Listening difficulties in background noise: using electrophysiology to complement behavioral measures

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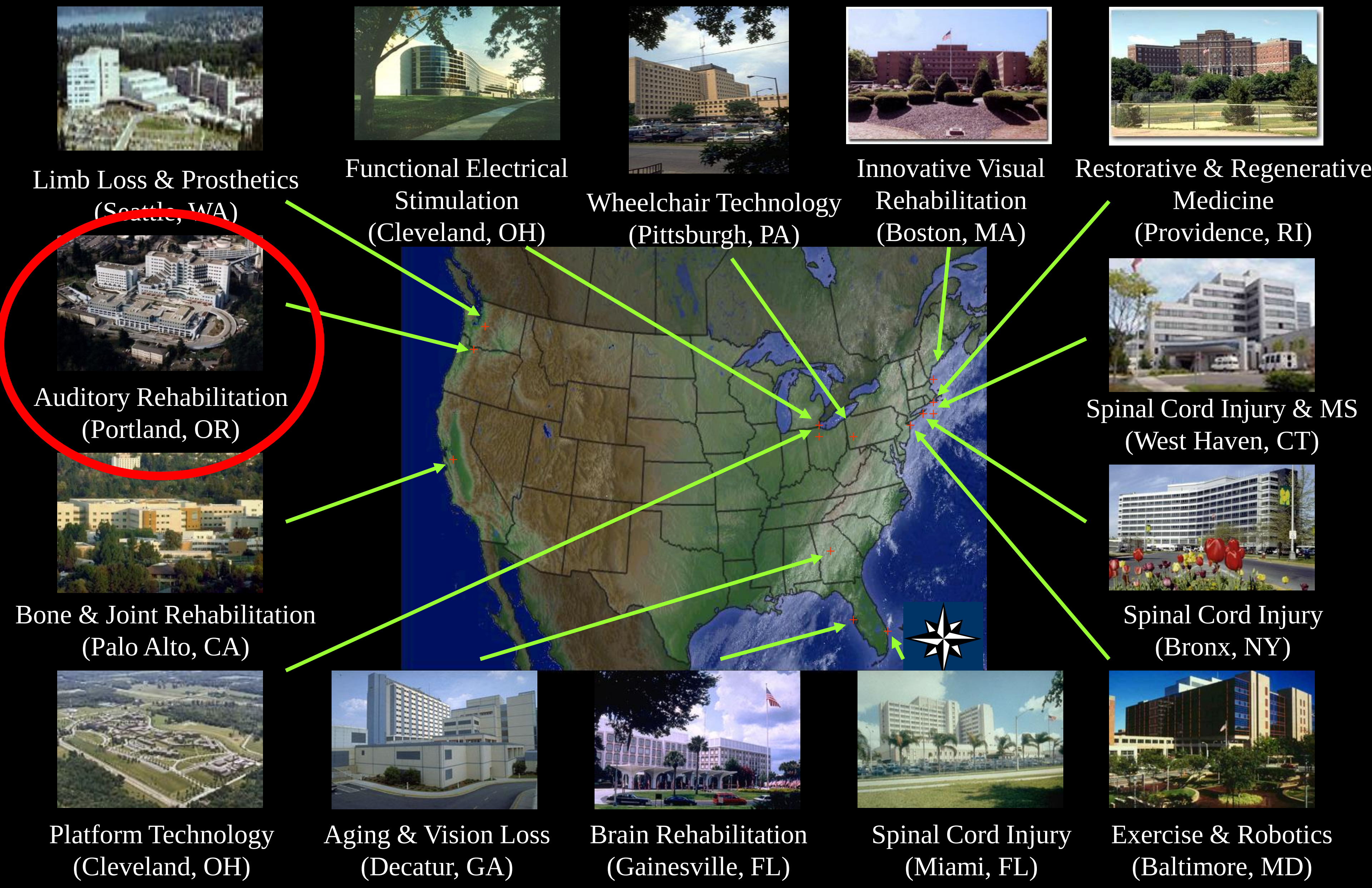
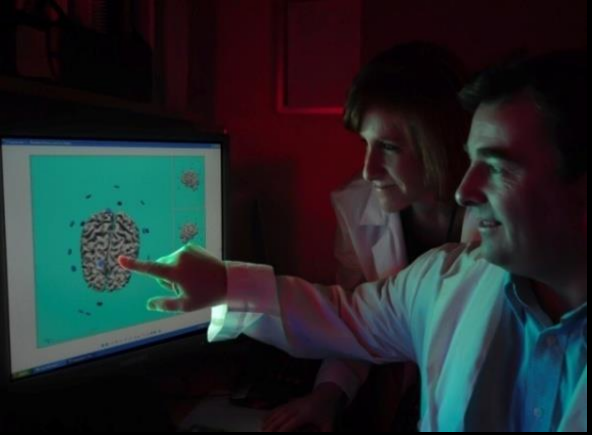
National Centers of Excellence

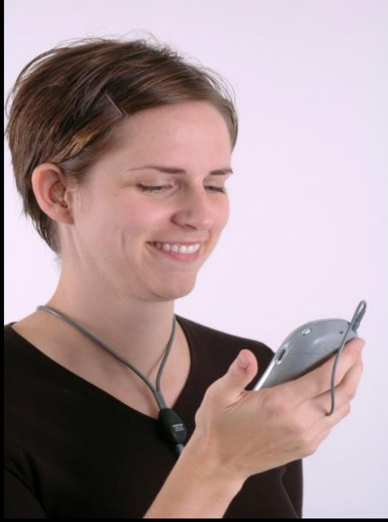




Prevention of Auditory Dysfunction

Diagnosis and Assessment

Rehabilitation Strategies

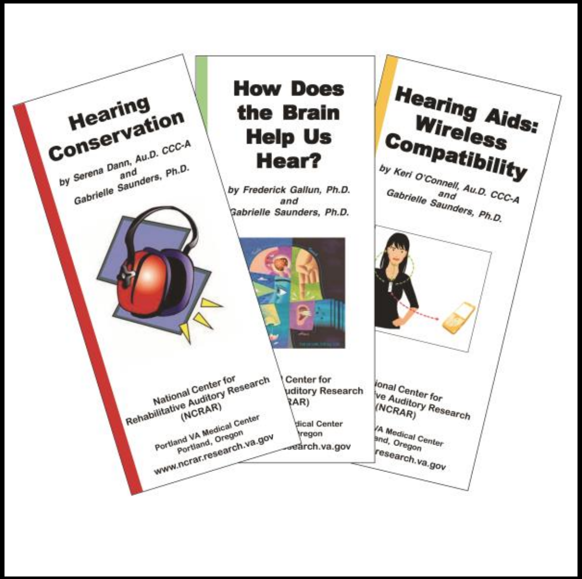


- ✓ Ototoxicity
- ✓ Telehealth
- ✓ Tinnitus
- ✓ Aging and the auditory system
- ✓ Auditory Rehabilitation
- ✓ Ear-Brain system
- ✓ Hearing aids
- ✓ Hearing conservation
- ✓ Traumatic Brain Injury (TBI)

RESOURCE FOR VETERANS AND THE COMMUNITY

Clinician and Patient Resources

- Eight patient brochures published.
- Tinnitus resources (PTM)
- Ototoxicity resources



Community Services

- **NCRAR Biennial Conference**.
- **COMMUNITY SEMINARS:** Seminars about hearing-related issues.
- **PATIENT SUPPORT/EDUCATION GROUPS:** Tinnitus, coping with hearing loss for patients and their family.

http://www.ncrar.research.va.gov

Acknowledgments

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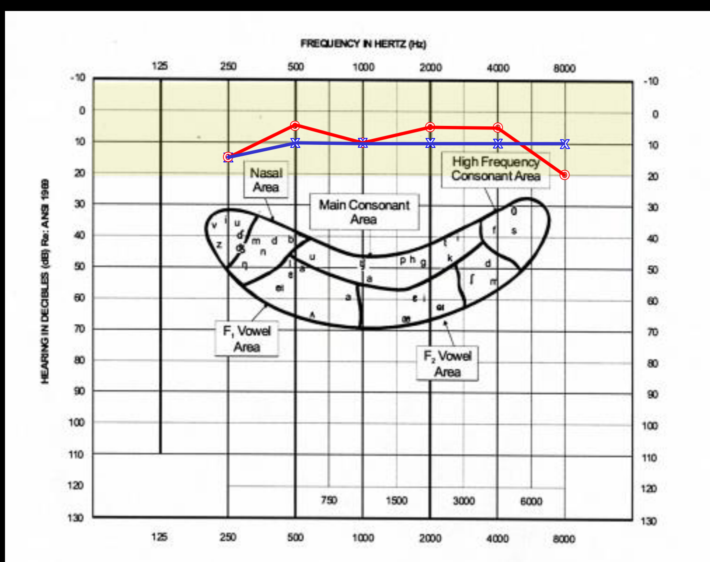
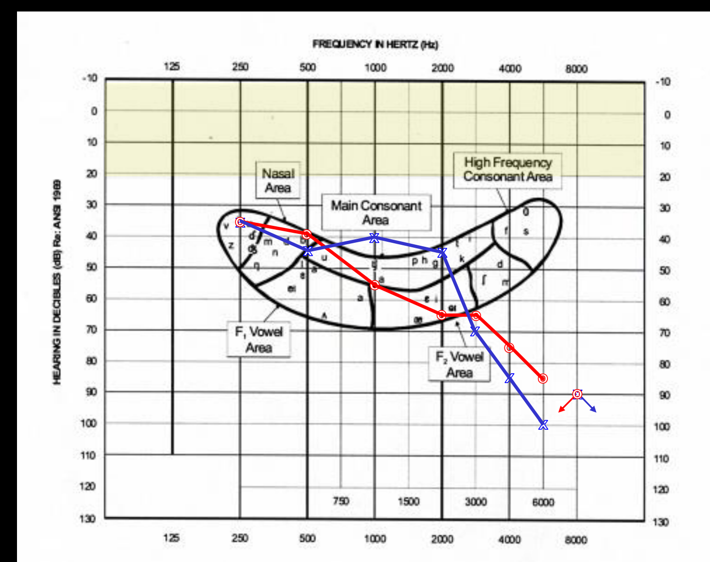
  - Investigator-Initiated Research (R01DC015240)

Today's Presentation

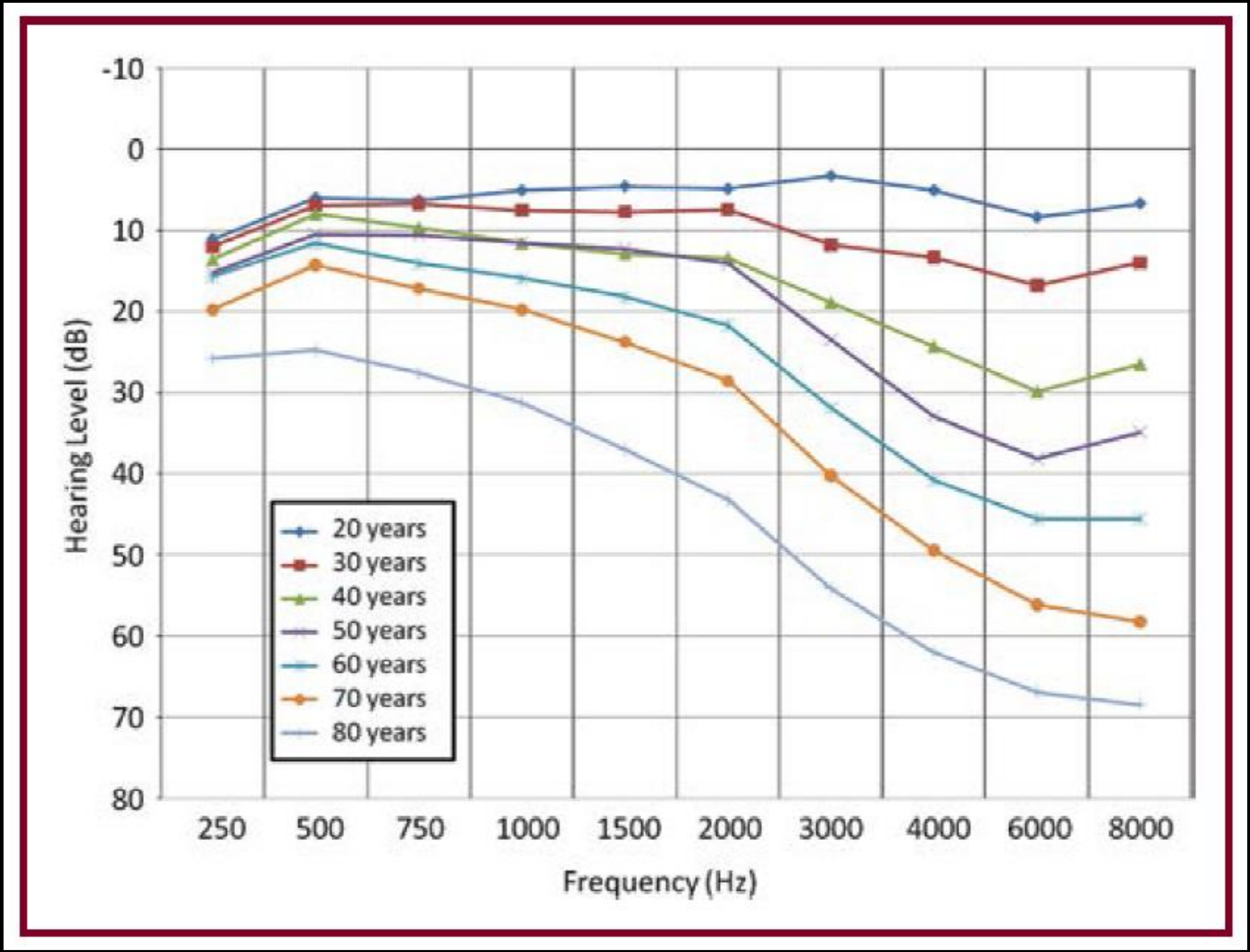
1) The Problem: Understanding speech in noise
2) Neural coding with aging, normal hearing, and hearing loss
3) A brain-behavior approach (correlations and predictions)
4) Adding cognition

“I can hear you, but I can’t understand you.”



