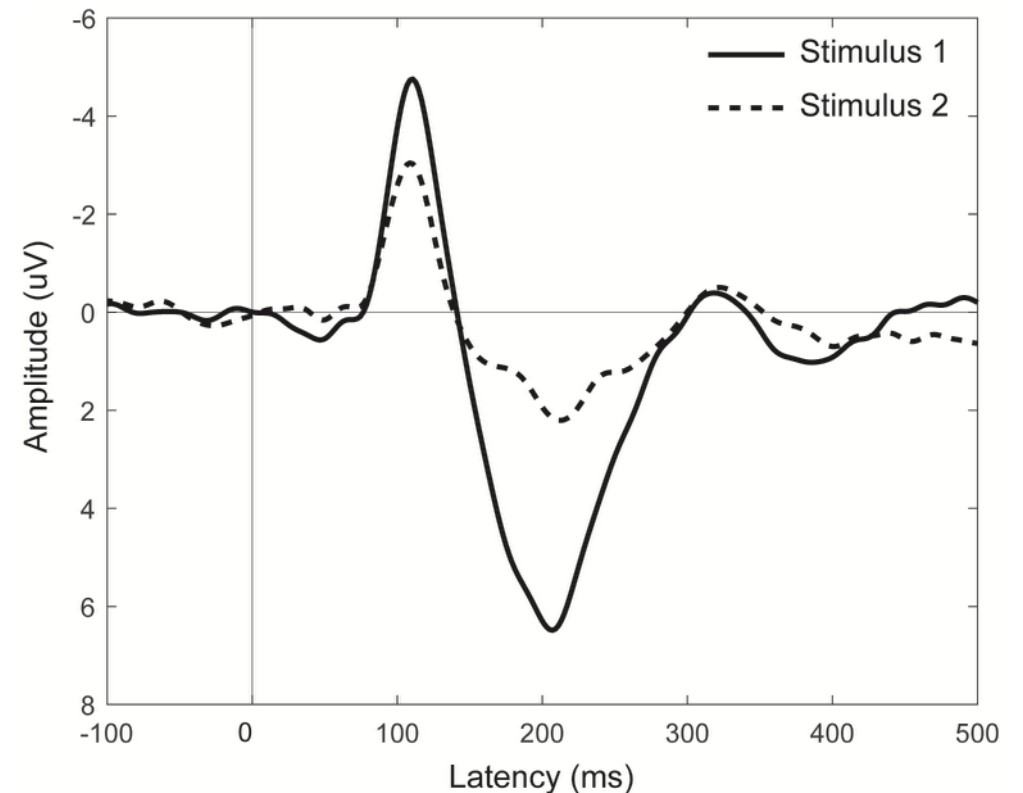


Auditory Sensory Gating: Paired Stimulus Paradigm



Auditory Sensory Gating Analysis

- Amplitude of stimulus 2 compared to stimulus 1
 - Smaller s2/s1 amplitude ratio consistent with 'gating out'
 - Larger s2/s1 amplitude ratio consistent with weaker gating
- 100% gating ratio → no gating
- 50% gating ratio → stronger gating

