Auditory IQ:

Understanding what the brain hears

Dr. Jacqueline R Scholl, AuD, CCC-A, PS

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Learning Outcomes

- Compare data as it relates to the estimation of unidentified children with auditory cognitive problems.
- Identify the parts of the auditory pathway that are plastic and how it changes through appropriate diagnosis and intervention.
- Discover new tools used to identify children with, or at risk, for auditory cognitive problems.

Disclosure

I have no financial interest/arrangement to report.


Agenda

Part 1

Prevalence of auditory pathway disorders

The breakdown from NBHS to the Classroom

How to identify kids with auditory issues beyond NBHS

Oklahoma Study revelations

Part 2

Visualization of how the brain encodes speech

Impact for future early intervention

Part 3

Demonstration of how to collect & analyze the frequency following response (FFR)

Part 1

The prevalence of auditory pathway problems in children

Leading congenital birth defect

Over 98% of babies are screened in 50 states & the District of Columbia


1.8 per 1,000 babies were identified in 2020
Early Hearing Detection & Intervention (EHDI) program in every state
National Center for Hearing Assessment & Management Utah State University (NCHAM) –
National Technical Resource Center for all state-based EHDI programs 2001-24
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The Left Behind

Acquired Hearing Loss

- Concussion
- Autoimmune Disorders
- Structural abnormalities of the Temporal Bone
- CMV
- Ototoxic Medications
- Measles
- Mumps
- Varicella zoster
- Syphilis
- Herpes
- Low Birth Weight
- Lyme Disease
- Otitis Media
- Meningitis
- Trauma
- Infection

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Nonsyndromic Hereditary Hearing Loss

Autosomal dominant 63
Autosomal recessive 86
Sex-linked 7
Mitochrondrial 9
Auditory neuropathy 5

153
GENES

Walls WD, Azaiez H, Smith RJH. Hereditary Hearing Loss Homepage. http//hereditaryhearingloss.org

NBHS uses best practice (AABR/OAE)