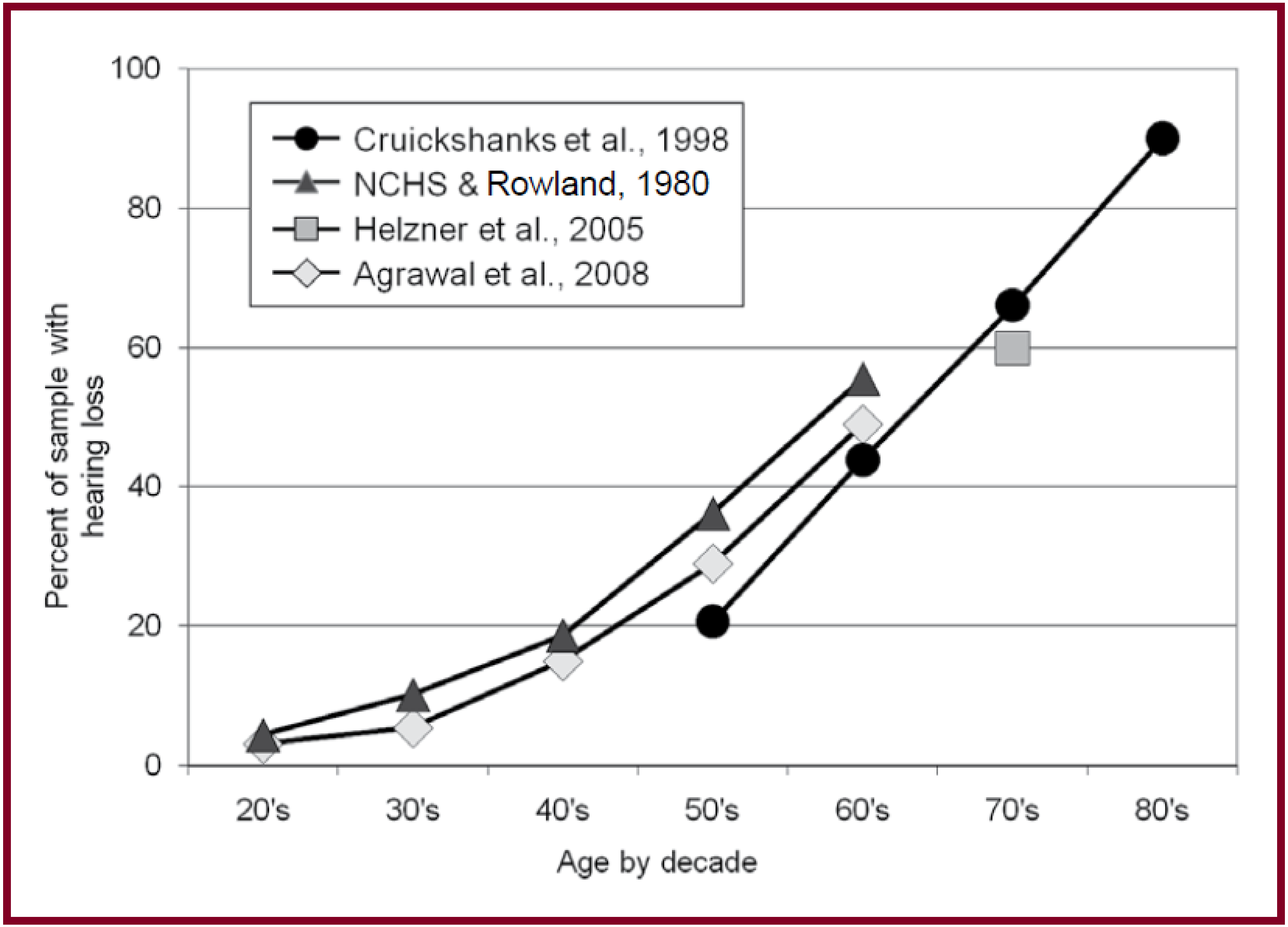


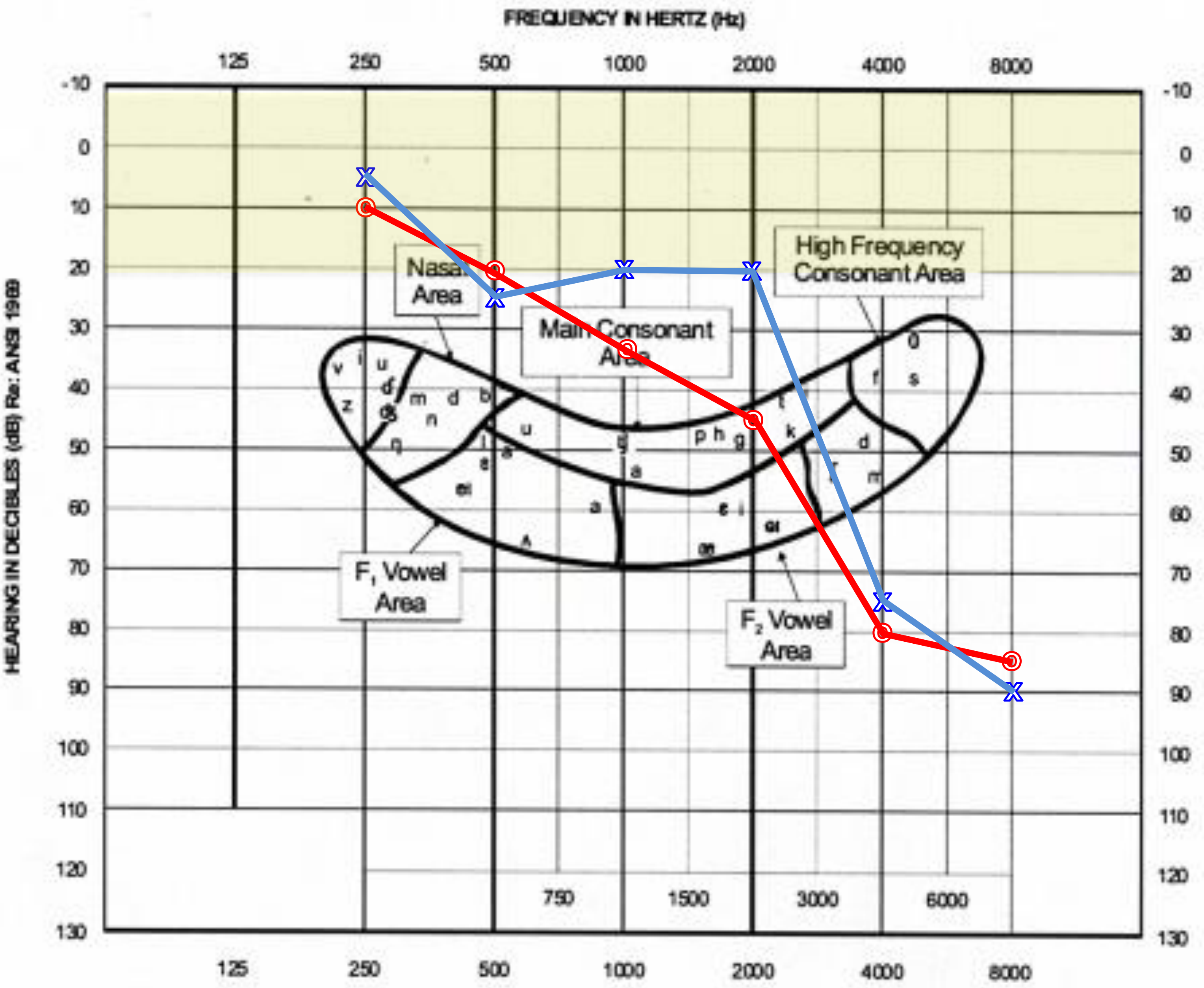
Audiogram Across the Lifespan

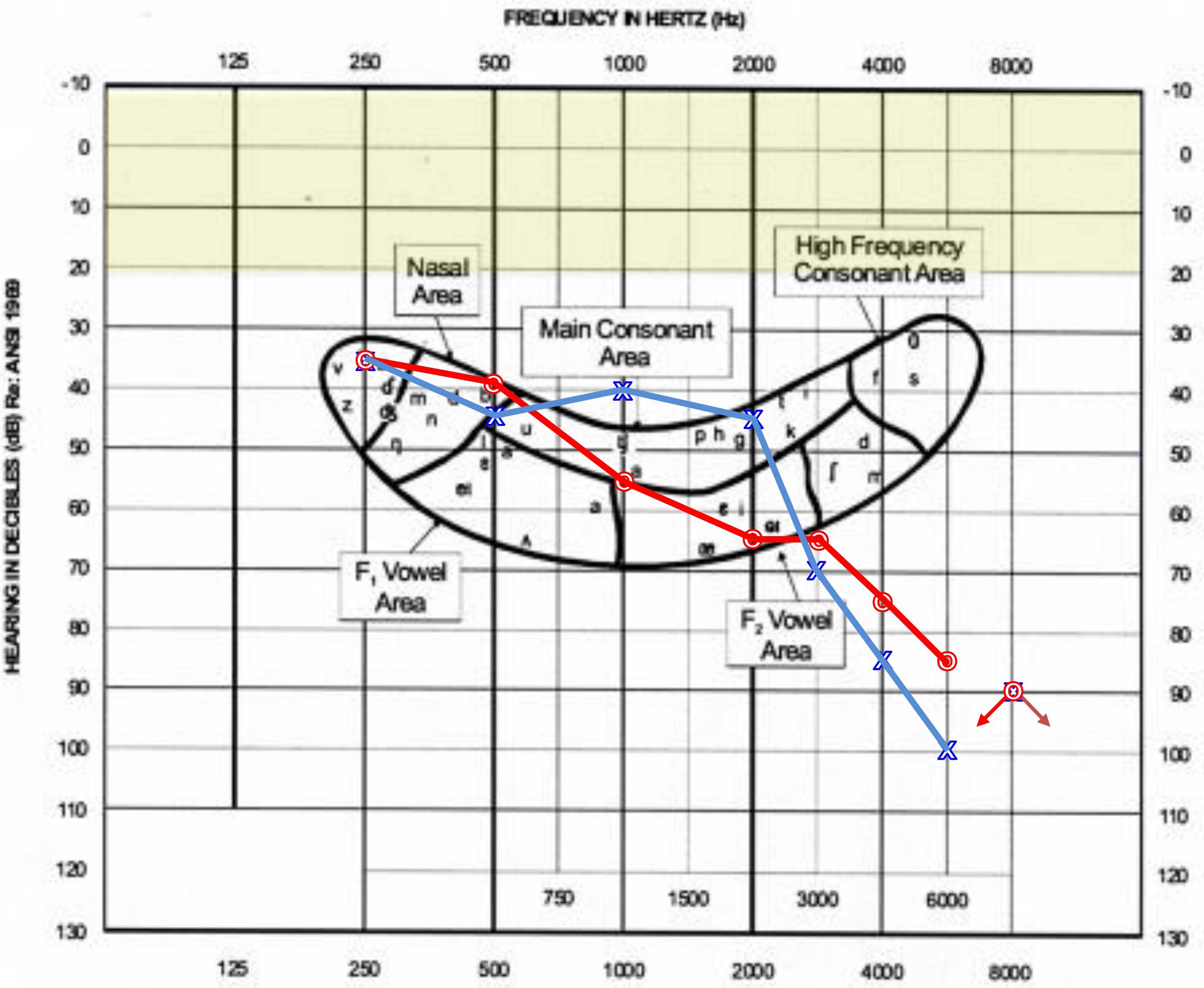


Billings et al., in Translational Perspectives in Auditory Neuroscience: Hearing Across the Lifespan – Assessment and Disorders, 2012.

With aging comes increase in prevalence of hearing loss




FREQUENCY IN HERTZ (Hz)
125
250
500
1000
2000
4000
8000
HEARING IN DECIBELS (dB) Re: ANSI 1989
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130
Nasal Area
Main Consonant Area
High Frequency Consonant Area
F1 Vowel Area
F2 Vowel Area
750
1500
3000
6000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750
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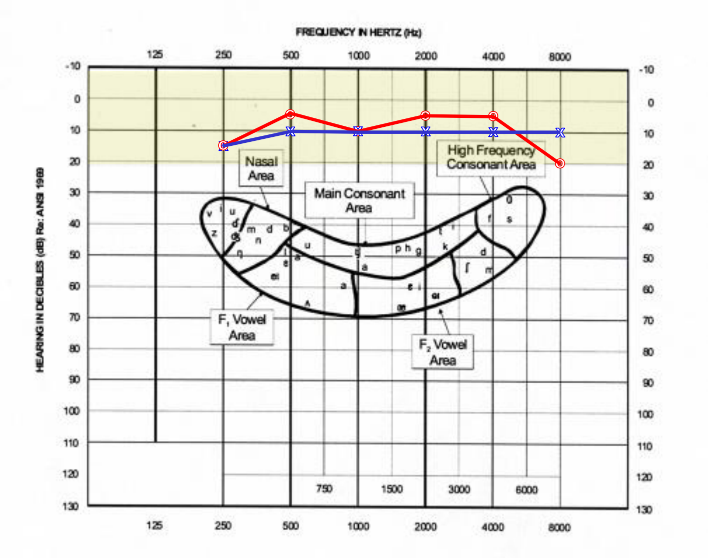
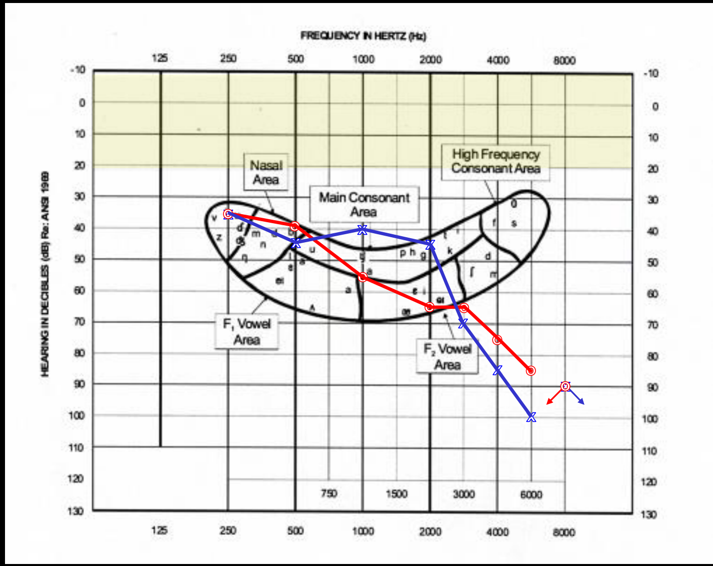
"I can hear you, but I can't understand you."





Bottom-up and top-down processing

Hair Cell Damage

Spiral ganglion shrinkage

GABA loss

Strial degeneration

Synaptic ribbons damage

Working memory

Attention

Confusion

Language Comprehension

Fatigue

Listening effort

Speech Understanding in Noise

- automobile
- restaurants
- meetings
- concerts
- telephone
- hospitals

<u>Signal-to-noise ratio (SNR):</u>

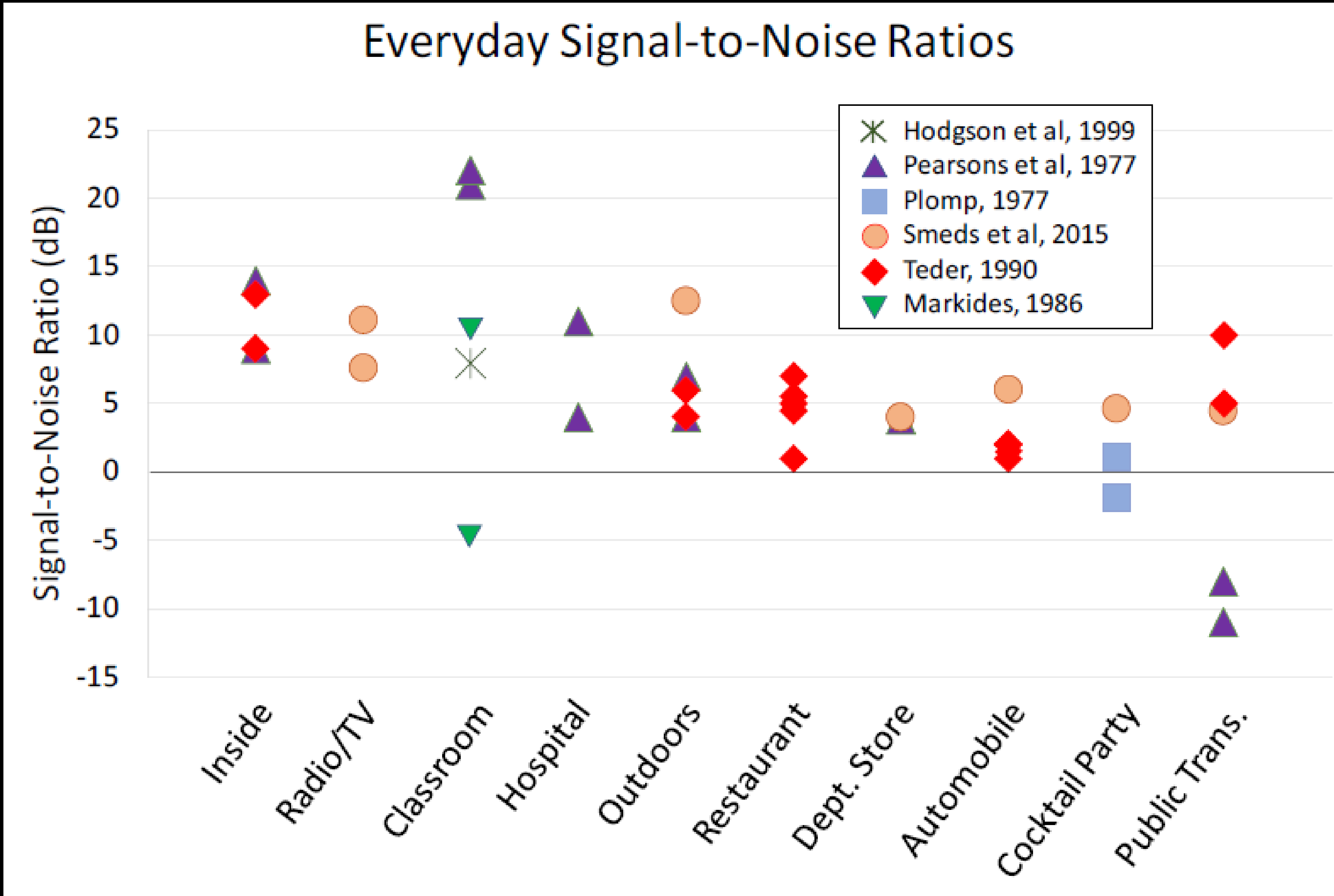
Signal

-5 dB

0 dB

+5 dB

Group Name	Specific Situation	SNR (dB)	Description	Study
Inside				
	Urban inside	9	Conversation in urban household noise	Pearsons et al, 1977
	Suburban inside	14	Conversation in suburban household noise	Pearsons et al, 1977
	Office	13	12x14 carpeted office	Teder, 1990
	Conference room	9	Carpeted conference room	Teder, 1990
Radio/TV				
	Music	11.1	Conversation in a music background	Smeds et al, 2015
	Radio/TV	7.6	Conversation in radio or TV noise	Smeds et al, 2015
Classroom				
	Classroom	7.9	University	Hodgson et al, 1999
	Classroom	22	High school, located near moderately busy street	Pearsons et al, 1977
	Classroom	21	High school, located under landing path for LAX	Pearsons et al, 1977
	Classroom	11.5	12 classrooms with ventilation	Markides et al., 1986
	Classroom	-4.5	12 classrooms with student-activity	Markides et al., 1986
Hospital				
	Hospital	11	Patient room	Pearsons et al, 1977
	Hospital	4	Nurses station	Pearsons et al, 1977
Outdoors				
	Urban outside	4	Urban backyard or patio area facing street	Pearsons et al, 1977
	Suburban outside	7	Suburban backyard or patio area facing street	Pearsons et al, 1977
	Outdoors	12.5	Conversing amongst traffic, birds singing, etc.	Smeds et al, 2015
	Outdoos	4	Suburban patio party	Teder, 1990
	Outdoors	6	Lakeshore, moderate wind	Teder, 1990
Restaurant				
	Bar	1	Neighborhood bar, Friday evening	Teder, 1990
	Restaurant bar	7	Restaurant bar, 1/3 full	Teder, 1990
	Small restaurant	5	Small restaurant, 1/2 full	Teder, 1990
	Small restaurant	4.5	Small restaurant, full	Teder, 1990
	Hilton bar	5.5	Hotel lobby bar with piano music	Teder, 1990
Dept. Store				
	Dept. Store	4	Department stores	Pearsons et al, 1977
	Dept. Store	3.8	Conversation at checkout or while shopping	Smeds et al, 2015
Automobile				
	Car	1	1986 Chevrolet Nova at 55 mph, asphalt	Teder, 1990
	Truck	2	1986 Dodge Ram at 60 mph, concrete	Teder, 1990
	Truck	1.5	1986 Dodge Ram at 40 mph, concrete	Teder, 1990
	Car	2	1988 Pontiac Bonneville at 65 mph, asphalt	Teder, 1990
	Car	6	Conversation in moving car	Smeds et al, 2015
Cocktail Party				
	Cocktail party	-2	In halls with a sound-reflecting ceiling	Plomp, 1977
	Cocktail party	1	Only taking into account horizontally-radiated sound	Plomp, 1977
	Babble	4.6	Conversation in multi-talker babble noise	Smeds et al, 2015

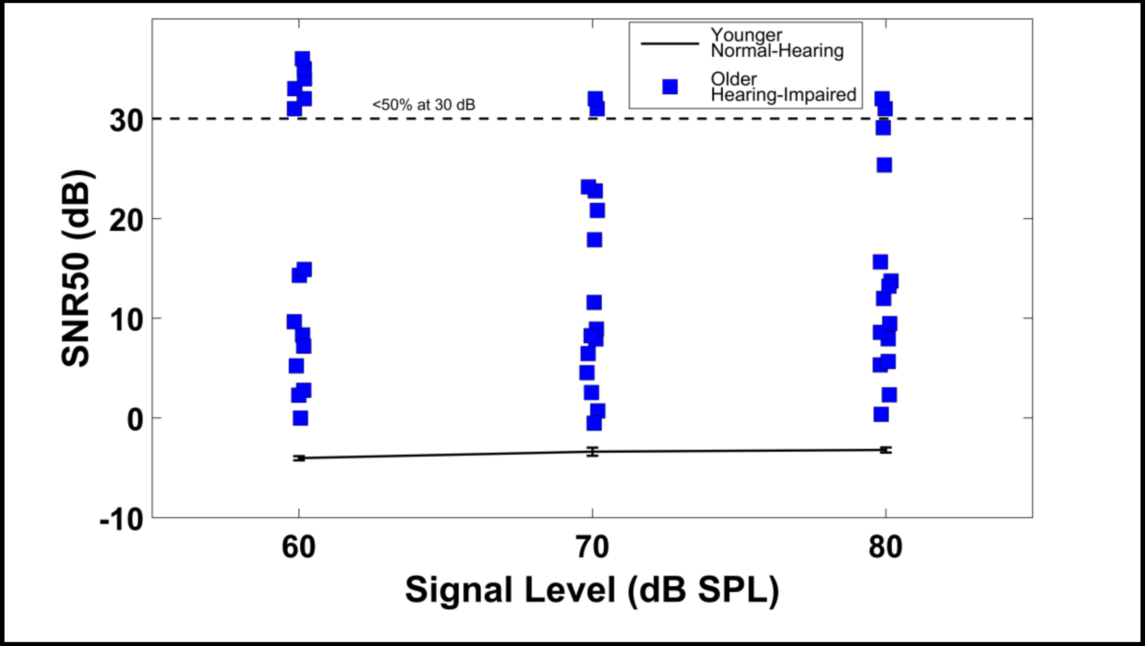


VA RR&D NCRAR

(Billings et al., Hear Res, 2018)

Speech Understanding in Noise

- Common problem for older individuals and individuals with hearing impairment
- Most frequent complaint among hearing aid users
- Difficult situation for many Veterans (e.g., traumatic brain injury, diabetes, etc.)

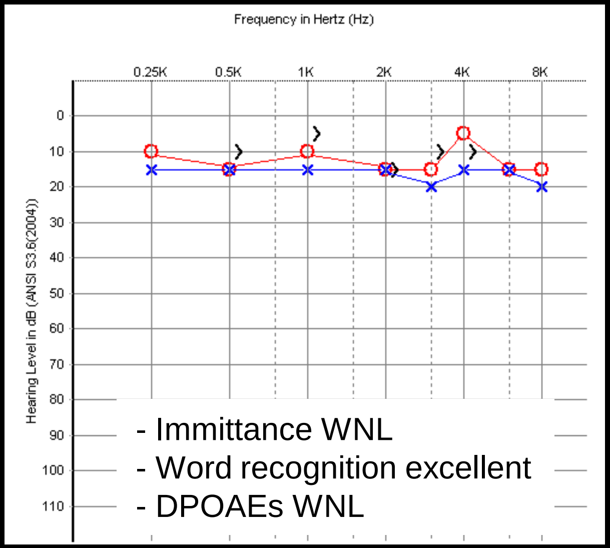


VA RR&D NCRAR

(Billings et al., Hear Res, 2018)

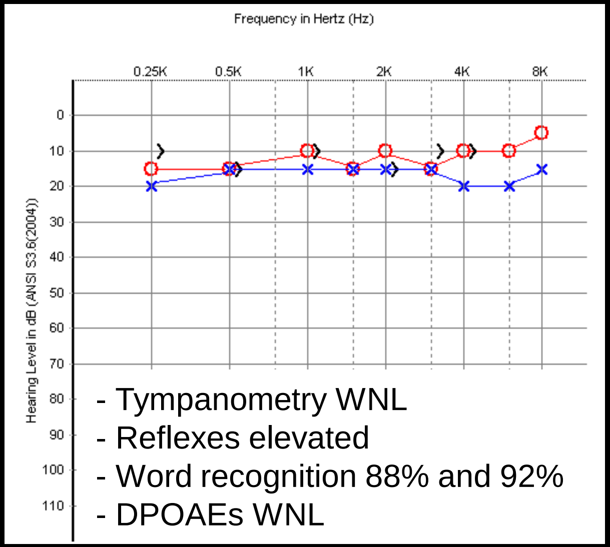
Veterans with Hearing Difficulties

31 yo male



- Referred to ENT by PCP because of vertigo
- Concussion and temporal bone fracture after fall
- Vertigo, tinnitus, headaches
- Hx of noise exposure: 2 deployments (6 years)
- PTSD, depression, easily distracted, needs repetition
- “Why do I have normal hearing but can’t seem to understand the speech of others?”
- Couldn’t finish testing due to fatigue
- Performed poorly on all subtests

30 yo male



- Referred by polytrauma; being evaluated for mTBI
- Concussion when truck flipped in Iraq
- Tinnitus, Hx of noise exposure
- PTSD, depression, anxiety, cognitive difficulties
- Needed breaks after every test; nausea because of anxiety (trying not to vomit)
- Performed poorly on all subtests
- Was it due to anxiety?