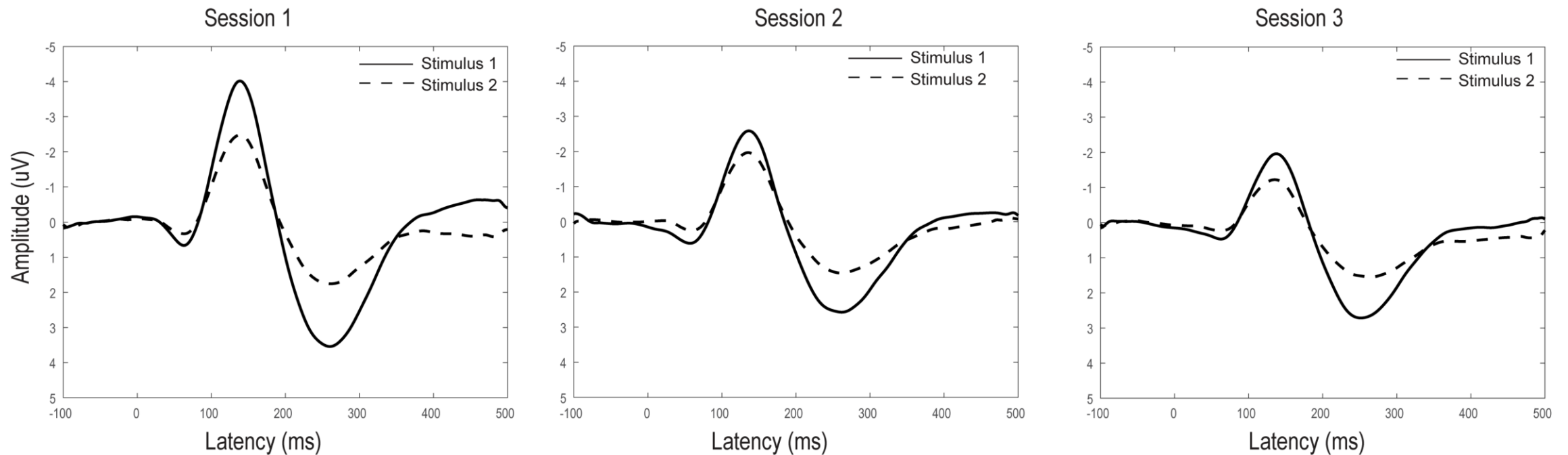




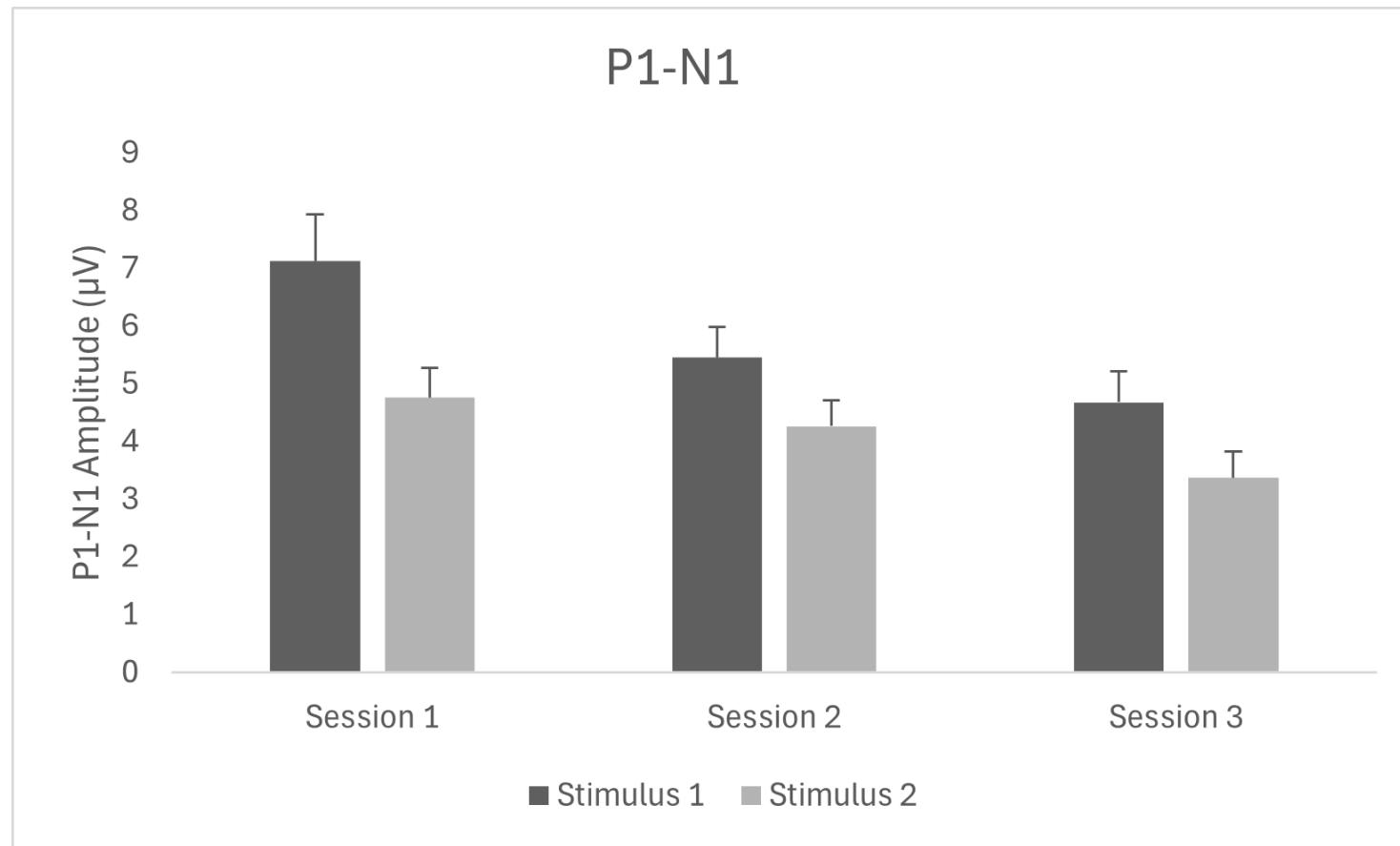
Baseline Electrophysiological Measures: Auditory Sensory Gating Paradigm

- Pairs of identical 1000 Hz tones
 - Presented at 40 dB SL
- Unaided and Aided Listening Conditions
- Passive listening design
- Continuous EEG recorded using 64 channel system (ANT Neuro)
- EEG Data Analysis [ASA, EEGLAB toolbox MATLAB]
 - Filter 0.1- 40 Hz
 - Epoch : -100 ~ 500 ms (100 ms pre-stimulus baseline)
 - Blind source separation ICA algorithm
- Peak P1-N1-P2 amplitudes and latencies to Stimulus 1 and 2 extracted from ERP waveform