Miss a mild hearing loss & cookie bite

Only tests hearing sensitivity

A “Pass” is for a moment in time

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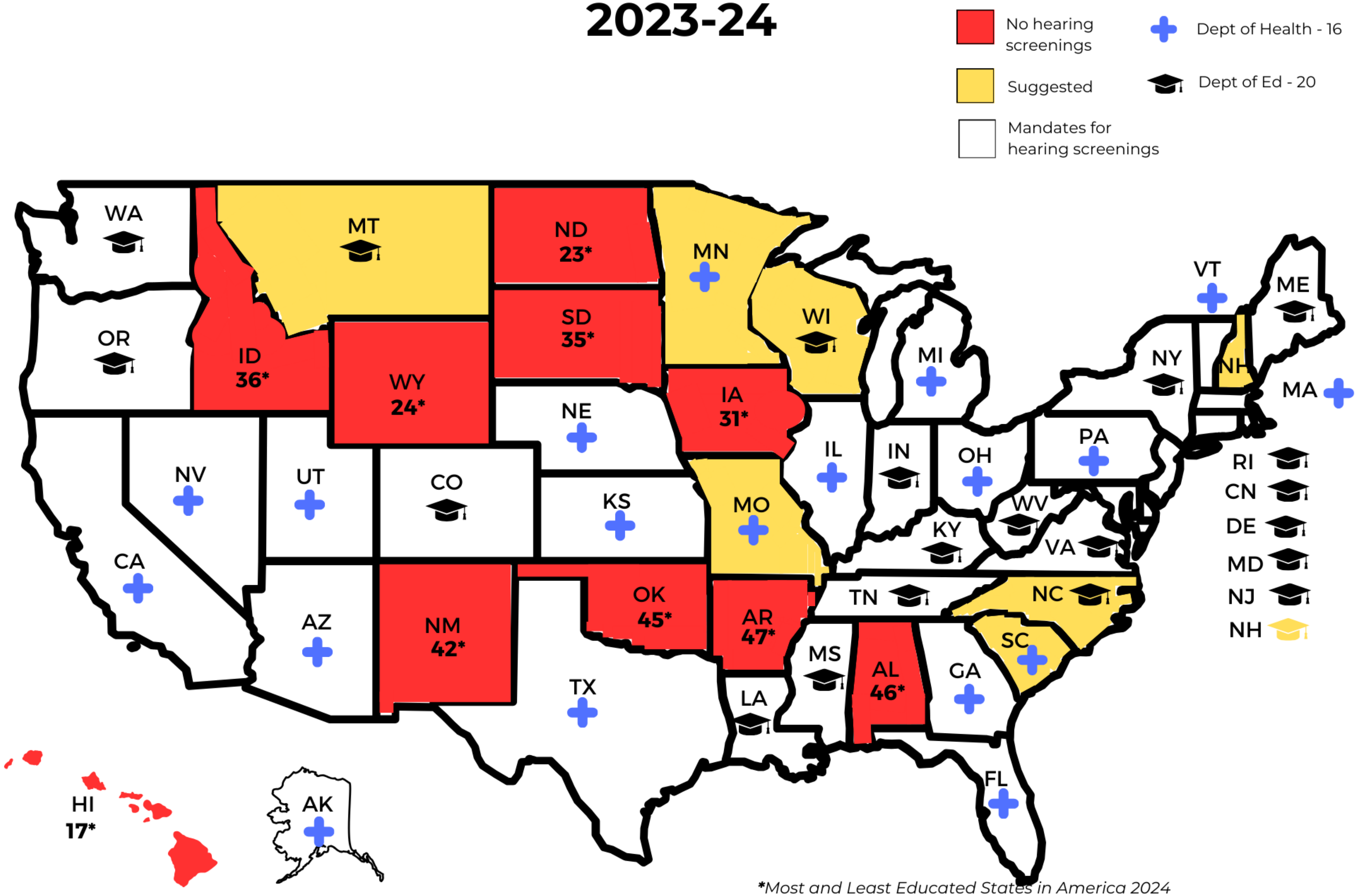
Syndromic Hearing Loss (over 400)

Up to 30% of hereditary hearing loss are syndromic[1]

Over 400 known syndromes that include hearing loss and affect various other systems of the body, including the kidneys, the eyes and the hear.

[1] Communications. "Genes and Hearing Loss." American Academy of Otolaryngology-Head and Neck Surgery, 3 Jan. 2018, www.entnet.org/content/genes-and-hearing-loss.

State Legislation for School Hearing Screenings 2023-24



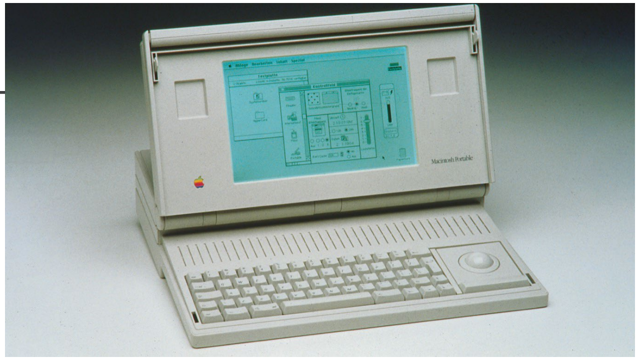
10 states – no legislation

7 states - suggest

*Most and Least Educated States in America 2024
Adam McCann, WalletHub Financial WriterFeb 12, 2024

ASHA - Hearing Screening Guidelines for Children 1989

One year prior the American Academy of Audiology was founded – Guidelines 2011



The Macintosh Portable

Data and Statistics About Hearing Loss in Children

U.S. CENTERS FOR DISEASE CONTROL AND PREVENTION

15.2%

Prevalence of hearing loss among children 6 to 19 years of age: the Third National Health and Nutrition Examination Survey

JAMA. 1998 Apr;279(14):1071-5. doi: 10.1001/jama.279.14.1071.