VA RR&D NCRAR

Understanding in Noise: Normal Hearing?

A Large-Scale Examination of Veterans with Normal Pure-Tone Hearing Thresholds within the Department of Veterans Affairs

DOI: 10.3766/jaaa.17091

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Abstract

Background: Department of Veterans Affairs (VA) audiologists have anecdotally reported examining numerous Veterans with normal pure-tone thresholds; however, the prevalence of these patients within the VA is unknown. The VA audiological data repository provides an ideal dataset to examine this group of Veterans. Knowing the prevalence of normal-hearing Veterans within the VA system is the first step to understanding the underlying referral patterns and clinical complaints of Veterans. Data repositories which capture data from both normal and impaired populations provide an indispensable view into hearing health care which can help to improve diagnosis and treatment of Veterans' hearing difficulties.

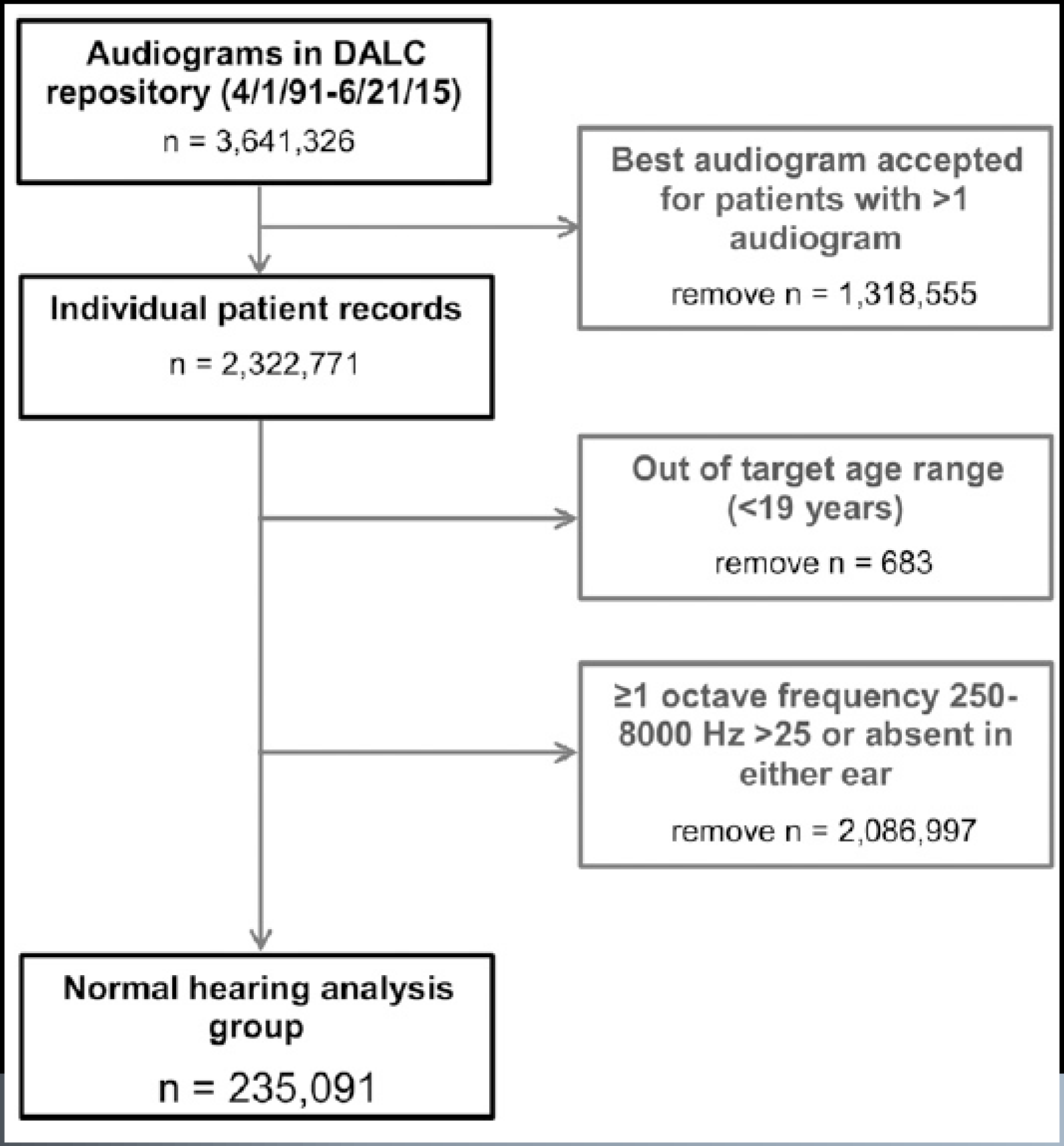
VA RR&D NCRAR

(Billings et al., *J Am Acad Aud*, in press)

Understanding in Noise: Normal Hearing?

Prevalence of normal pure-tone thresholds =

10.12%

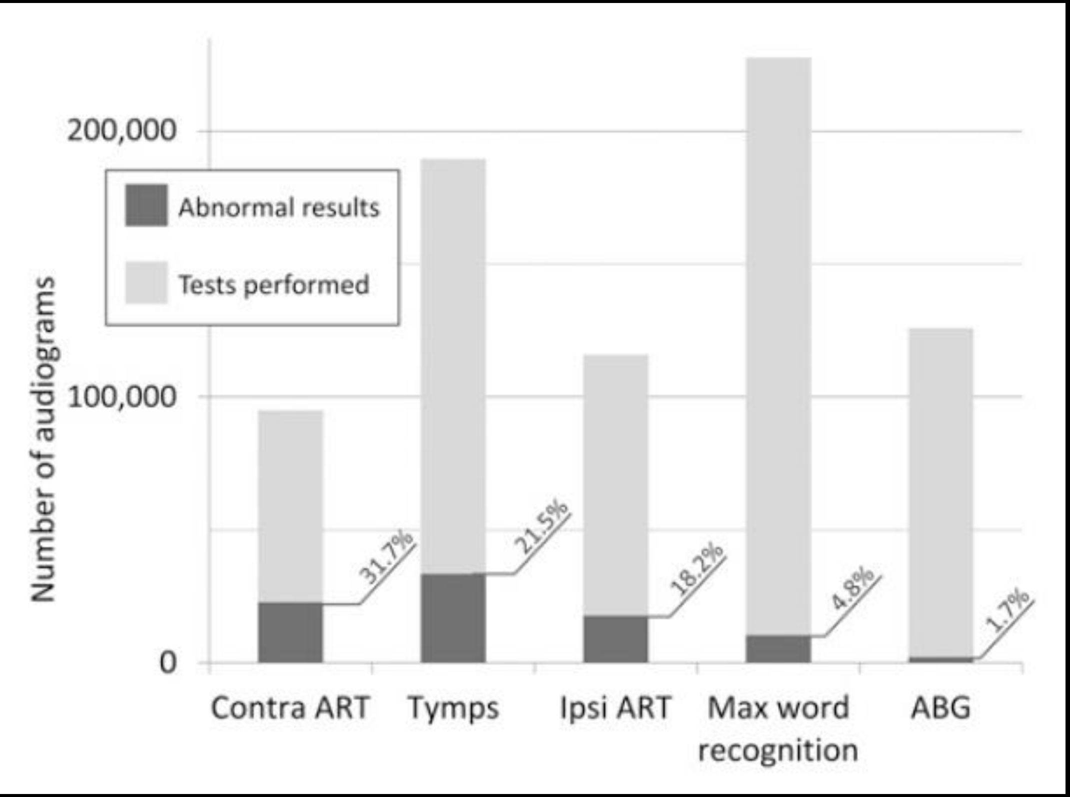


(Billings et al., *J Am Acad Aud*, in press)

Prevalence of Other Abnormal Results

Table 2. Breakdown of Included Records by Decade of Life

Age	Number	Percent
19–29	81,662	34.75
30–39	59,902	25.49
40–49	54,604	23.23
50–59	27,602	11.74
60–69	10,416	4.43
70–79	743	0.32
80 and older	85	0.04
Sub-total	235,014	100
No age available	77	—
Total	235,091	—

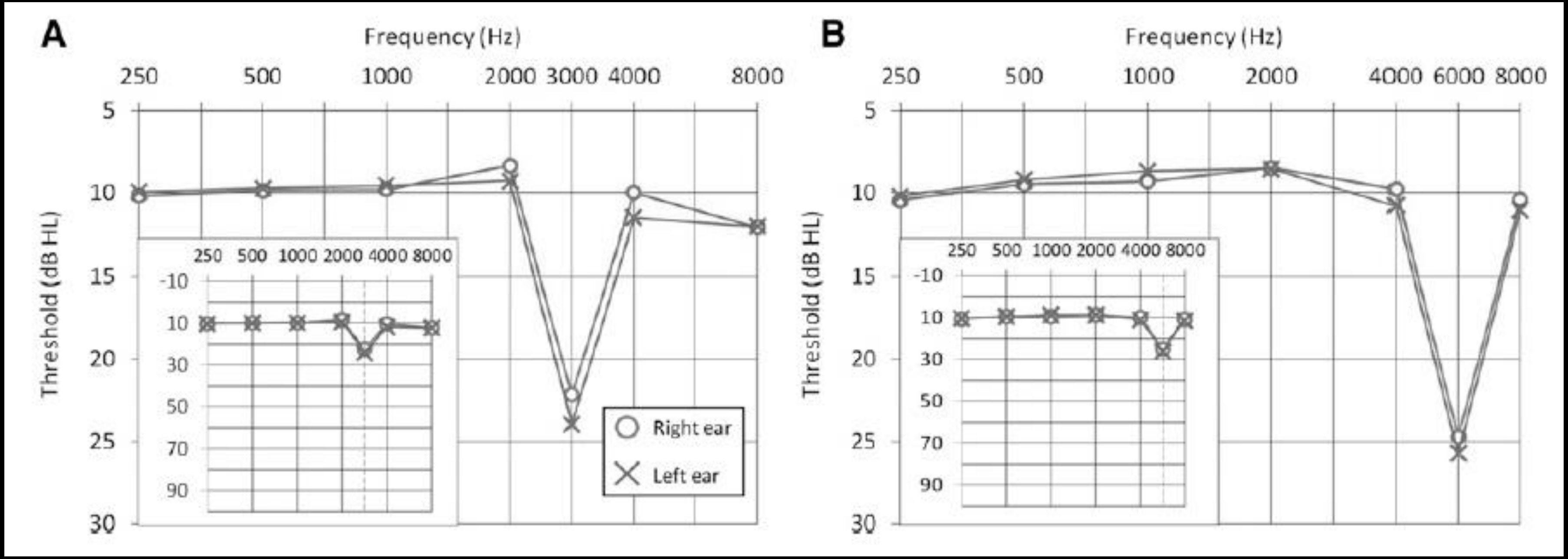


(Billings et al., *J Am Acad Aud*, in press)

Prevalence of Notches

Table 3. Depth and Prevalence of Unilateral and Bilateral Notches

Notch Frequency (Edge Frequency)	Right-Ear Notch Depth (Standard Deviation)	Left-Ear Notch Depth (Standard Deviation)	Right-Ear Notch Prevalence (%)	Left-Ear Notch Prevalence	Prevalence of Bilateral Notch (%)
4 (2, 8)	12.728 (2.94)	13.29 (3.20)	4.79	6.66	2.18
3 (2, 4)	12.69 (4.01)	13.34 (4.62)	2.22	2.54	0.46
6 (4, 8)	14.13 (5.04)	14.40 (5.36)	5.85	6.41	2.21



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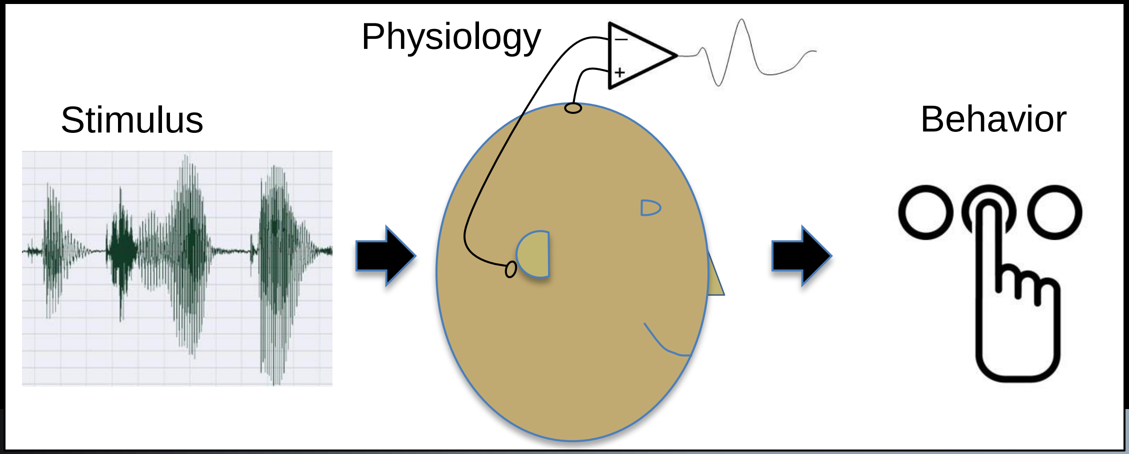
(Billings et al., *J Am Acad Aud*, in press)

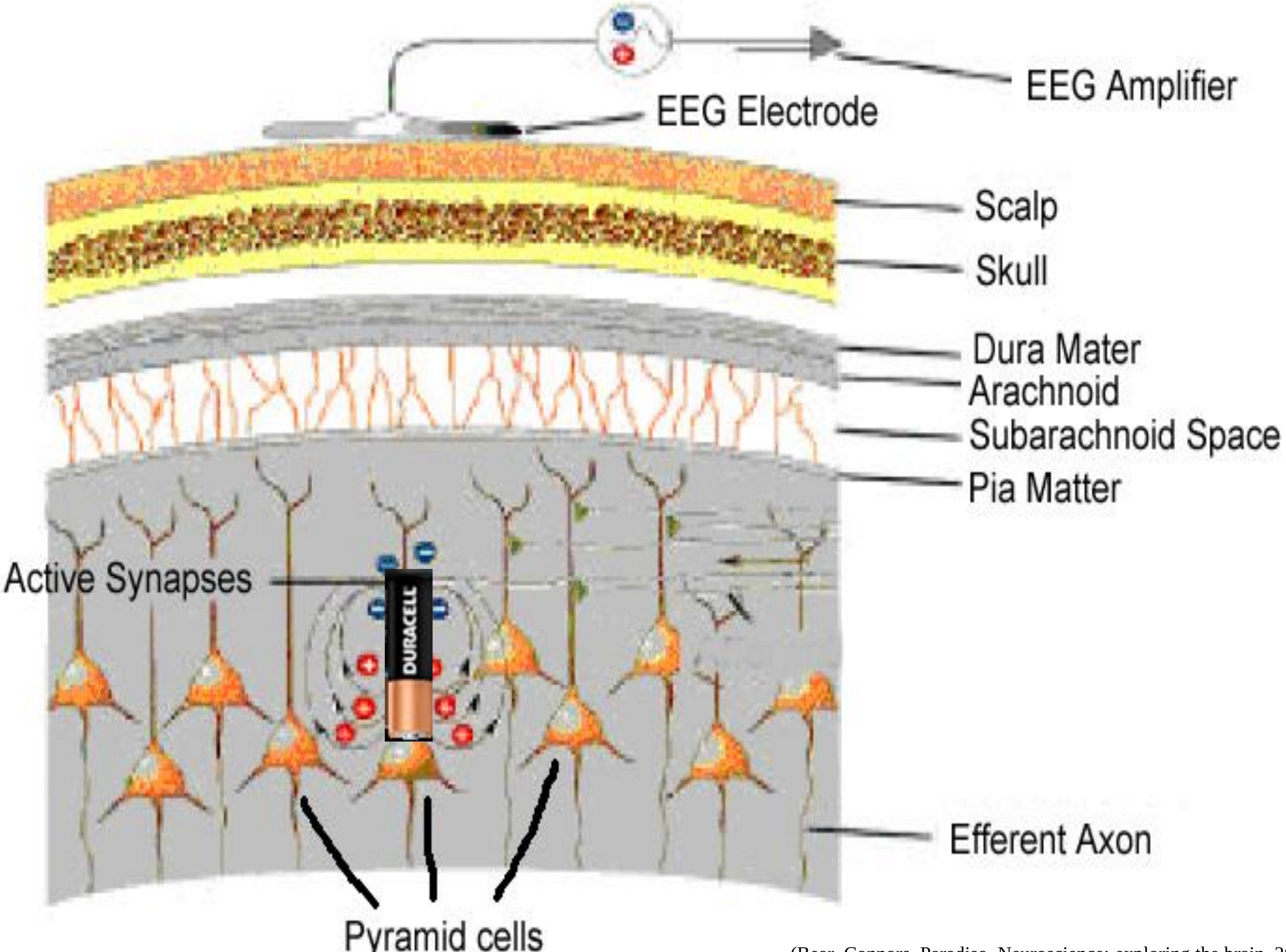
Speech Understanding in Noise

- Common problem for older individuals and individuals with hearing impairment
- Most frequent complaint among hearing aid users
- Difficult situation for many Veterans (e.g., traumatic brain injury, diabetes, etc.)