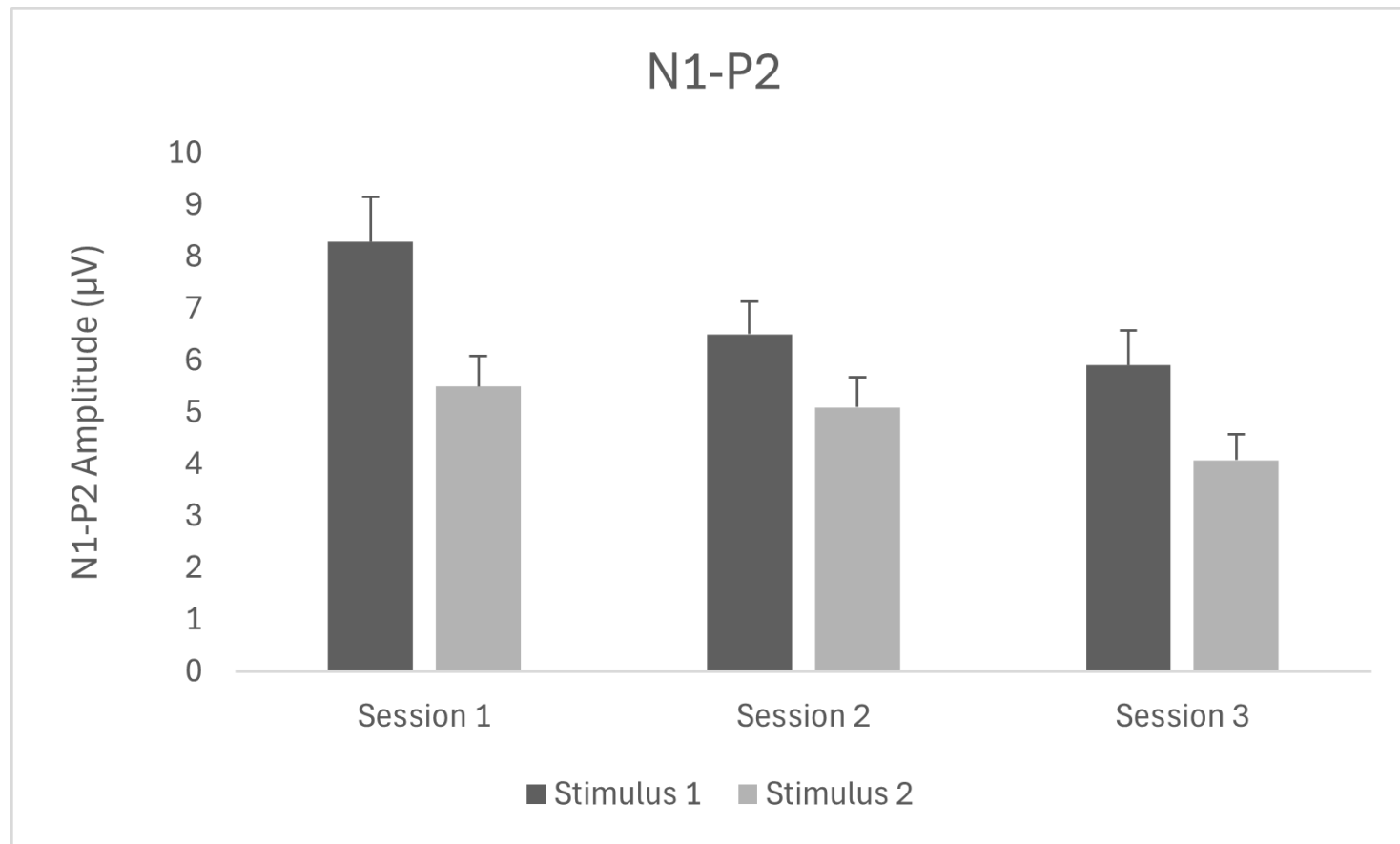
4 months of hearing aid use improves unaided central inhibition