15.2% children had at least 16dB of hearing loss in 1 or both ears;

7.1% had low frequency HL

12.7% had high frequency HL

` Most were either unilateral and/or slight in severity (16- to 25-dB)

Health Care Use and Health and Functional Impact of Developmental Disabilities Among US Children, 1997-2005 – 3-17 years

(Retrospective analysis of US households from the 1997-2005 National Health Interview Surveys)

Arch Pediatr Adolesc Med. 2009;163(1):19-26. doi:10,1001/archpediatircs.2008.506

4.5 per 1,000 children ages 3-17 years

CP, autism, MR, blindness, deafness/a lot of trouble hearing – associated with the highest levels of health and functional impact indicators.

"We do not know exactly how many children have hearing loss. CDC data have shown that approximately 1 to 3 per 1,000 children have hearing loss. Other studies have shown rates from 2 to 5 per 1,000 children."

U.S. CENTERS FOR DISEASE CONTROL AND PREVENTION

Why?

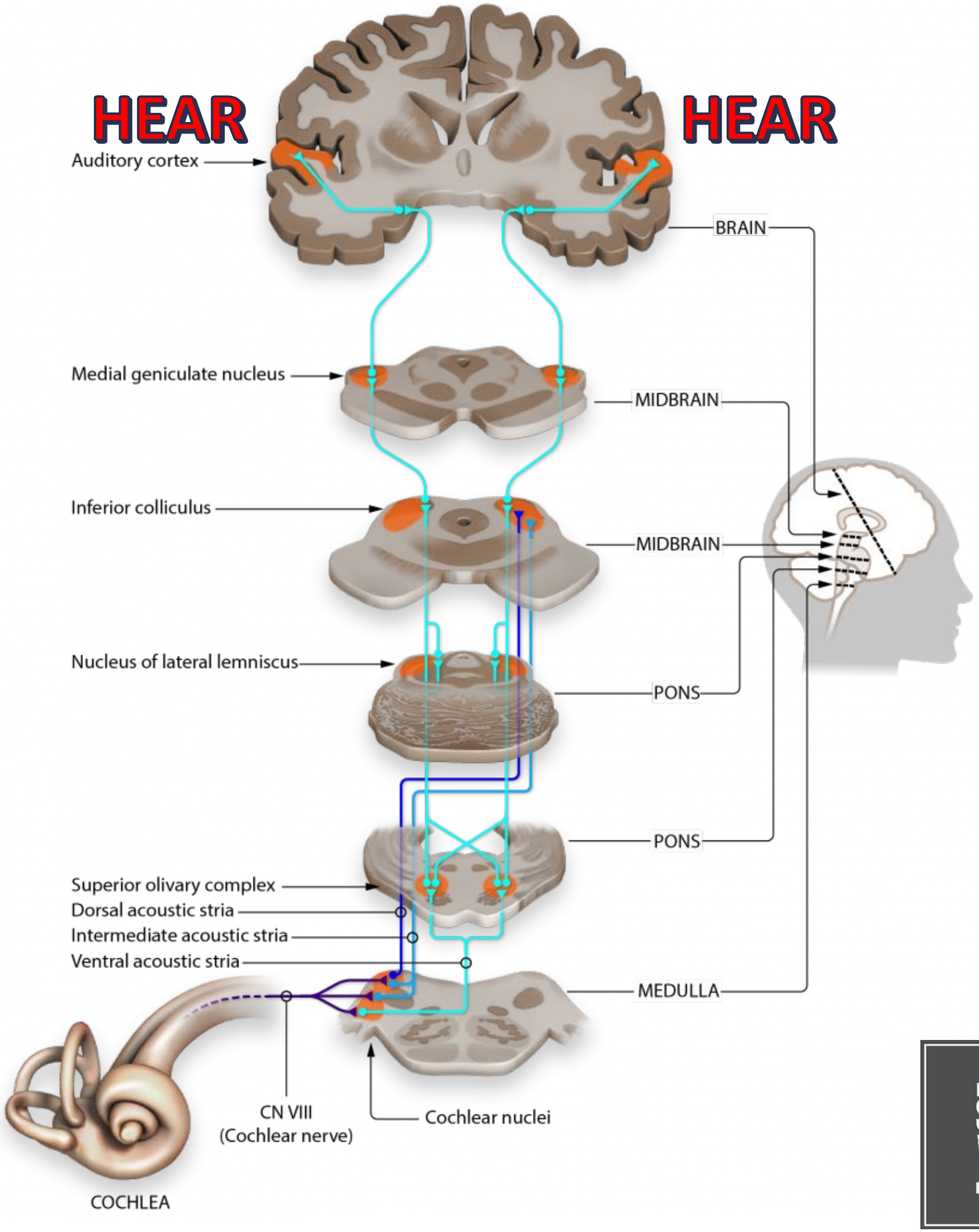
Definition of hearing loss

Ages studied

Sample size

Methodologies

No Standardization



Tasked by OK Depts of Ed/Health

WHAT IS THE PREVALENCE OF AUDITORY PROBLEMS IN OKLAHOMA SCHOOL CHILDREN?

Study looked at prevalence & best practice

Rural & Urban School

Children ages 5-9 years old (learning to read)

Total 150 kids

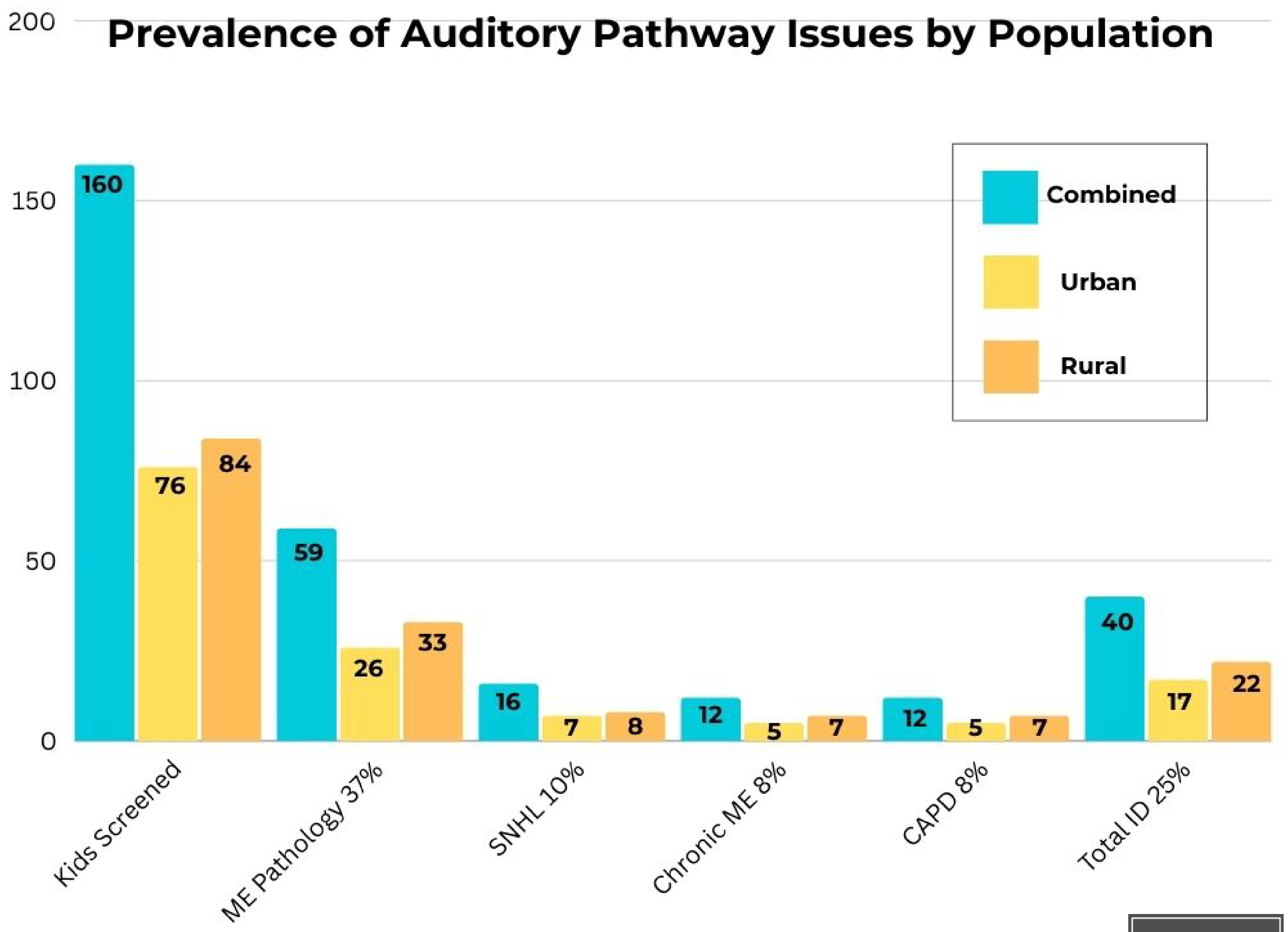
Used 8 screeners:

- Otoscopy
- Tympanometry
- Acoustic Reflexes
- OAEs
- Kid's Hearing Games
- Pure Tones @500, 1000, 2000, 4000, 6000, 8000Hz
- Sound Scouts
- Rhythmicity

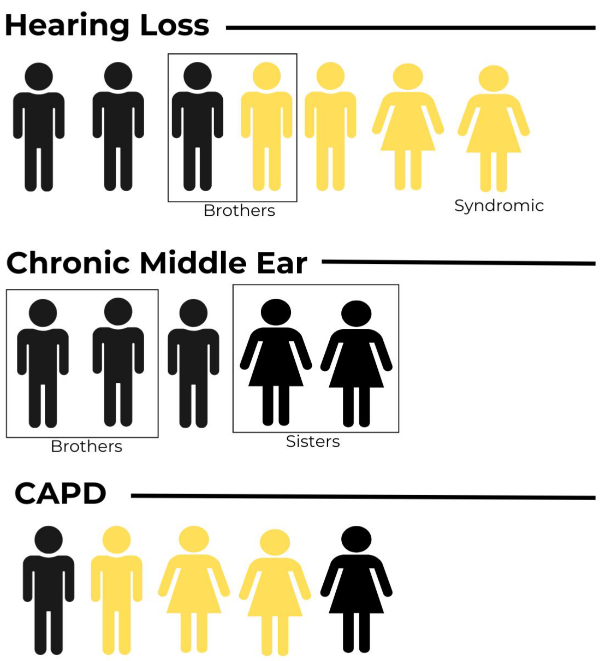
25% of OK school-aged children had some form of auditory problem