Our approach: Combine <u>behavior</u> with <u>brain</u> measures

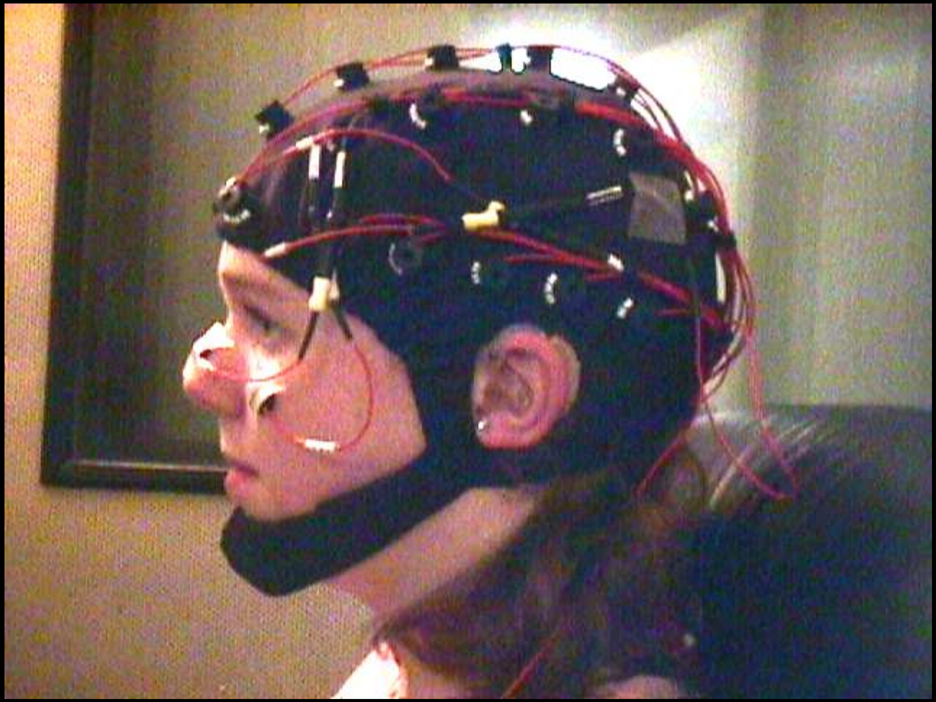
to improve understanding of perception-in-noise difficulties

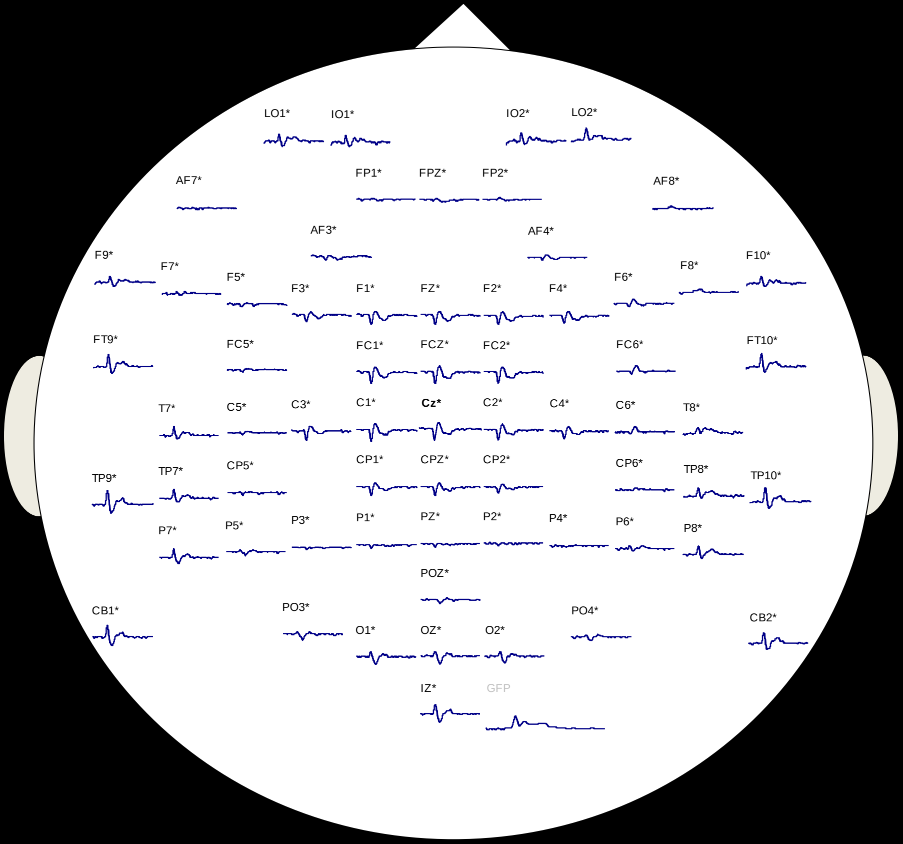




(Bear, Connors, Paradiso, Neuroscience: exploring the brain, 2001)

What are Auditory Evoked Potentials (AEPs)?





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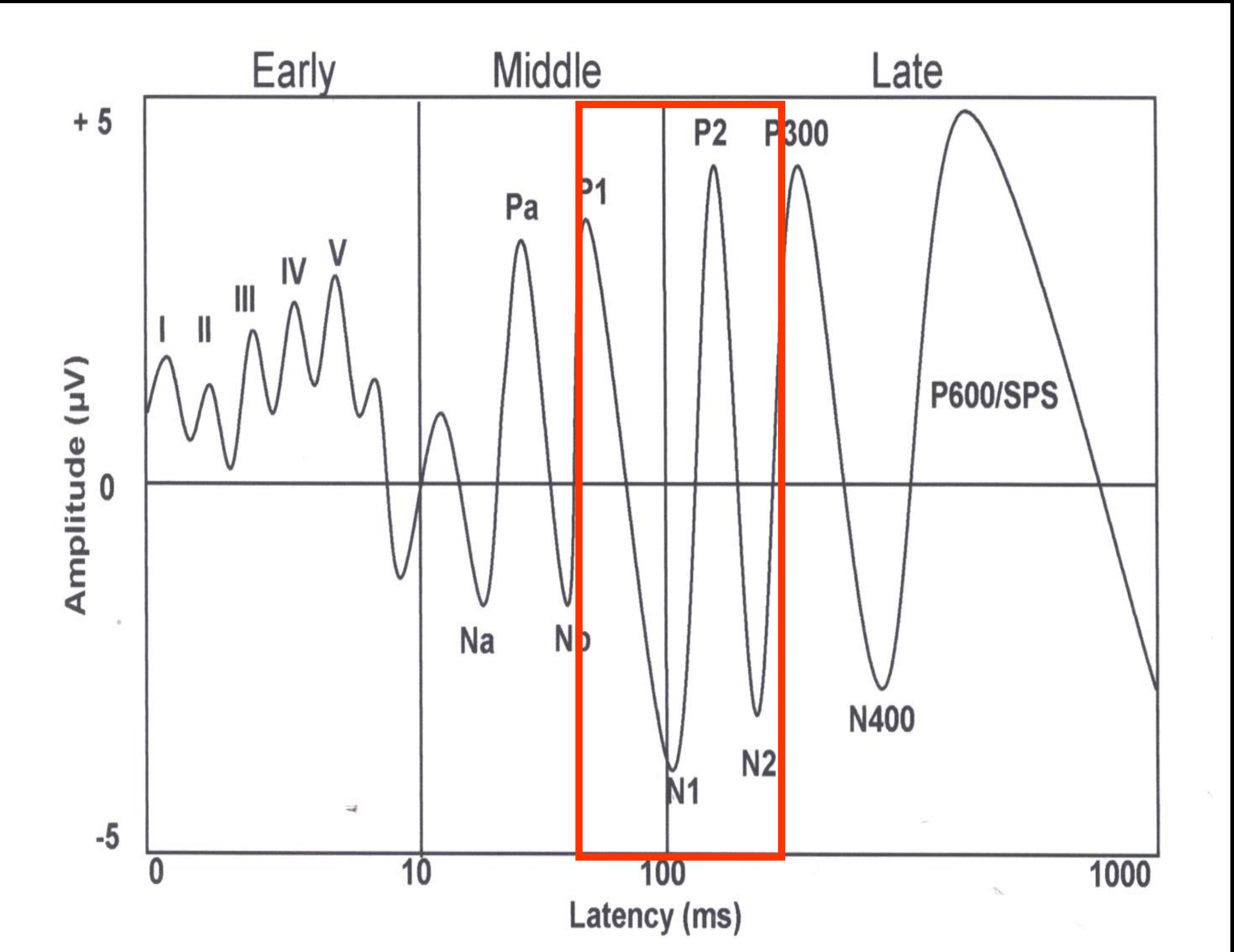
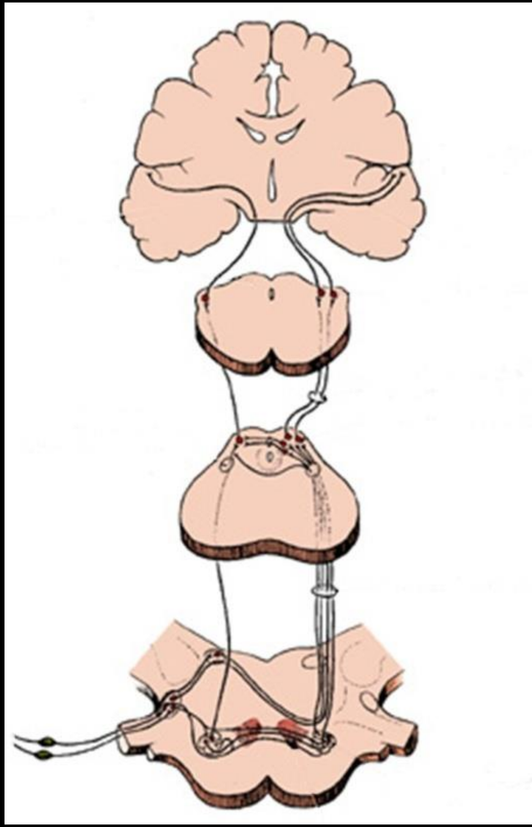
NCRAR

Auditory Evoked Potentials

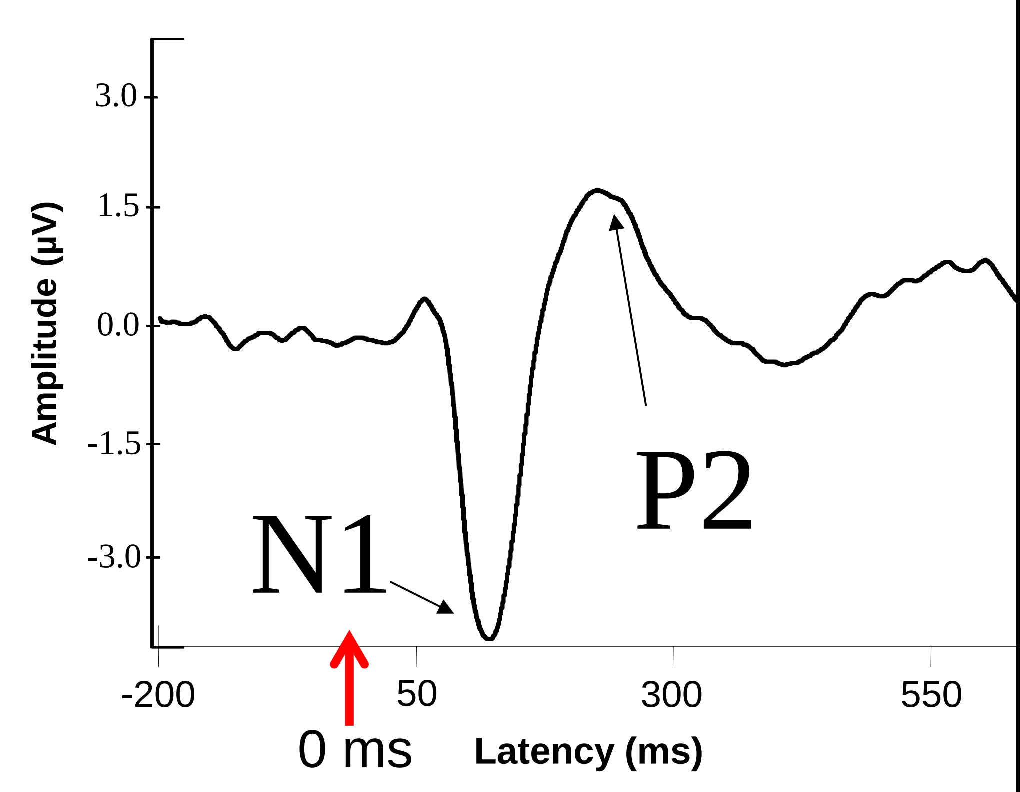




P1-N1-P2

(a.k.a., P50-N100-P250, vertex potential, obligatory response, slow cortical response, CAEP, ACC, etc)

Sensitive to acoustics of a stimulus



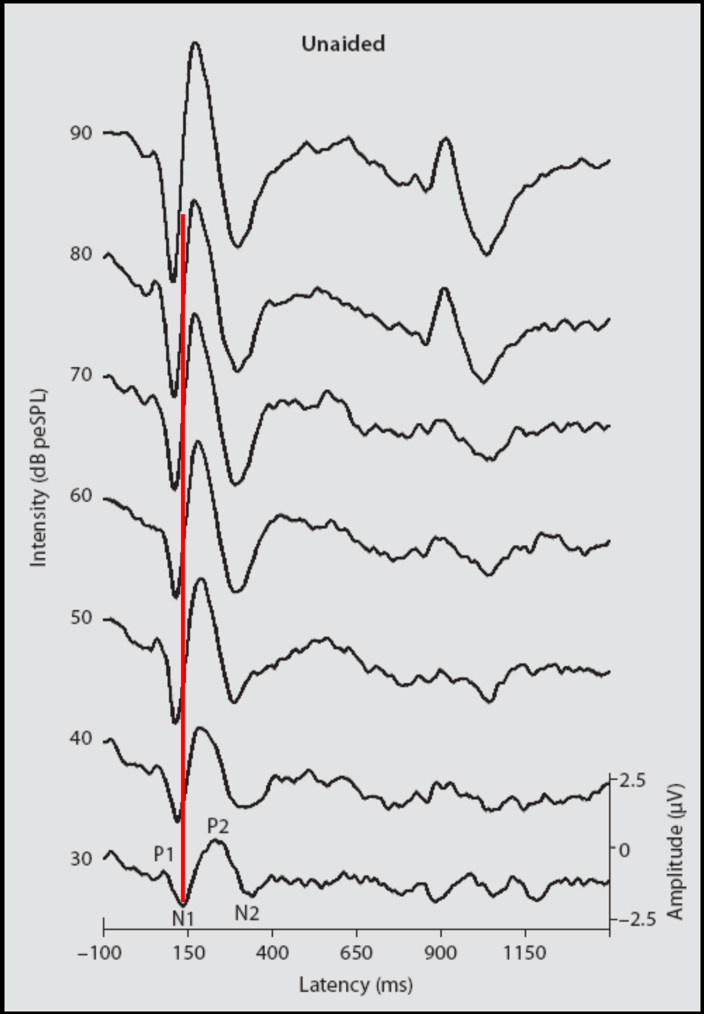
Sensitive to acoustic changes in environment:

- Consonant to vowel change (Tremblay et al., *Ear Hear* 27(2), 2006; Ostroff et al., *Ear Hear* 19(4), 1998)
- Amplitude envelope change (Martin et al., *JASA* 107(4), 2000)
- Tone-noise & noise-tone change (Martin et al., *Ear Hear* 20(1), 1999)
- Spectral change (Martin et al., 2000)
- VOT changes (Steinschneider et al., *J Neurophysiol* 82(5), 1997; Tremblay et al.,*Neuroreport* 13(15), 2002)
- SNR changes (Whiting et al., 1998; Billings et al., 2009)

Auditory Evoked Potentials

Increases in stimulus intensity

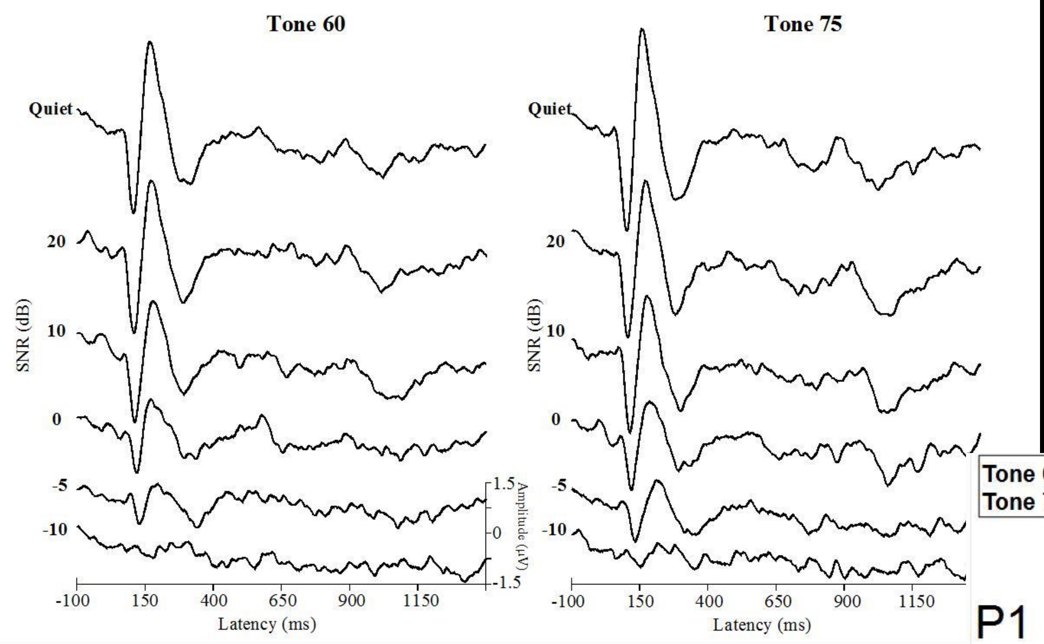
- amplitude ↑
- latency ↓



Question:

What is the effect of signal level and SNR on P1-N1-P2 complex?

Effect of SNR & tone level



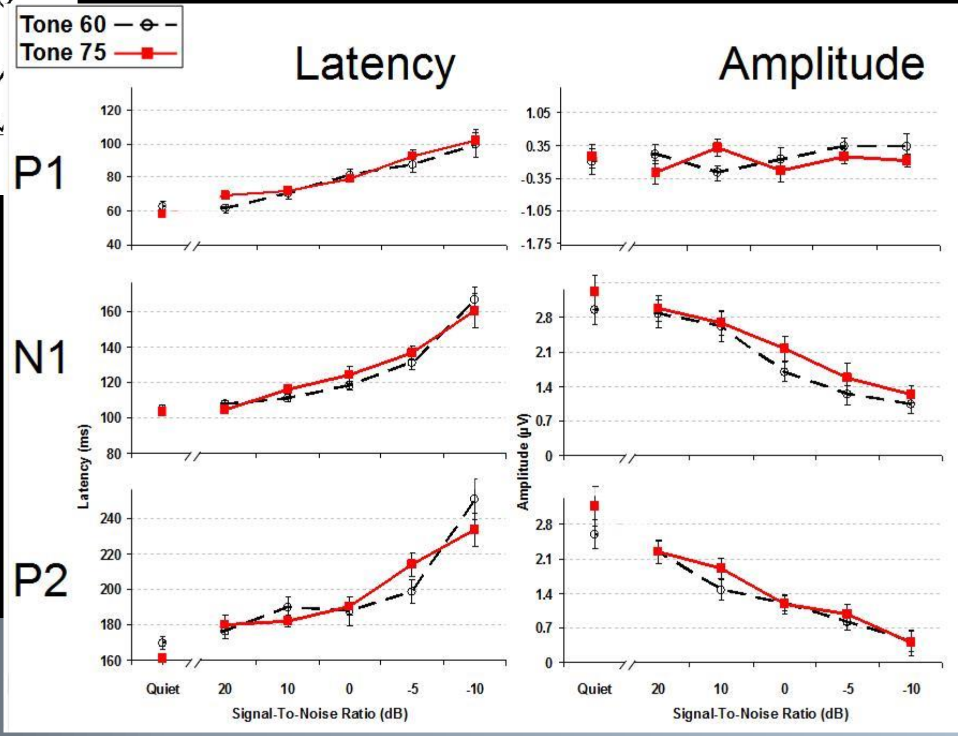
Subjects: 15 normal hearing

Stimuli: tones in noise

- 1k Hz tone: 750 ms duration; 7 ms rise/fall
- Noise: shaped white noise

12 Conditions (no hearing aid)

- 2 tones levels: 60 & 75 dB SPL
- 6 SNRs: Quiet, 20, 10, 0, -5, -10 dB



Question:

What is the effect of tone level and SNR on P1-N1-P2 complex?