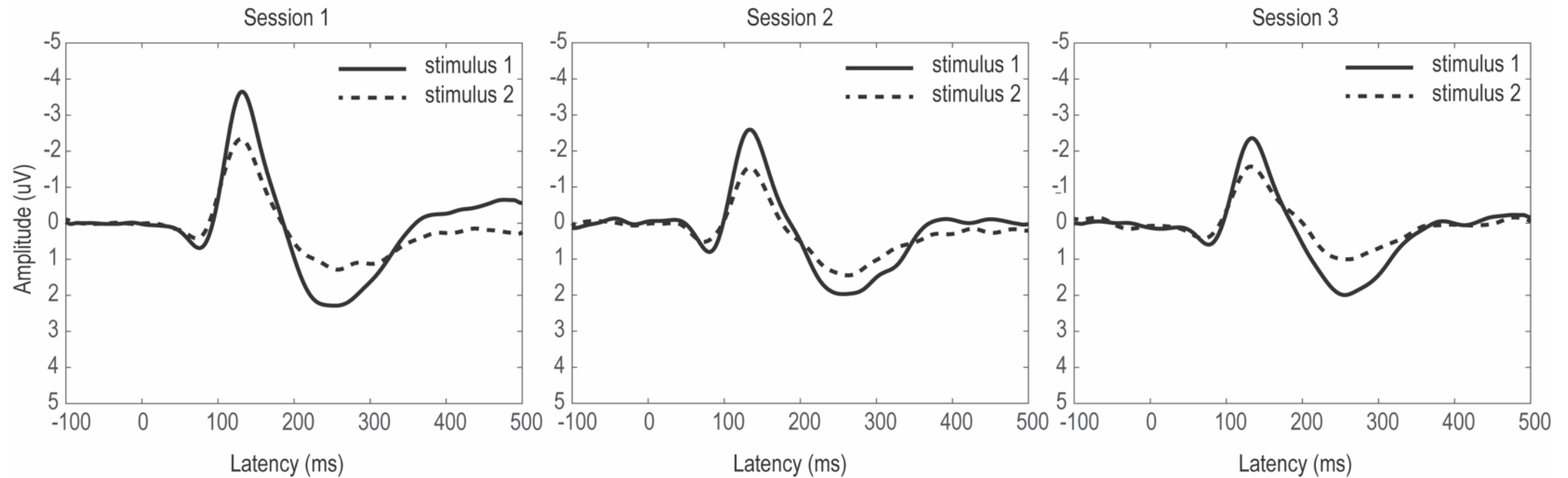
Unaided P1-N1 s1 and s2 amplitudes were significantly smaller at session 3



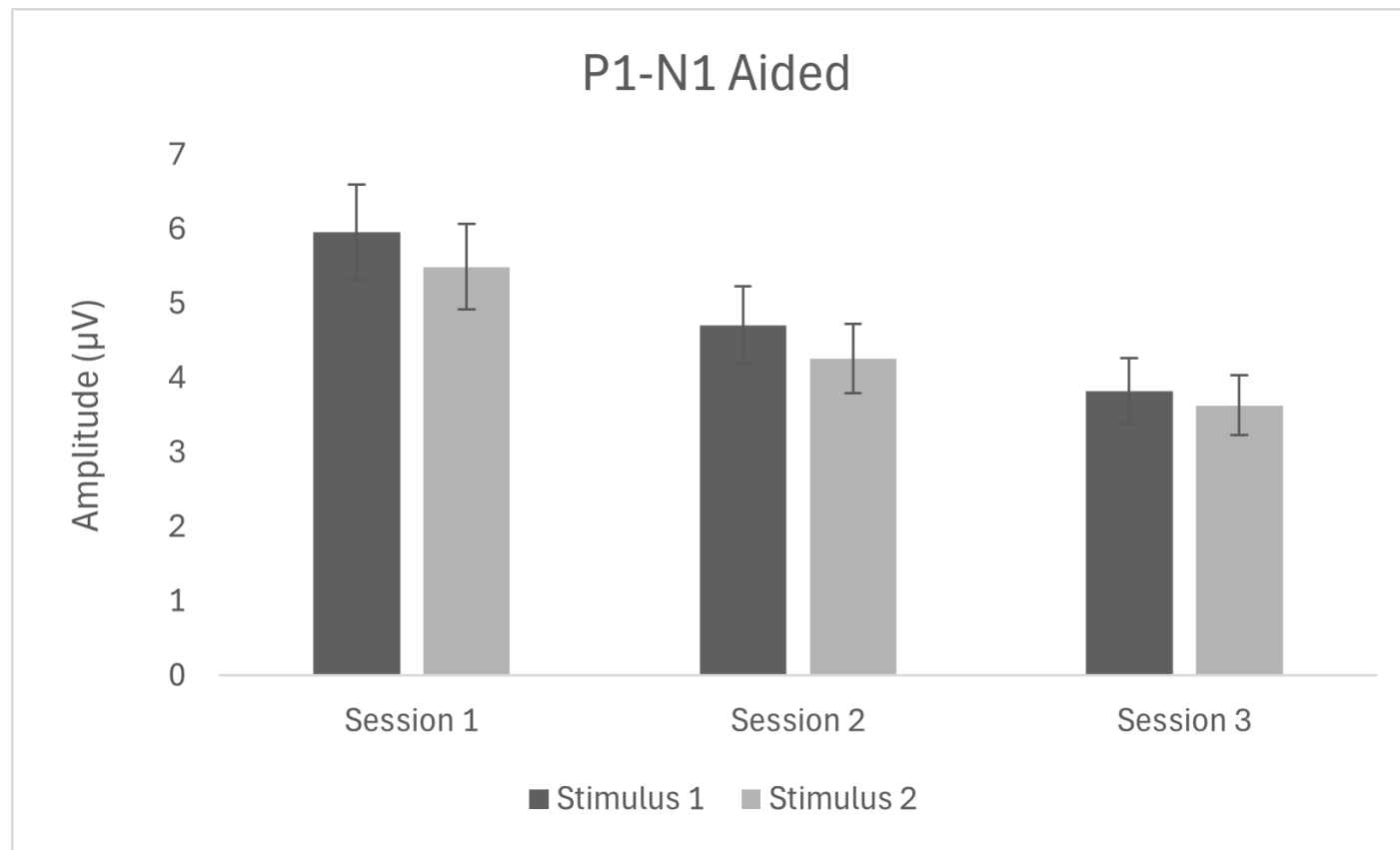
Unaided s1 and s2 N1-P2 amplitudes were significantly smaller at session 3