25%

All were struggling readers



URBAN SCHOOL

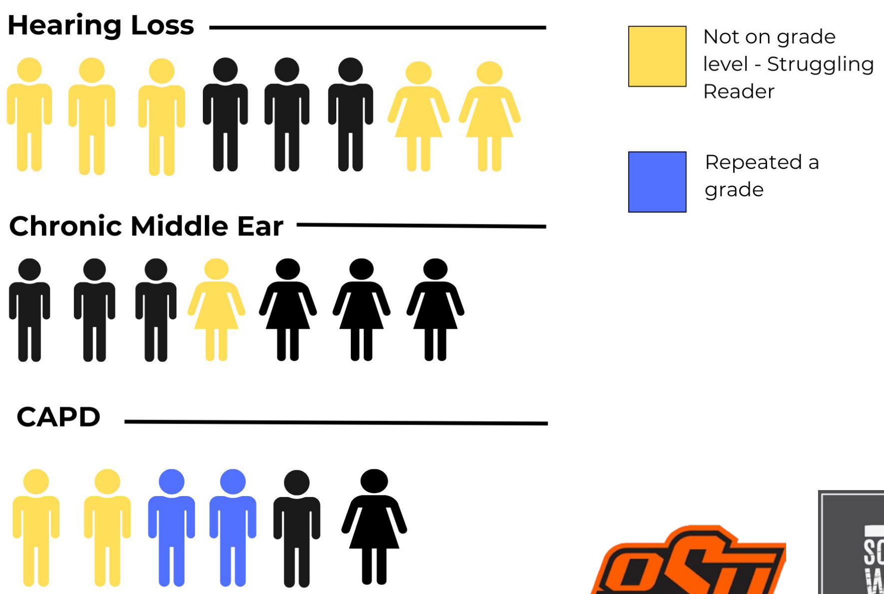


SNHL – 10%

Chronic Middle Ear – 8%

CAPD – 8%

RURAL SCHOOL



SNHL was primarily slight to mild (16- to 25-dBHL) and/or unilateral.

Disability categories for school-age kids with IEPs

Source: U.S. Department of Education (2023)

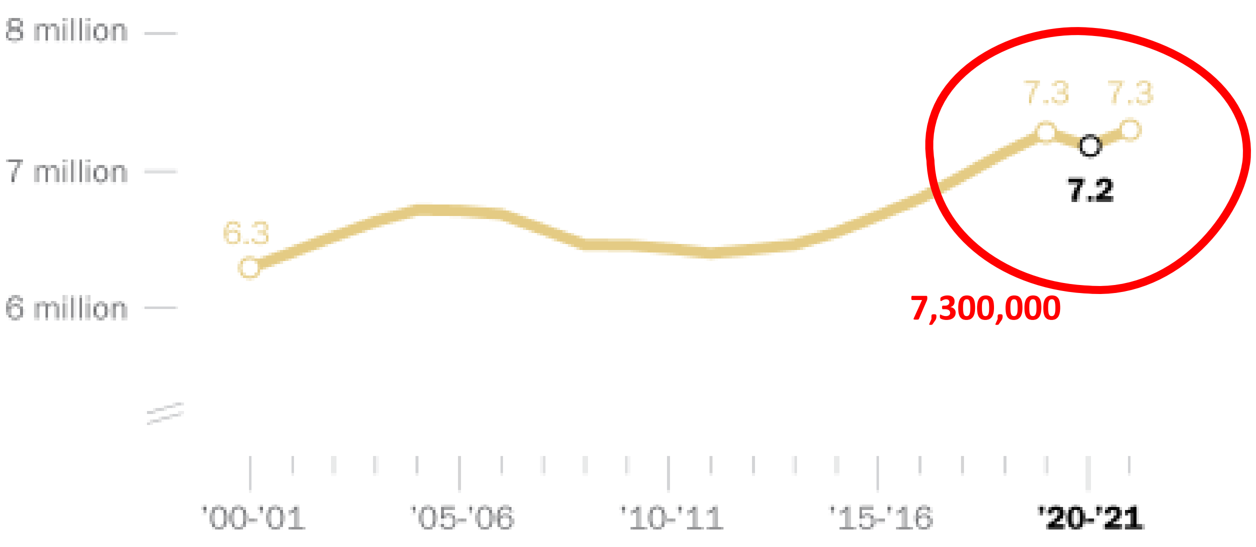
Percentages rounded

Dyscalculia

(learning disability in math)

Fewer U.S. children received special education services in first full school year of COVID-19 pandemic

Number of students with disabilities served each school year under the Individuals with Disabilities Education Act (IDEA)



Note: Data is for public school students ages 3 to 21 served under IDEA.
Source: National Center for Education Statistics.

PEW RESEARCH CENTER

7,300,000 * 1% = 73,000
Students in SPED — HI — TTL HI in US

6,000 * 18 years = 108,000
Babies w/HI per year — Min w/HI
(-35,000)

7,300,000 * 15% = 1,095,000
(-1,022,000)

7,300,000 * 25% = 1,825,000
(-1,752,000)

Important take-aways from the study

Most hearing loss is slight-to-mild (16- to 25-dB) in one/both ears and is rarely identified.

They are all struggling readers.

The teachers know who they are.