-AEPs demonstrate sensitivity to SNR rather than absolute signal level

VA RR&D NCRAR

(Billings et al., *Hear Res* 254(1-2):15, 2009)

Speech Understanding in Noise

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Our approach: Combine behavior with brain measures

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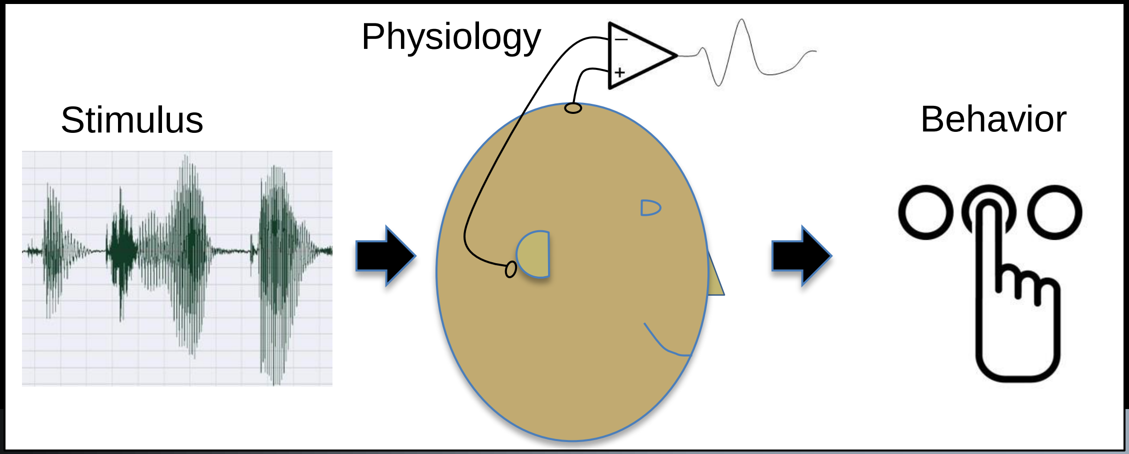


Possible Uses of Combining AEPs and Behavior:

- Understand variability of understanding in noise
- Difficult-to-test individuals
- Identify supra-threshold hearing impairments
- Aid in rehabilitation planning
- Monitor effectiveness of auditory training

Relationship between brain and behavior: Experiment 1

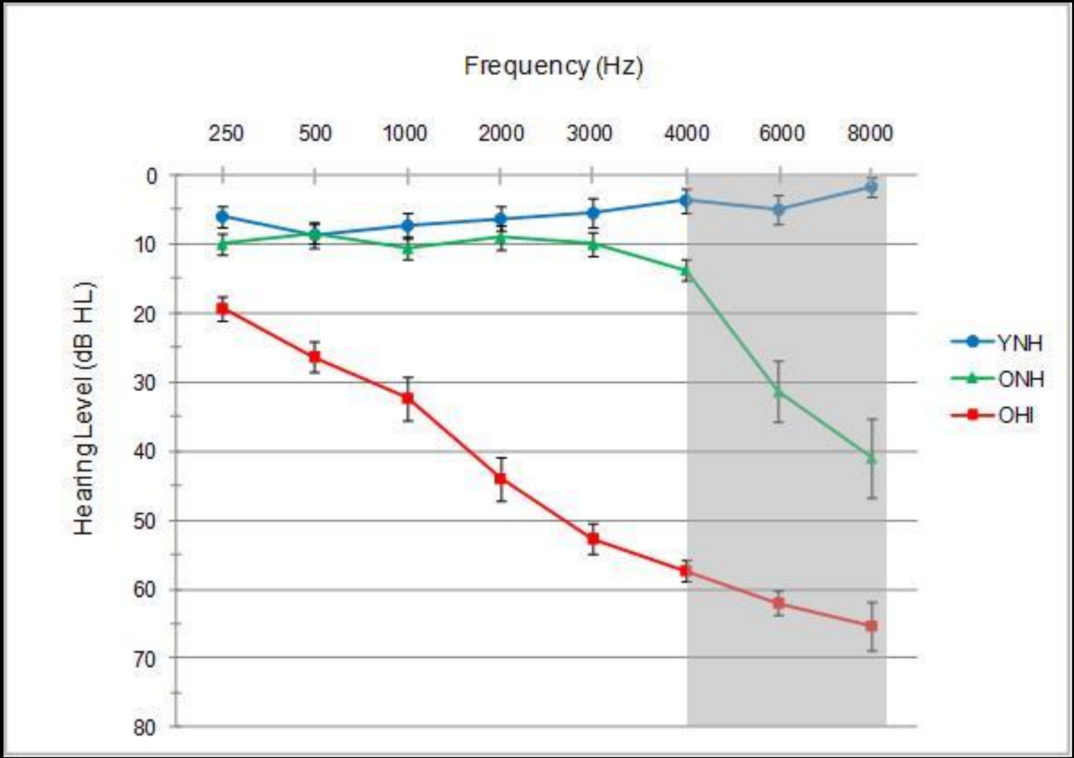
- Signals:
  - 4 signal levels = 50, 60, 70, and 80 dB SPL
  - Electrophysiology = syllable /ba/
  - Behavior = IEEE sentences
- Noise:
  - steady-state speech-spectrum noise
  - SNRs ranging from -10 to 35 dB

Signal Level (dB SPL)	Signal-to-Noise Ratio (dB)						
	-10	-5	0	+5	+15	+25	+35
50	Beh	Beh / CAEP	Beh	Beh / CAEP	—	—	—
60	Beh	Beh / CAEP	Beh	Beh / CAEP	Beh / CAEP	—	—
70	Beh	Beh / CAEP	Beh	Beh / CAEP	Beh / CAEP	Beh / CAEP	—
80	Beh	Beh / CAEP	Beh	Beh / CAEP	Beh / CAEP	Beh / CAEP	Beh / CAEP

B= Behavioral testing; EP = Evoked Potential; — = Did not test

Relationship between brain and behavior: **Experiment 1**

- Younger normal-hearing (YNH; n=15)
- Older normal-hearing (ONH; n=15)
- Older hearing-impaired (OHI; n=15)



Relationship between brain and behavior: Experiment 2

- Signals:
  - 4 signal levels = 50, 60, 70, and 80 dB SPL
  - No Electrophysiology
  - Behavior = NU-6 words (scored words correct & phonemes correct)
- Noise:
  - steady-state speech-spectrum noise
  - SNRs ranging from -10 to 35 dB
- Participants:
  - Younger normal-hearing (YNH; n=20)
  - Older normal-hearing (ONH; n=20)
  - Older hearing-impaired (OHI; n=20)

(Billings et al., Am J Audiol, 2016)

Relationship between brain and behavior:

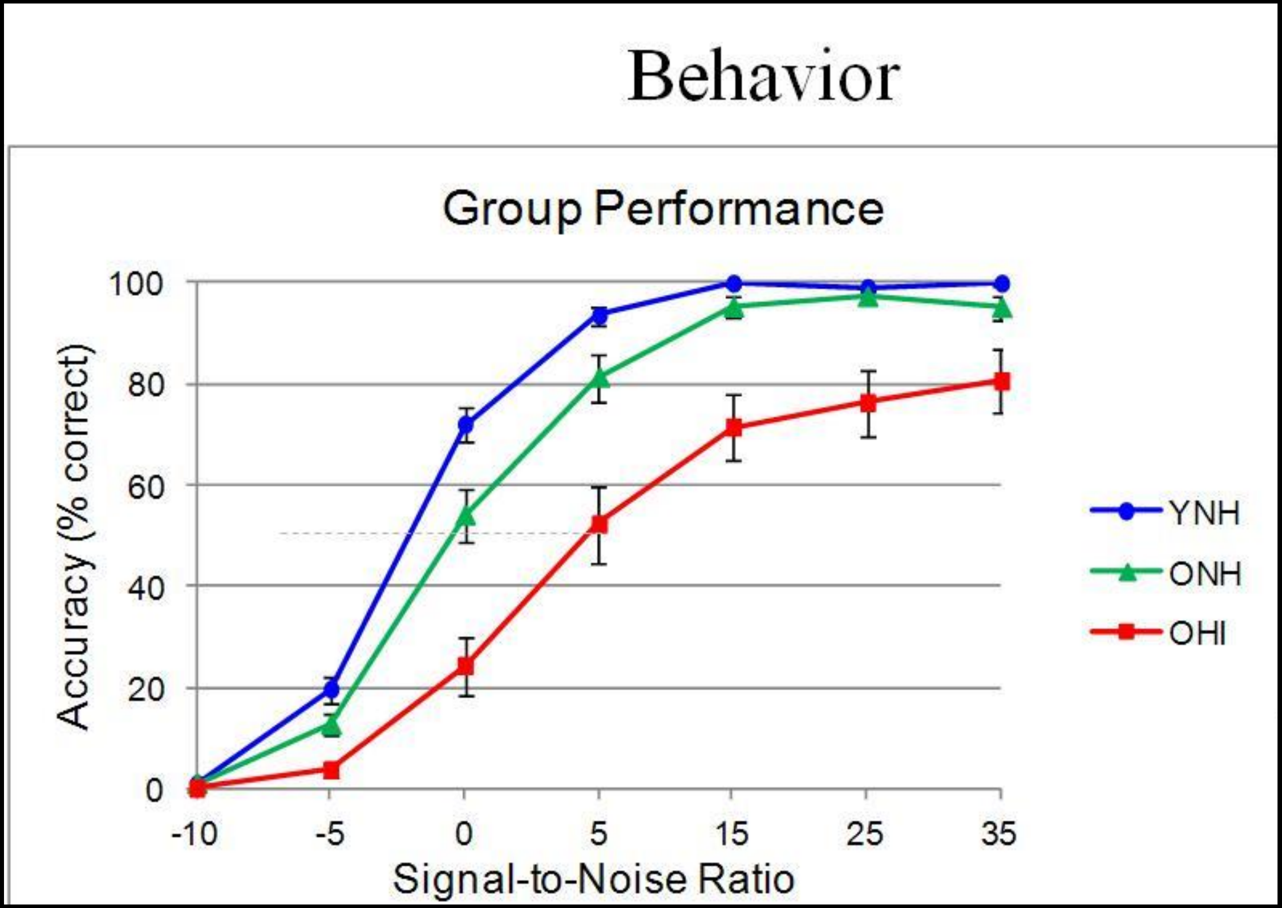
Experiment 3

- Signals:
  - 1 signal level = 75 dB SPL
  - Electrophysiology = syllable /ba/
  - Behavior = QuickSIN, WIN
- Noise:
  - steady-state speech-spectrum, four-talker babble, 1-talker modulated
  - SNRs ranging from -3 to 9 dB
- Participants:
  - Younger normal-hearing (YNH; n=10)
  - Older normal-hearing (ONH; n=10)
  - Older hearing-impaired (OHI; n=10)

(Maamor & Billings et al., Neurosci Lett, 2016)

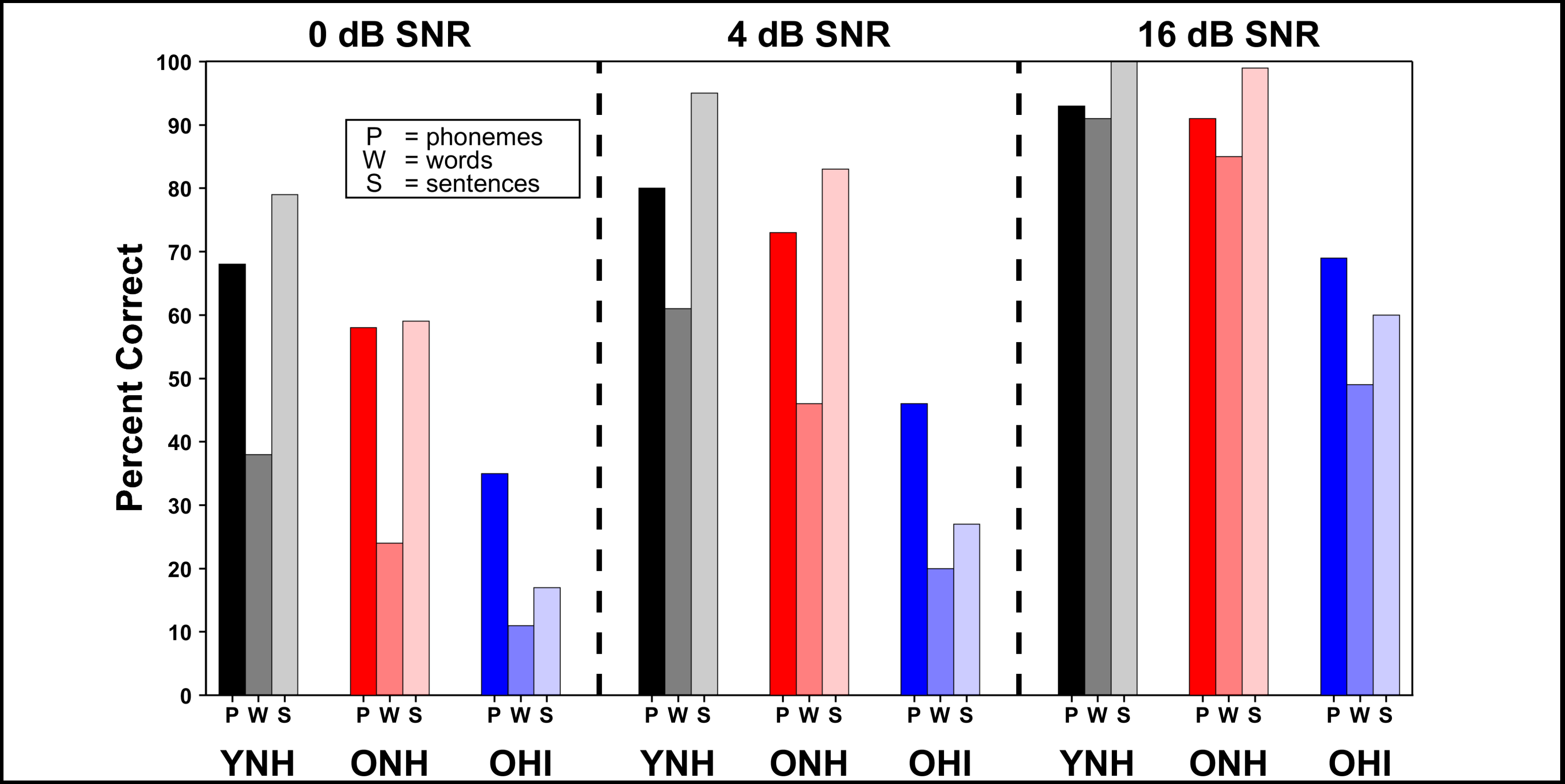
Relationship between brain and behavior

Experiment 1



(Billings et al., *Ear Hear*, 2015)

Relationship between brain and behavior: Experiments 1 & 2

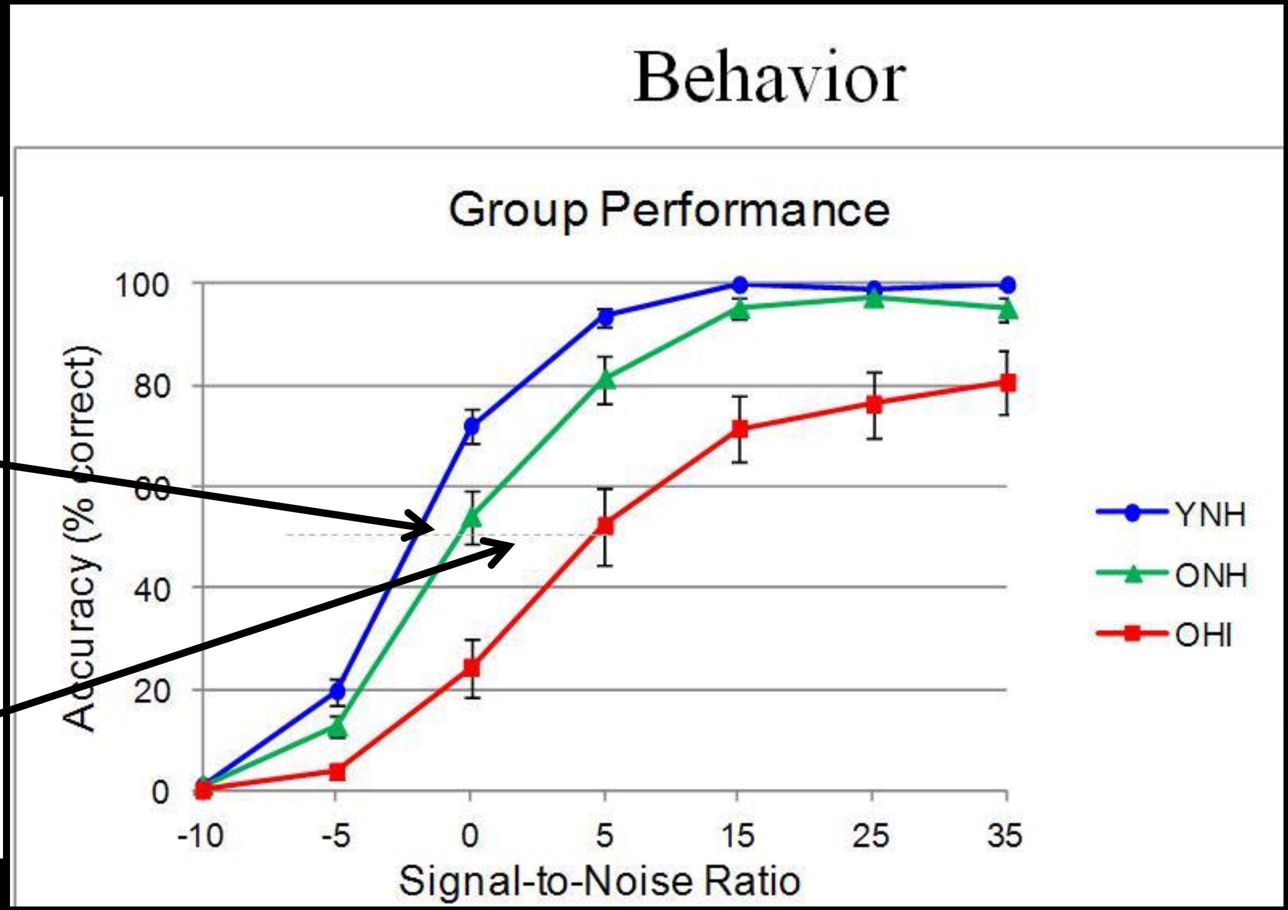


Relationship between brain and behavior

Experiment 1

-Difference between YNH and ONH (i.e. age effect)
~ 2-3 dB

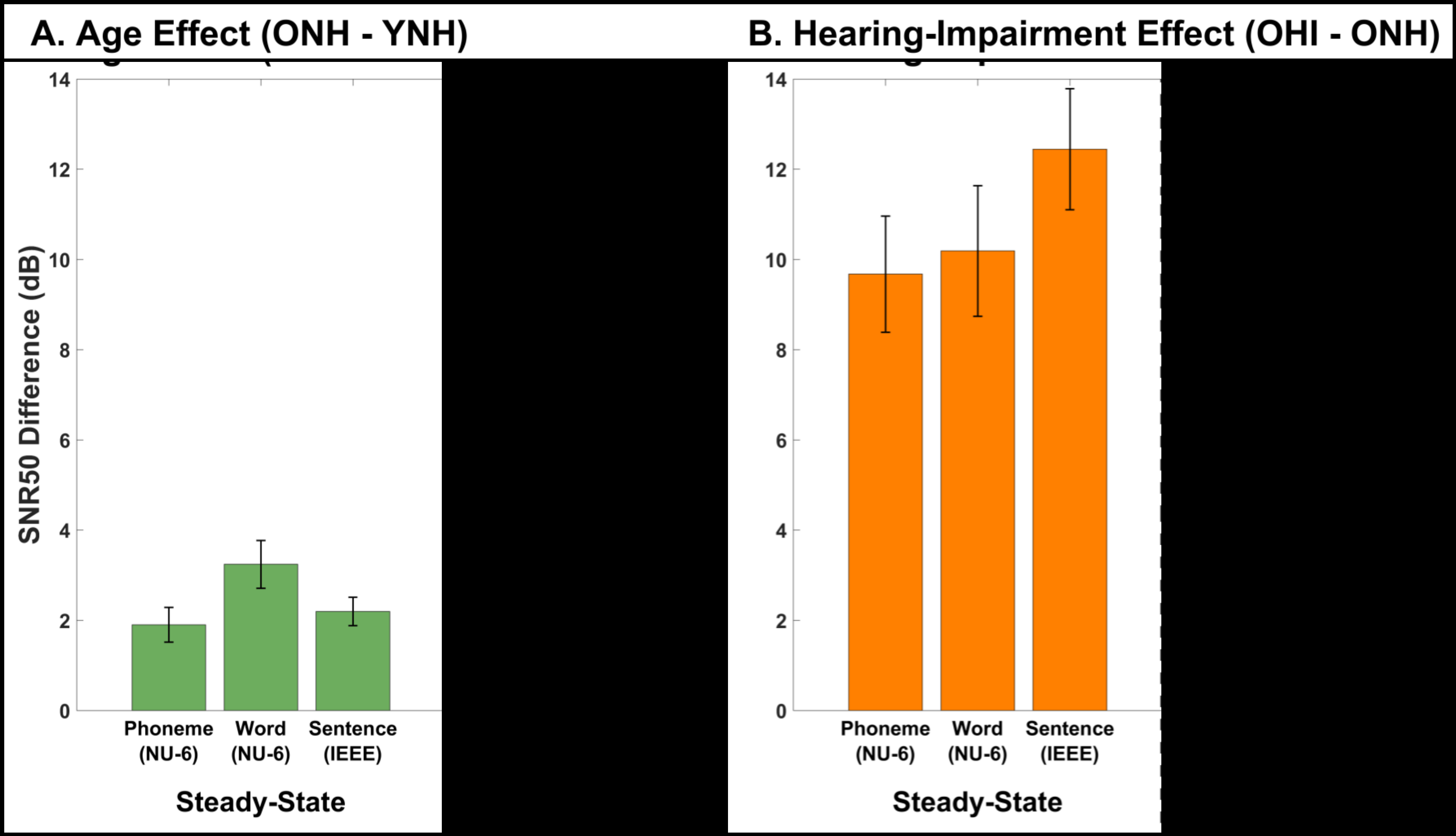
-Difference between ONH and OHI (i.e. hearing impairment effect)
~ 5-10 dB