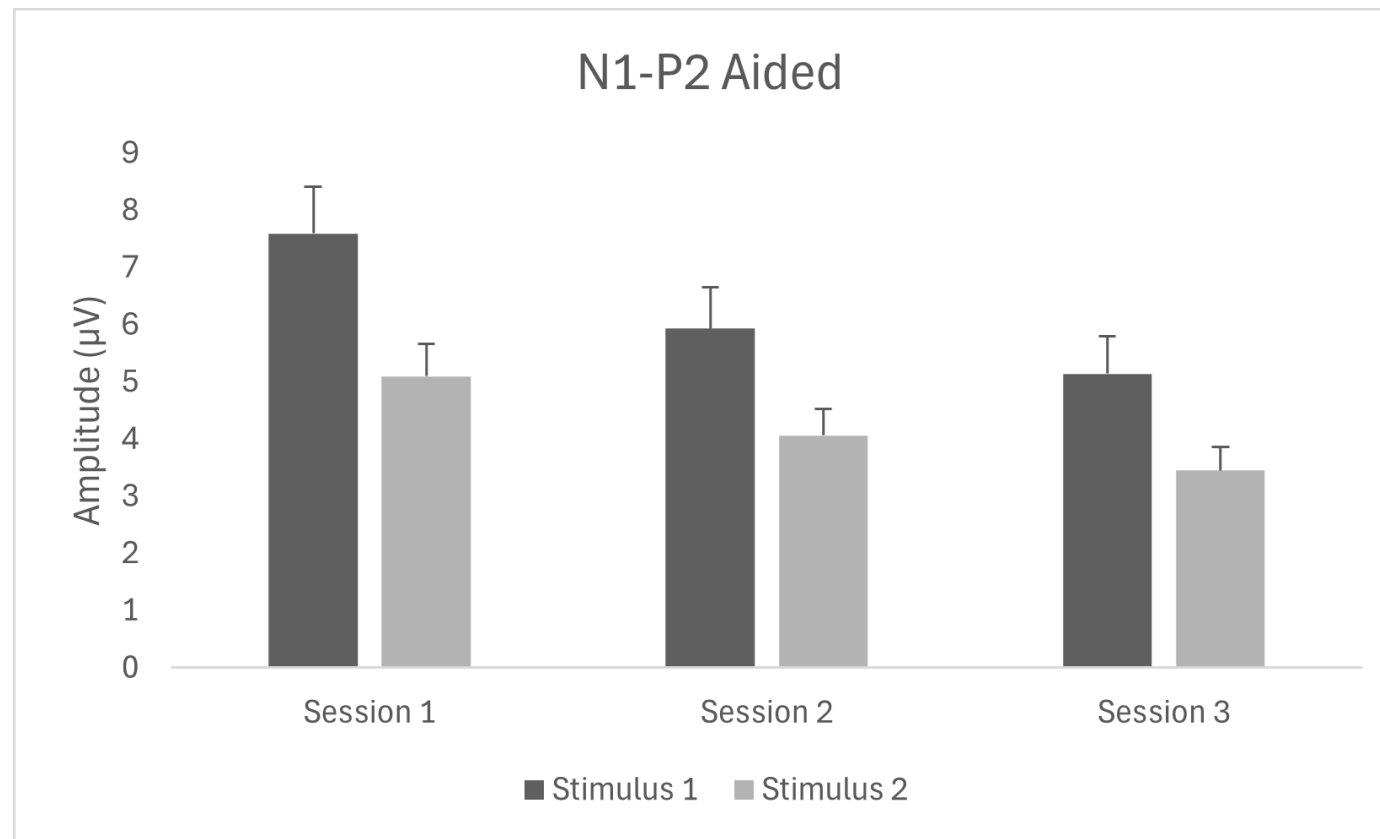
4 months of hearing aid use improves aided central inhibition