(Billings et al., *Ear Hear*, 2015)

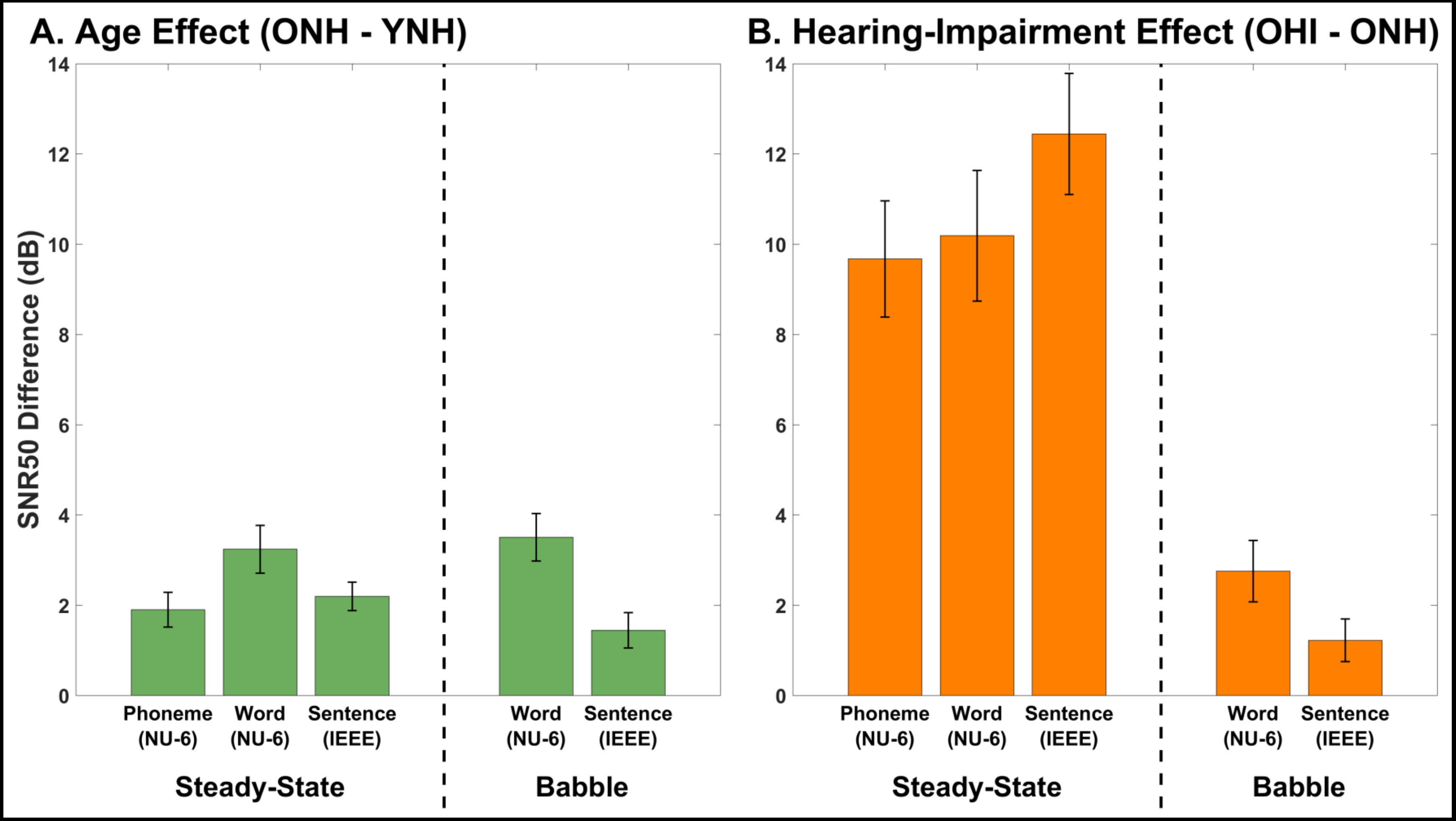
Effects of Age and Hearing Impairment

Experiments 1 & 2



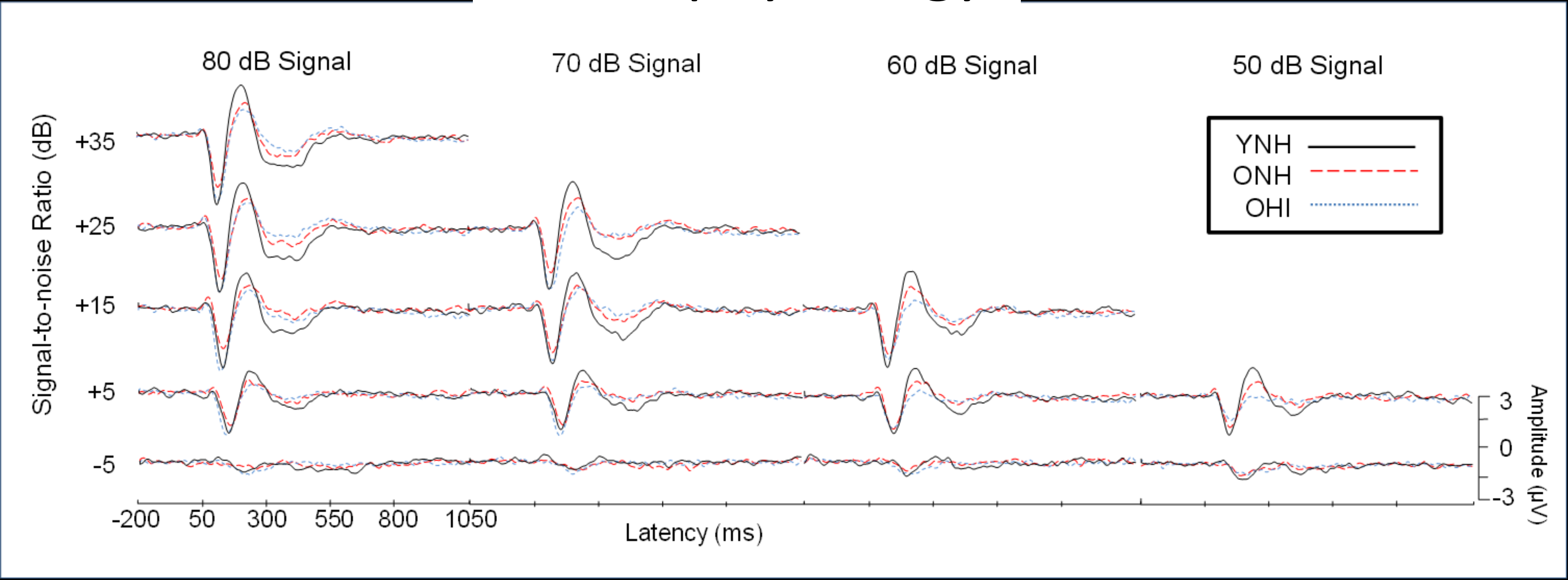
Effects of Age and Hearing Impairment

Experiments 1, 2 & 3



Relationship between brain and behavior
Experiment 1

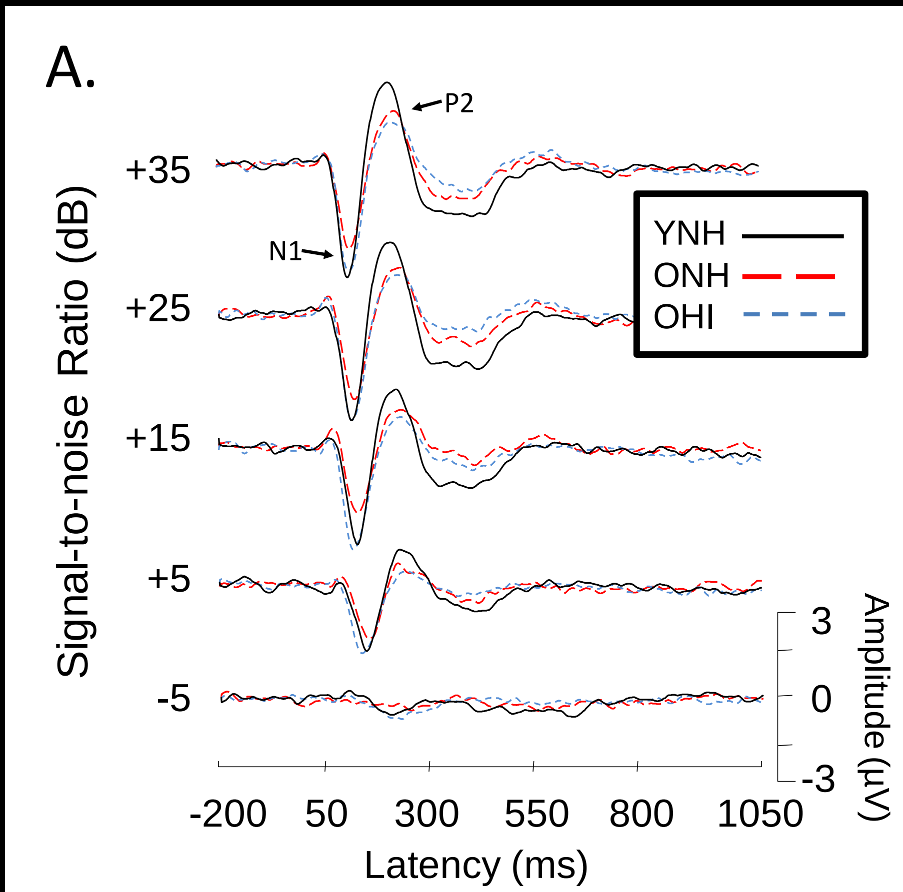
Electrophysiology

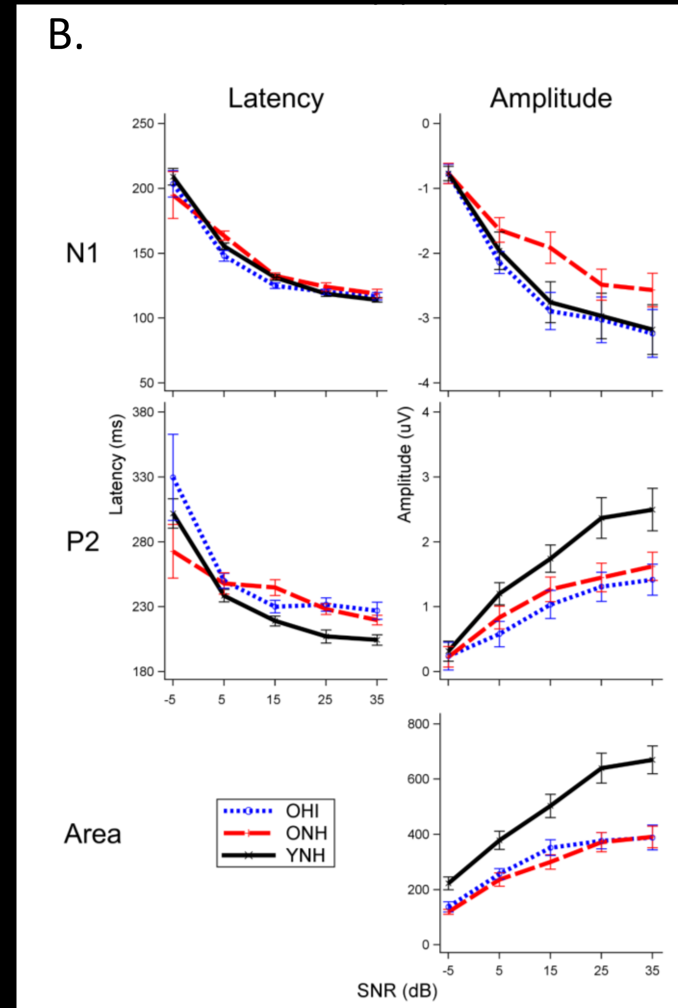


(Billings et al., *Ear Hear*, 2015)

Relationship between brain and behavior

Experiment 1

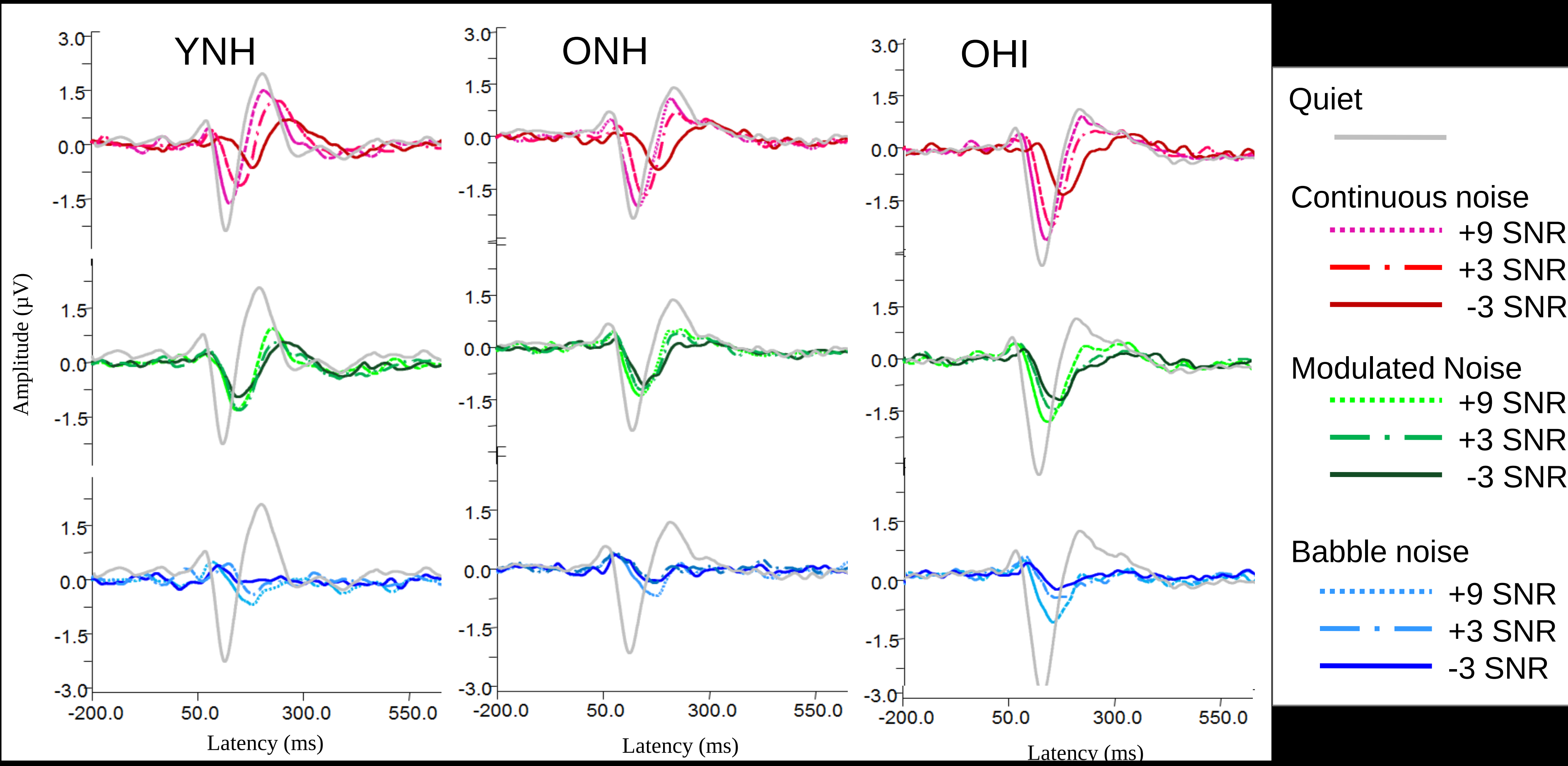




(Billings et al., *Ear Hear*, 2015)

Relationship between brain and behavior

Experiment 3

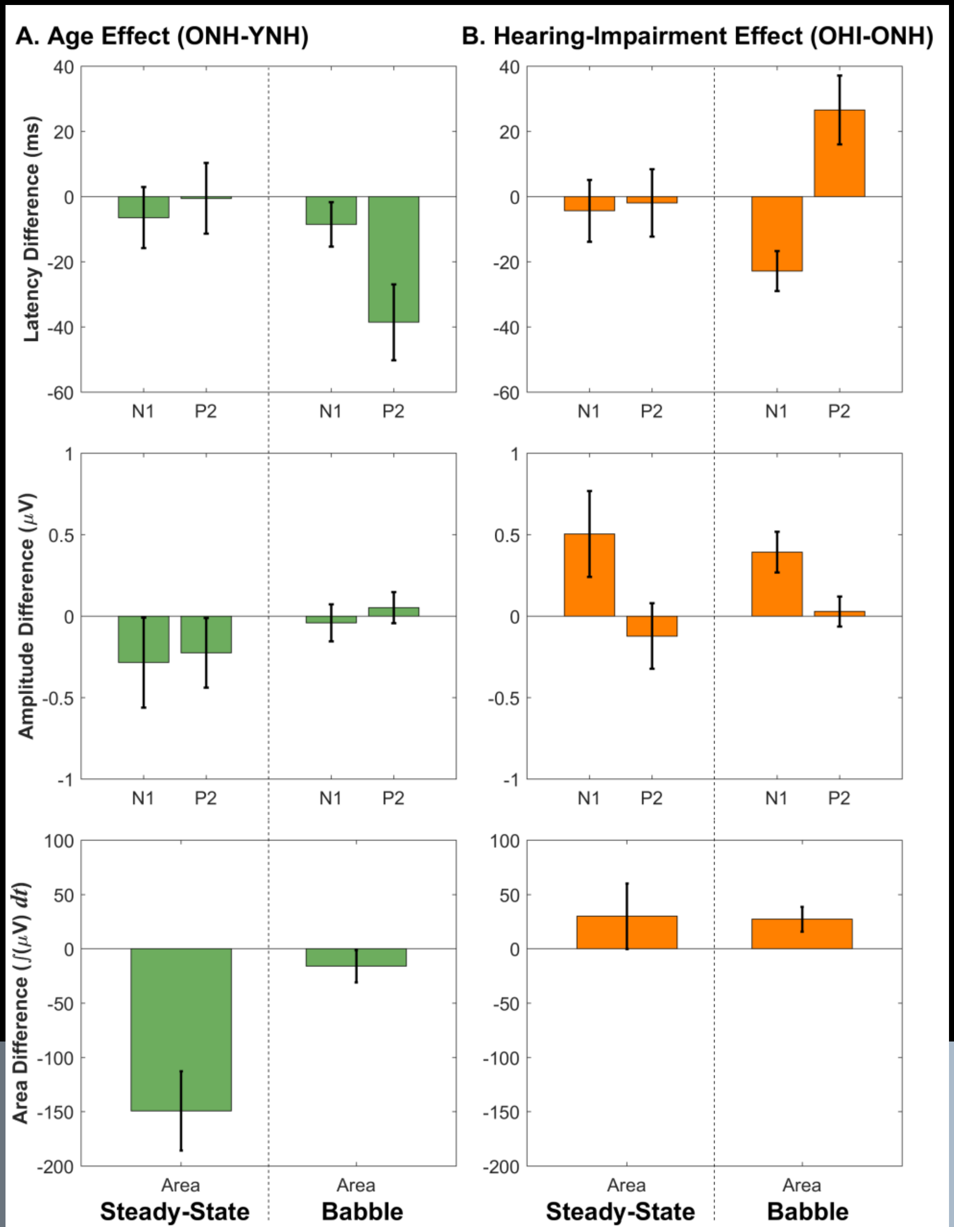


(Maamor & Billings et al., Neurosci Lett, 2016)

Effects of Age and Hearing Impairment
<u>Experiments 1 & 3</u>

Effects of <u>aging</u> generally
- minimal change in latency (babble?)
- reductions in amplitude/area

Effects of <u>hearing impairment</u>
- minimal change in latency (babble?)
- increases in amplitude/area



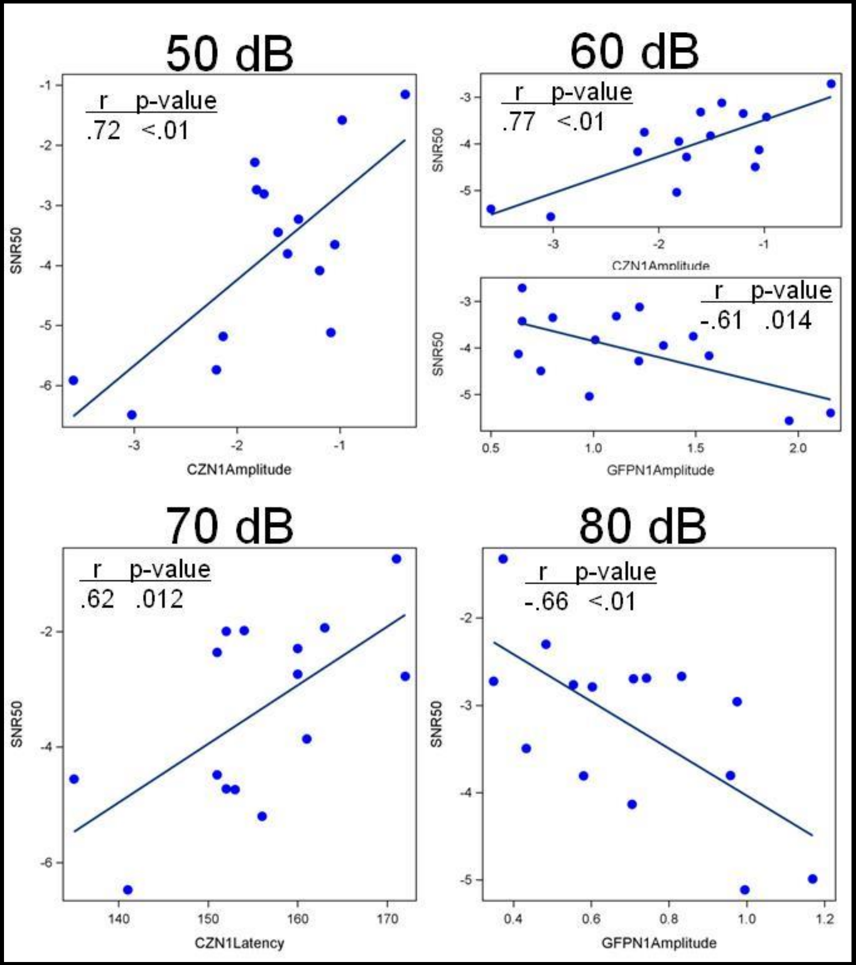
The Brain-Behavior Relationship: Correlation

Experiment 1

Correlations

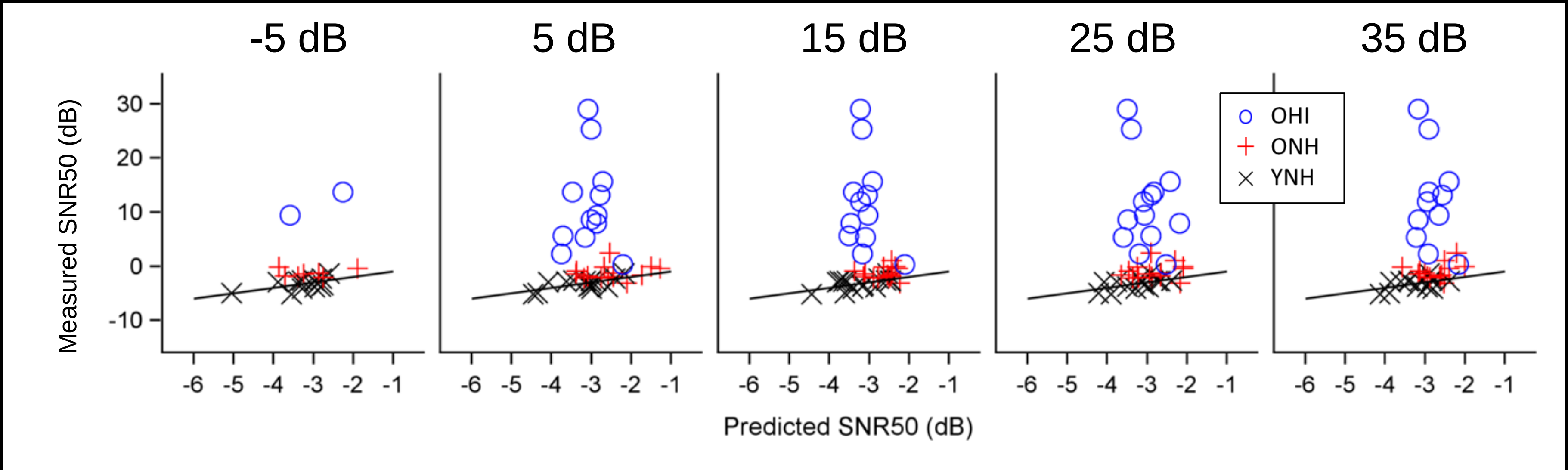
- Behavior vs. Electrophysiology
  SNR50 Peak value

- N1 stood out as best correlate, especially N1 amplitude



Using brain measures to predict behavior (SNR50)

Experiment 1



Prediction Accuracy with Model:

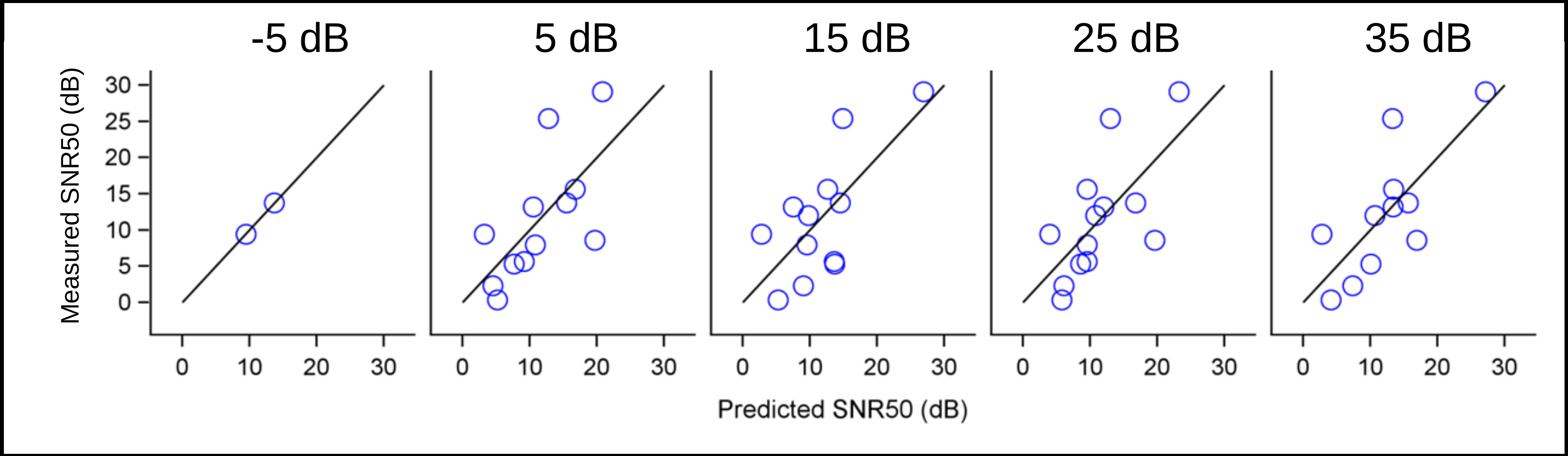
- predictions of YNH SNR50 within 1 dB
- predictions of ONH SNR50 within about 2 dB
- predictions of OHI SNR50 within 16 dB

VA RR&D NCRAR

(Billings et al., *Ear Hear*, 2015)

Using brain measures to predict behavior (SNR50)

Experiment 1



Prediction Accuracy With OHI Prediction Model:

- Predictions of OHI SNR50 within 7 dB
- Needs improvement to be clinically meaningful

VA RR&D NCRAR

(Billings et al., *Ear Hear*, 2015)

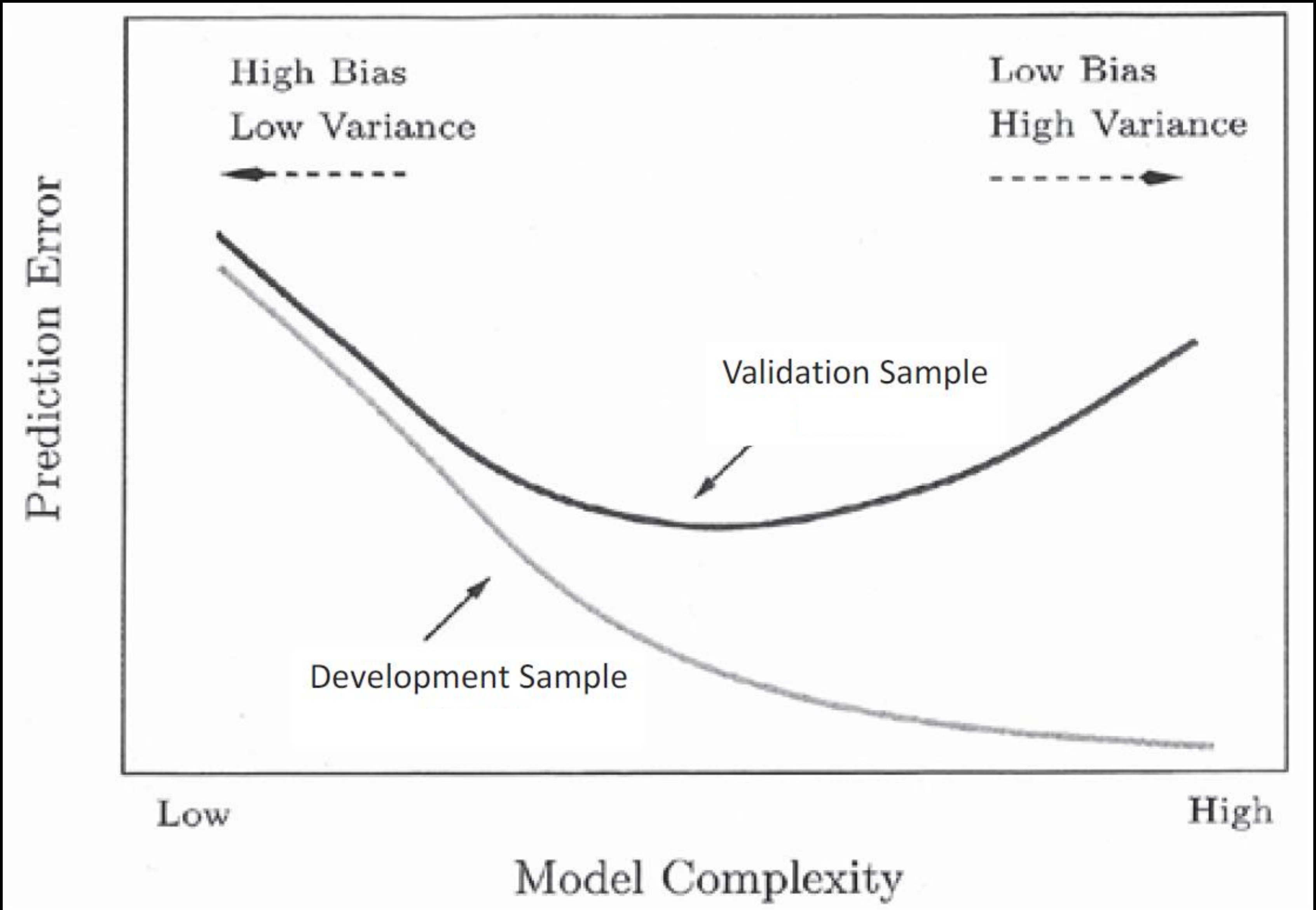
Using brain measures to predict behavior (SNR50)

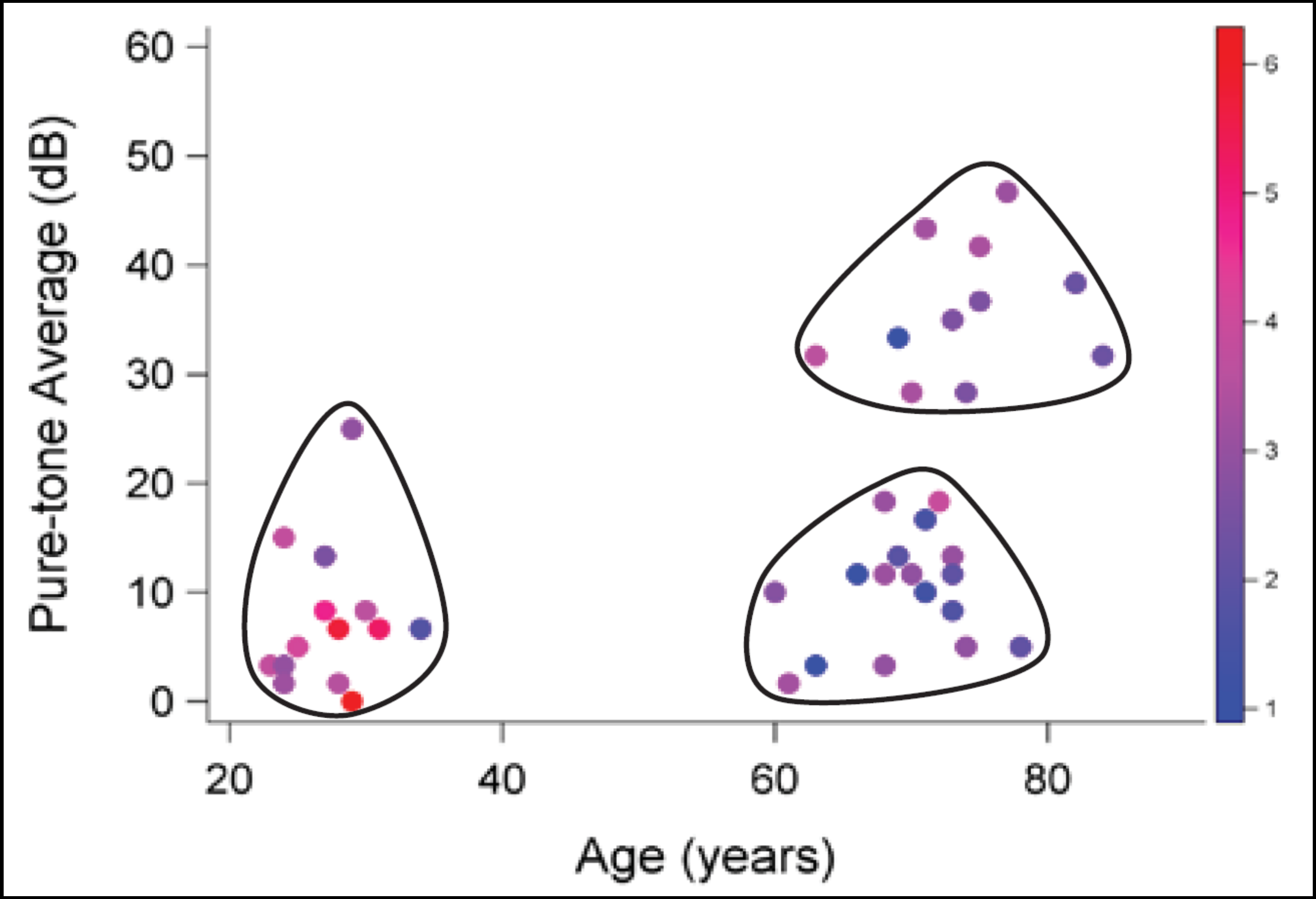
Experiments 1 & 3

With babble noise and one model for all 3 groups, predictions get a little worse for YNH, but improve for ONH and OHI; justifies one model for all groups.

	Model Development			Model Accuracy	
	Predicted Variable	Training Group	EP Measures	Test Group	RMPSE (dB)
Experiment 1					
	IEEE SNR50				
		YNH	5 peak + 2 area	YNH	0.7
				ONH	1.9
				OHI	16.7
			2 area	YNH	0.7
				ONH	2.7
				OHI	16.5
		OHI	5 peak + 2 area	OHI	7.8
			2 area	OHI	6.9
Experiment 3					
	QuickSIN SNR50				
		All subjects	2 peak + 2 area		
				YNH	1.1
				ONH	1.2
				OHI	1.2
				All subjects	1.2
	WIN SNR50				
		All subjects	2 peak + 2 area		
				YNH	2.9
				ONH	2.1
				OHI	2.3
				All subjects	2.4

VA RR&D NCRAR


High Bias
Low Variance
Low Bias
High Variance
Prediction Error
Validation Sample
Development Sample
Low
High
Model Complexity

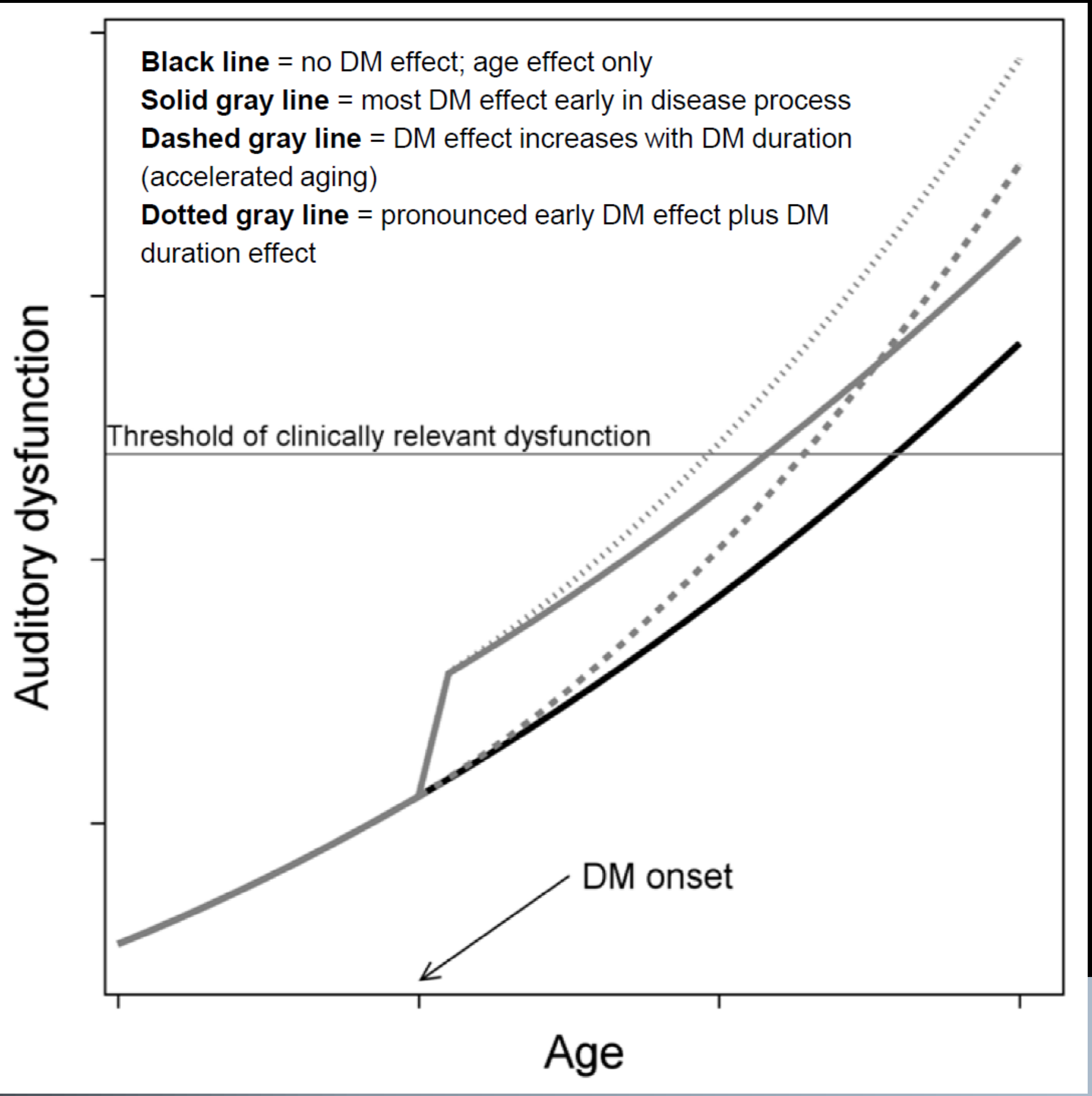

Pure-tone Average (dB)
60
50
40
30
20
10
0
20
40
60
80
Age (years)
6
5
4
3
2
1

Summary

1. Variability in understanding speech in noise is large, with SNR50s differing by 30 dB within a relatively homogenous OHI
2. Aging effects on behavior (SNR50) are 2-4 dB; Hearing impairment effects are 2-12 dB
3. Aging and hearing impairment effects on AEPs are complex for latency; for amplitude, smaller amplitudes with age, and larger amplitudes with hearing impairment
4. Brain measures are correlated with behavior and can predict behavior well in certain cases (to within 1 dB for YNH; 2 dB for ONH; 2-6 dB for OHI or better in babble)
5. Further development of prediction models needed
    - Larger studies with continuous age and hearing loss
    - Use of validation samples to avoid overfitting

Interactions between aging and other pathologies

Aging may interact with different pathologies in distinct ways.