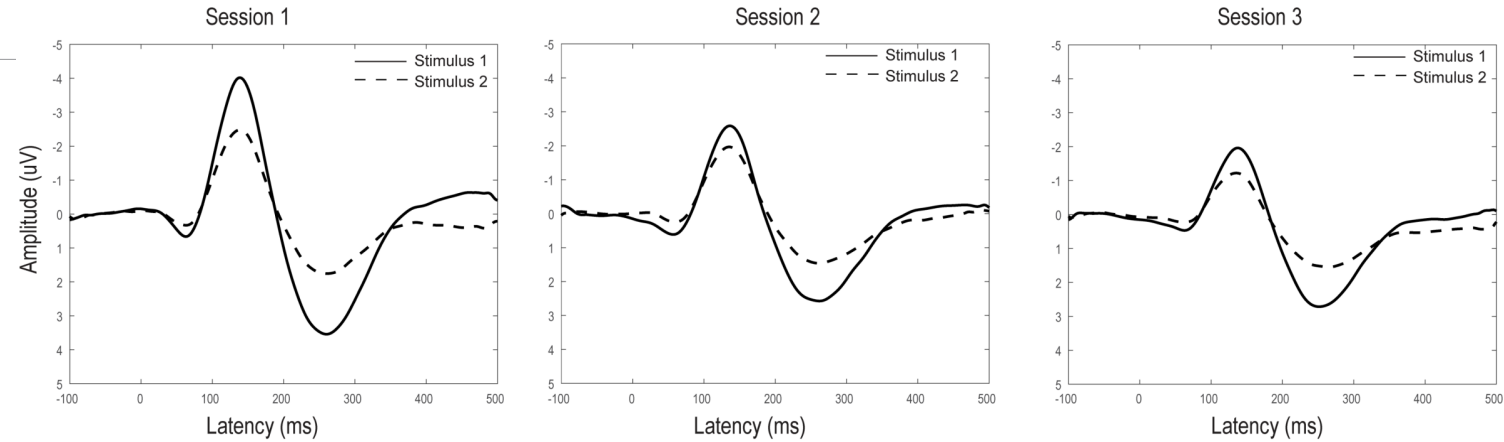
Aided s1 and s2 P1-N1 amplitudes were significantly smaller at session 3



Aided s1 and s2 N1-P2 amplitudes were significantly smaller at session 3



Central Gain and Hearing Loss

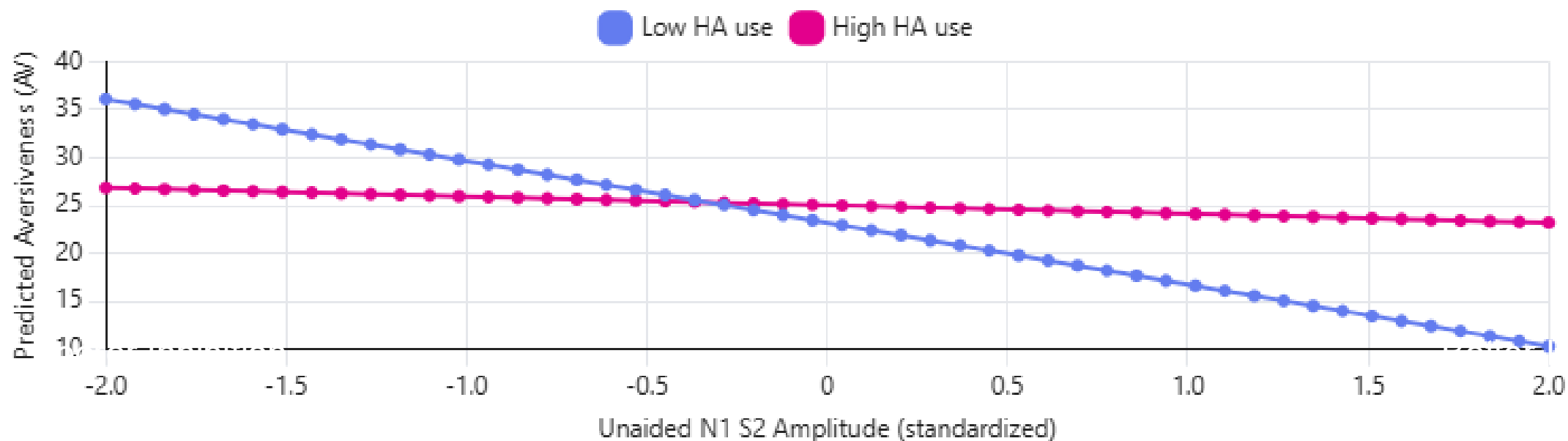


- With hearing loss, the central auditory system increases its neural activity to compensate for a loss of sound input from the ear (e.g., Auerbach et al. 2014)
 - Phenomenon referred to as Central Gain (Eggermont and Roberts, 2014)
 - The central auditory system essentially overcompensates for this lost sound input by increasing the gain of incoming signals
 - Our gating results suggest that hearing aids can address the maladaptive aspects of central gain and increase neural inhibition of irrelevant sounds
 - What are the consequences of central gain?

HA Use is the Strongest predictor of Aversiveness

Dependent Variable: Aversiveness to Sound		
Predictor	Relationship to AV	Interpretation
Hearing Aid Use*	Decreases AV	Greater Usage → Reduced Aversiveness
Session*	Decreases AV	Aversiveness significantly lower at session 3
N1 S2 Amplitude	Larger amplitudes → Higher Aversiveness	Trend toward weaker gating being associated with higher aversiveness ($p=0.06$)
N1 S2 Amplitude x Session*	The relationship between aversiveness and gating depends on session	By session 3, the effect of poor gating on aversiveness became weaker. Hearing aid treatment may reduce negative impact of sensory gating deficits
N1 S2 Amplitude x Session x Hearing Aid Use*	The relationship between gating and aversiveness depends on hearing aid usage	Individuals with poorer baseline gating may require more hearing aid use to lessen aversiveness.

Poorer Gating Related to Higher Aversiveness Outcomes

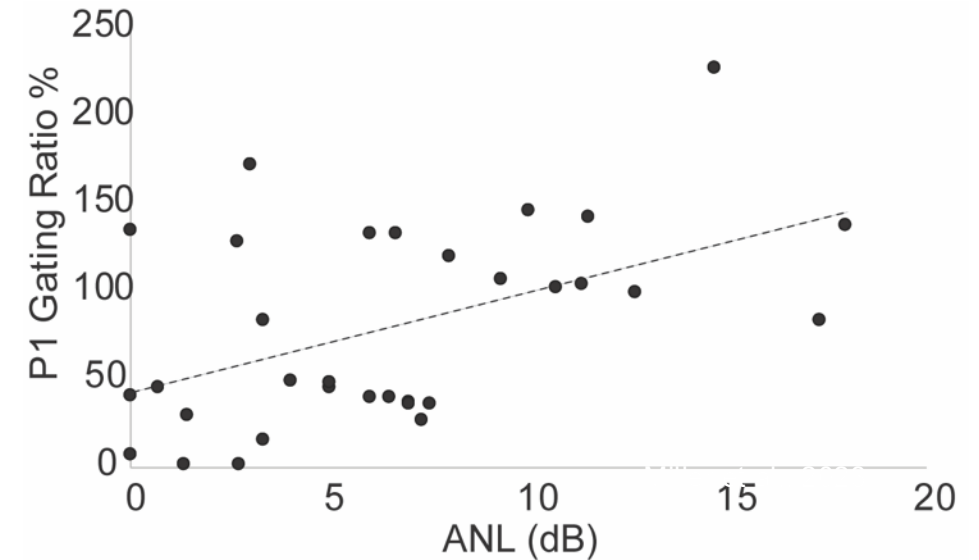


Auditory Gating, Inhibition, and ANL

- Acceptable Noise Level (ANL)
 - MCL-BNL



- Larger cortical responses associated with high ANL (Harkrider et al)
- Weaker gating is associated with a higher Acceptable Noise Level (ANL) (e.g., poorer noise acceptance)
 - Neural noise cancellation model (Rauschecker et al. 2010)



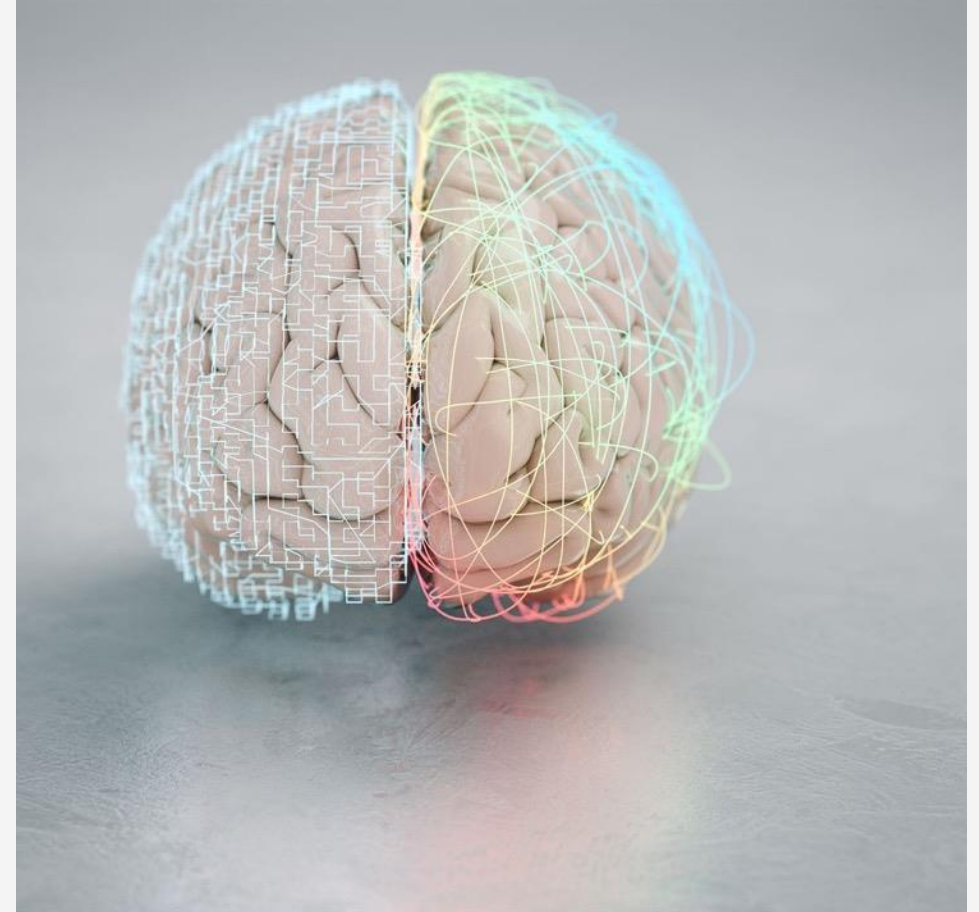
Scatterplot of individual listener data showing P1 gating ratio (in percent) as a function of Acceptable Noise Level (ANL). Miller et al. 2023 JSLHR.