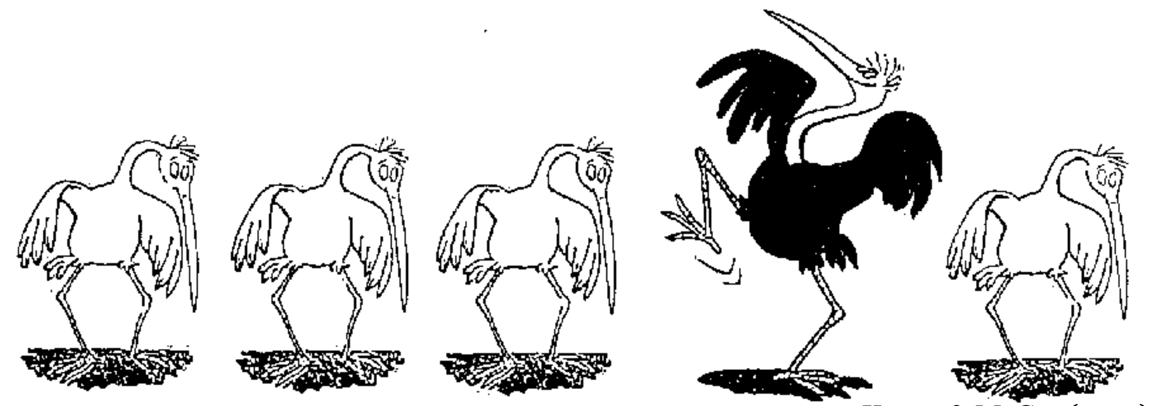


(Konrad-Martin et al., *Ear Hear*, 2016)

VA RR&D NCRAR

Adding Cognitive Measures to Brain-Behavior Relationship

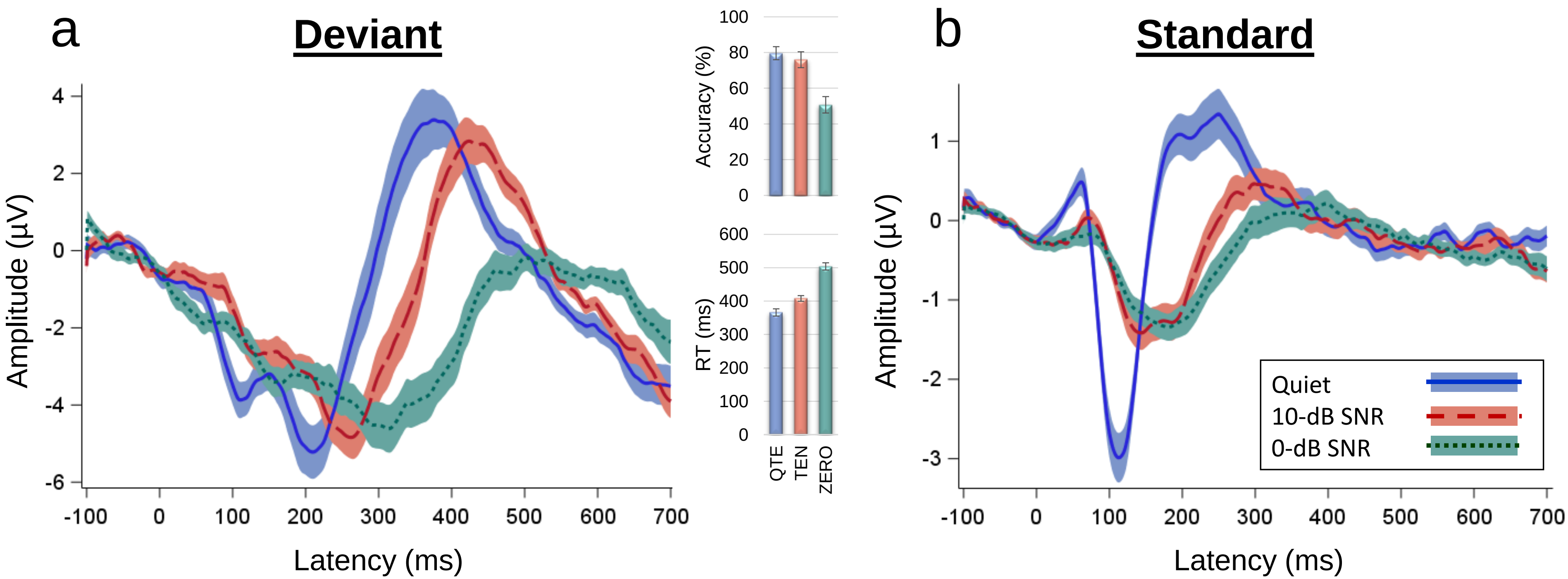
- Electrophysiology: /ba/ & /da/ presented in oddball
  - with 4-talker noise background
  - 3 signal-to-noise ratios: 0 dB, 10 dB, and Quiet (no noise)



Kraus & McGee (1994)

- Behavior: QuickSIN
- Cognitive: Digit-Symbol Coding from WAIS-III
- n=34 non-diabetic controls from diabetes study

Adding Cognitive Measures to Brain-Behavior



VA RR&D NCRAR

(Billings et al., *Ear Hear*, in press)

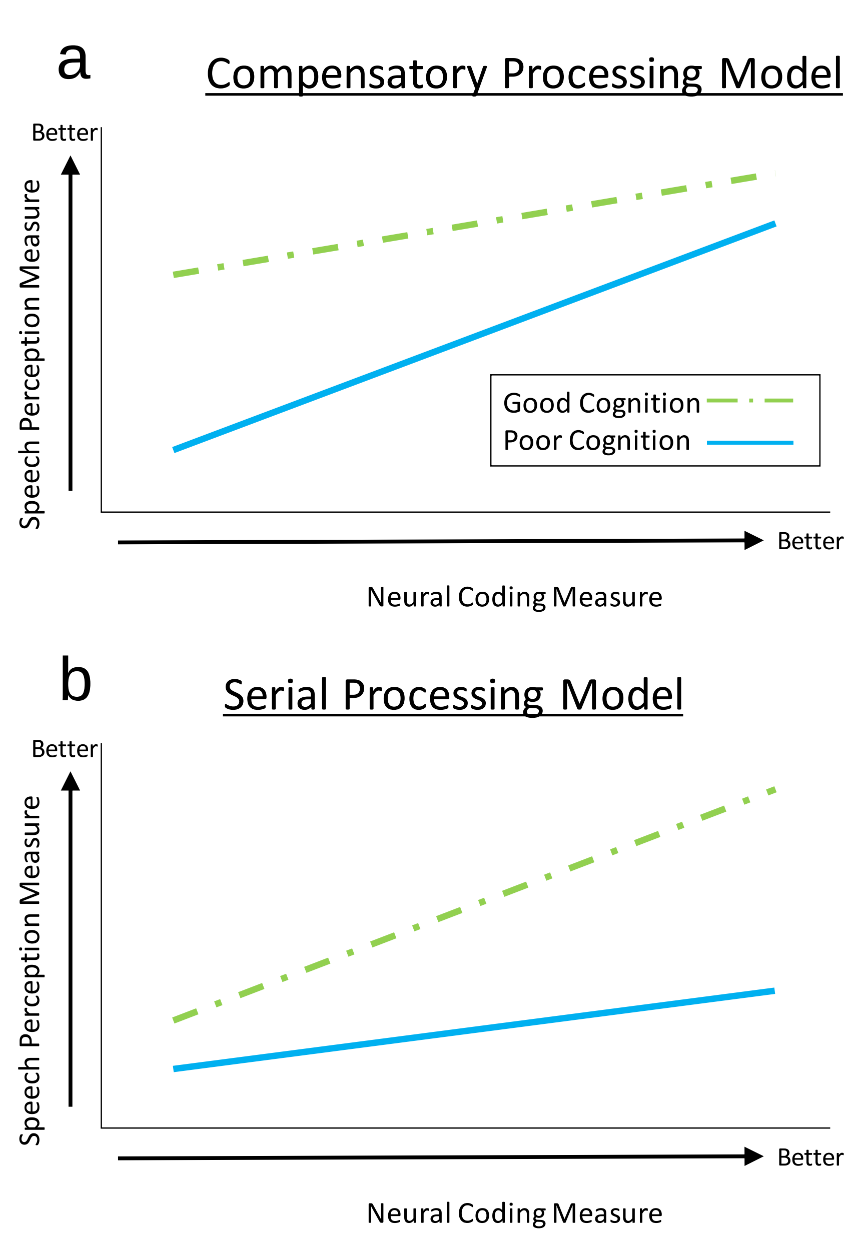
Adding Cognitive Measures to Brain-Behavior

Model Assumptions:
-better neural coding = better speech perception
-better cognition = better speech perception

Compensatory Processing Model:
-cognition compensates for poor neural coding
-less compensation when coding is good

Serial Processing Model:
-poor coding limits cognitive benefit
-effect of cognition is greatest when signal is best represented neurally

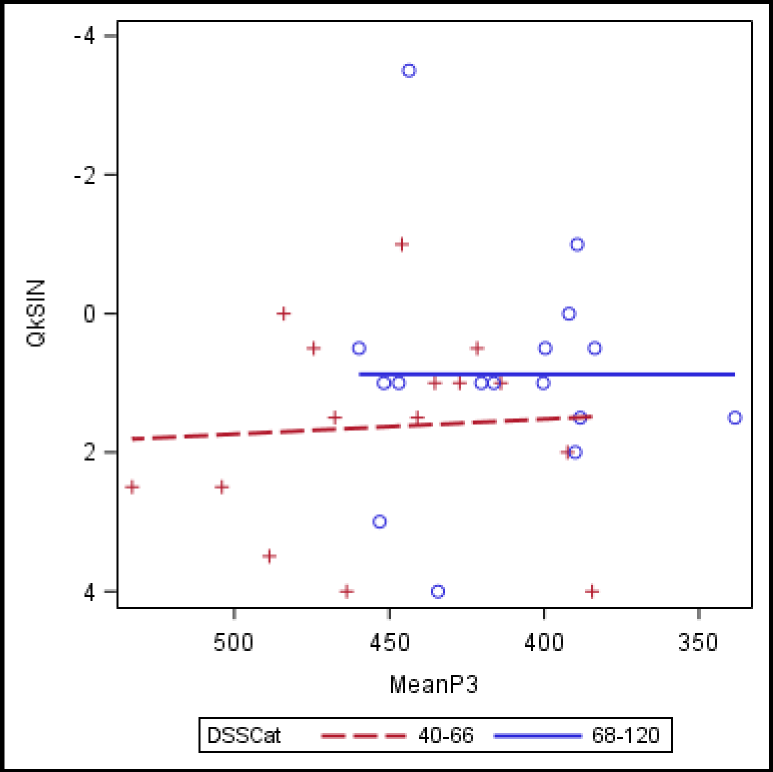
P3 vs N1

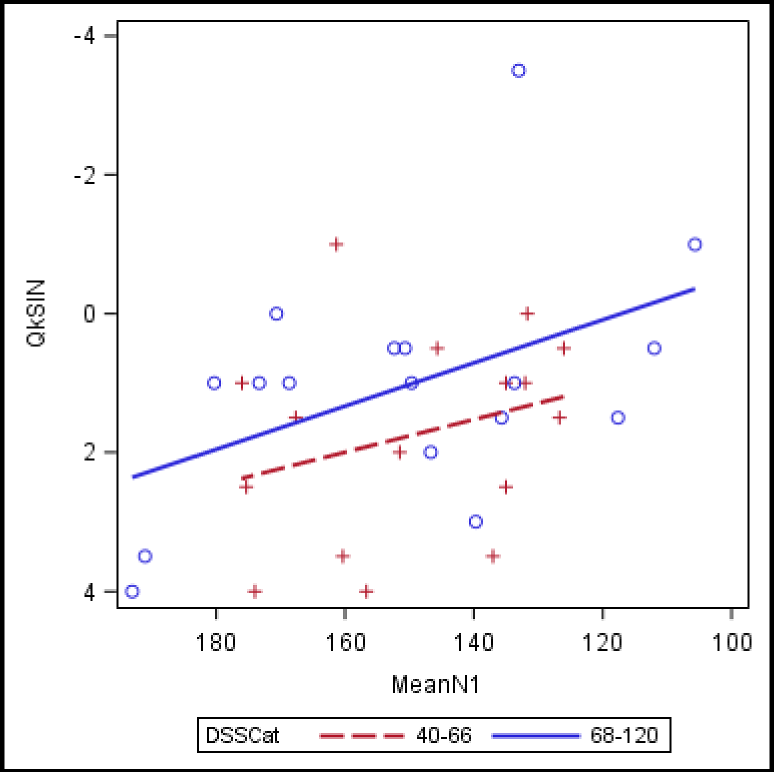


VA RR&D NCRAR

(Billings et al., *Ear Hear*, in press)

Adding Cognitive Measures to Brain-Behavior





-better cognition results in better speech perception
-better coding results in better speech perception (only for N1)
-compensatory and serial processing models not supported
-data appear to support an additive processing model

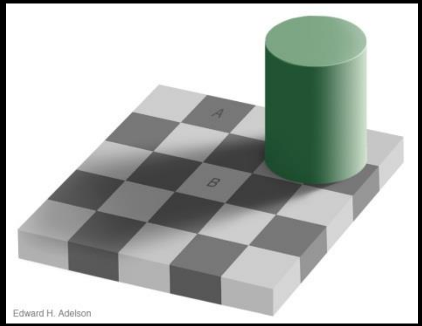
VA RR&D NCRAR

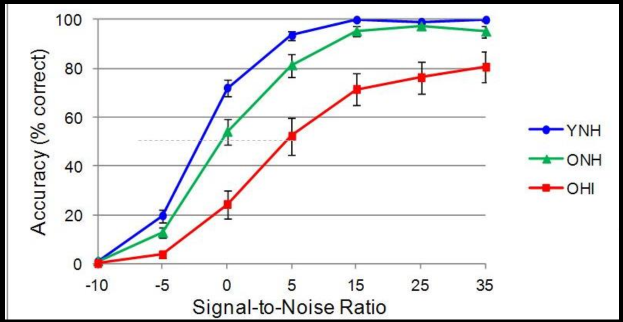
(Billings et al., *Ear Hear*, in press)

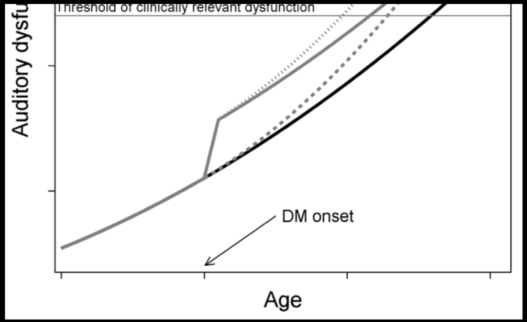
How does this impact the clinic?

Good vs Poor Performers

- Subject factors: Subject factors: hearing status, age, medical history, innate ability, cognitive processing, neural plasticity & learning, etc
- Stimulus factors: signal level, SNR, signal type, noise type, spatial separation, multisensory, etc.

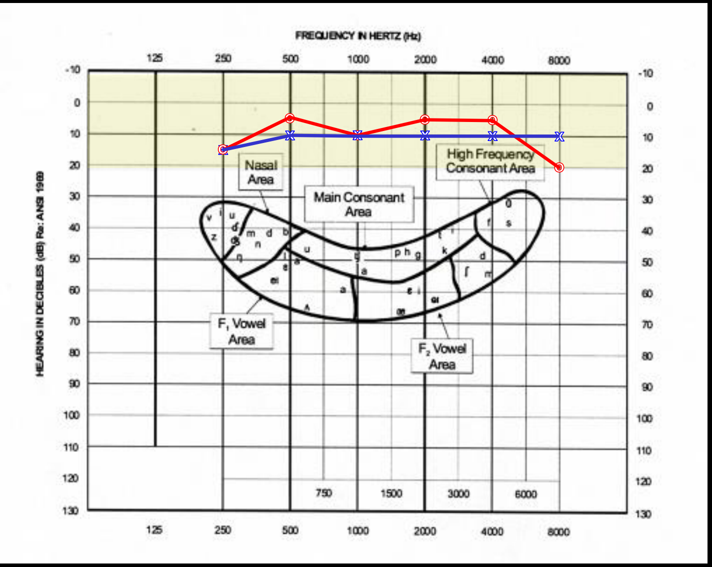


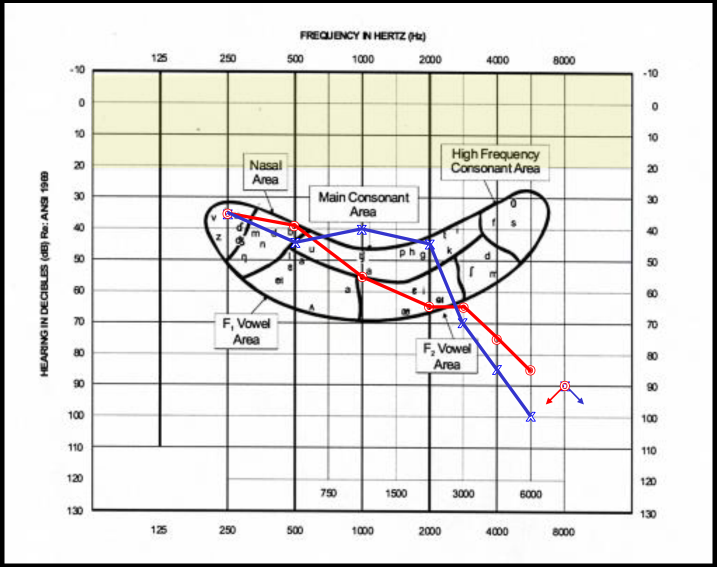




"I can hear you, but I can't understand you."

Improve diagnosis/assessment and tailor treatment to the needs of the individual





Thank You!

curtis.billings2@va.gov

http://www.ncrar.research.va.gov/