HA Use Impacts Gating and ANL

Dependent Variable: ANL	
Predictor	Interpretation
Hearing Aid Use	Slight association between longer daily use and lower ANLs (better noise acceptance) but nonsignificant
N1 S2 Amplitude	No relationship to ANL when hearing aid use is ignored
HA Use x N1 S2 Amplitude*	The relationship between hearing aid use and ANL depends on baseline gating status • Poorer baseline gating + high HA usage → greater noise acceptance • Poor baseline gating + low HA usage → less noise acceptance

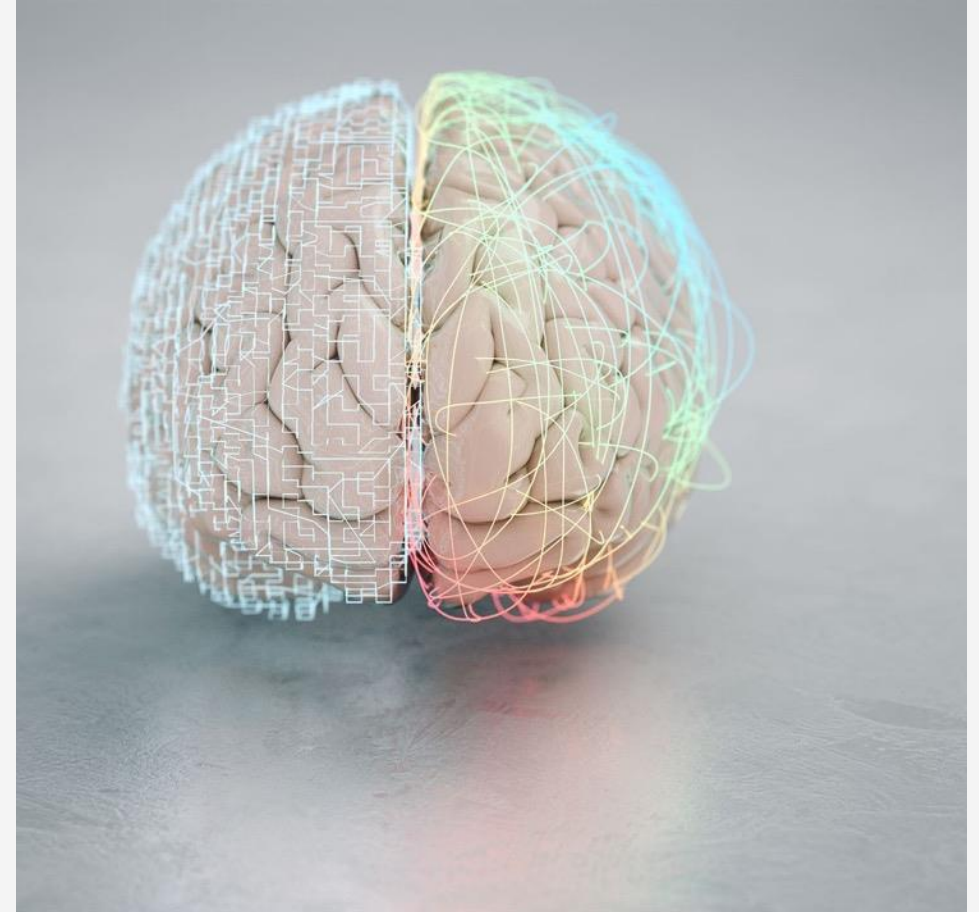
Summary of Neural Findings

- Neural plasticity underlies perceptual adaptation to hearing aid amplification
- Auditory Sensory Gating improves with hearing aid use
 - N1
- Patients who report greater aversiveness to sound have larger cortical responses to acoustic stimuli
 - N1 could serve as neural biomarker for identifying patients at risk for sound intolerance



Summary of Neural Findings

- Poorer N1 auditory gating is associated with higher ANLs (less tolerance for background noise)
- Patients with greater hearing aid usage are able to accept MORE noise
- With continued hearing aid use, neural processing becomes more efficient
 - Neural adaptation supports improved noise acceptance over time



Clinical Implications



- Set realistic expectations
- Important to counsel patients on that initial aversion to sounds is common but that with continued hearing aid use, their brains should adapt to the new sounds
- Monitor aversiveness ratings
- Patients with larger cortical responses could need slower gain increases to facilitate adaptation
- Initial hearing aid usage may be accompanied by limited noise tolerance, but with consistent daily use of hearing aids, the cortical system will adapt to handle amplified sounds over time

Future Directions

- Assess cortical gating to different sounds
 - Speech sounds
 - Attention conditions
- Loudness modeling in addition to aversiveness ratings

Questions?

Thank you for your attention.

Erin Schafer, PhD, CCC-A
Sharon Miller, PhD





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