Most will be missed because we don't screen high frequencies.

Noise induced hearing loss happens early!

(rural America)

We should be educating our children early and often how to protect their ears.

We must meet the families/kids where they are – in the schools.

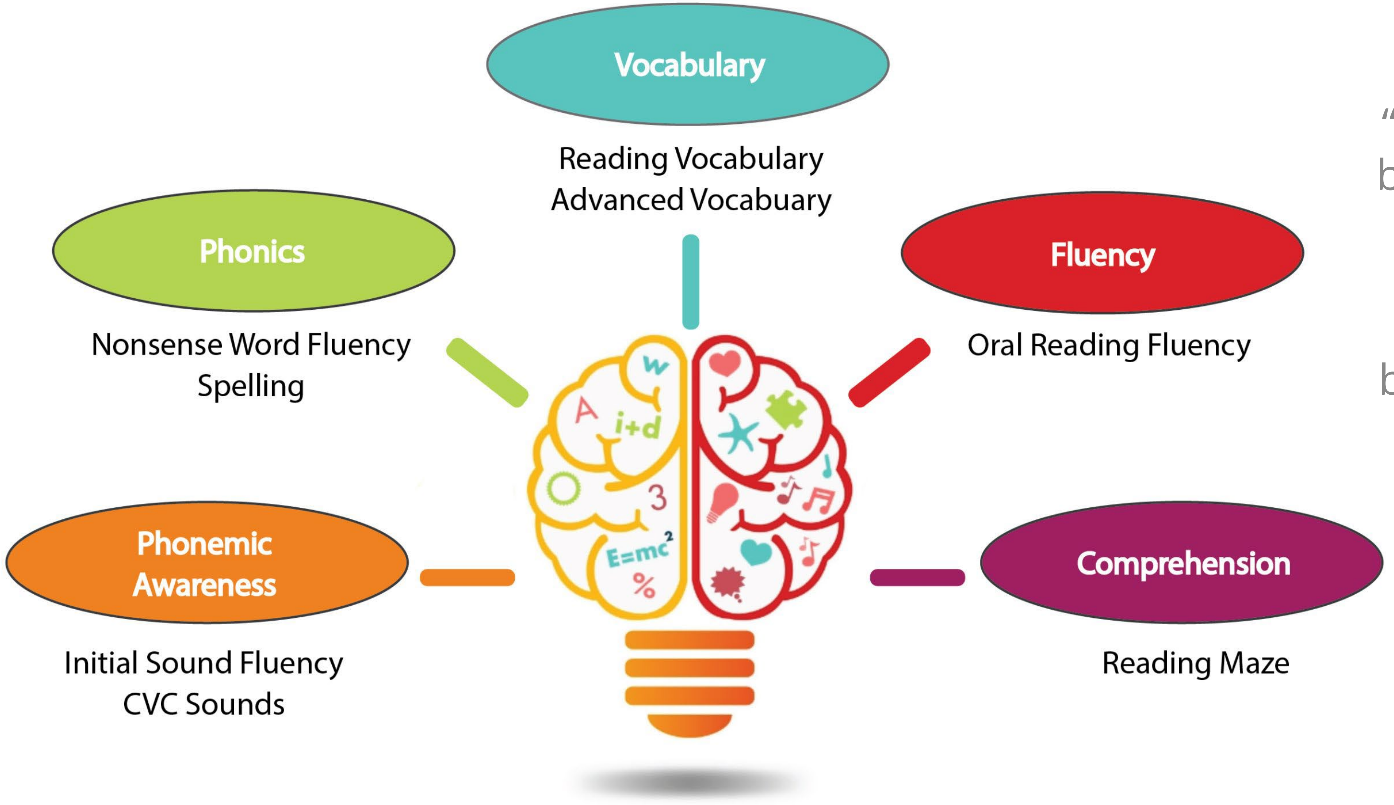
Screening with speech will find more kids than pure tones.

There's a lot more than we think!

Key indicator: Struggling Reader

IF INFORMATION IS NOT AUTHENTICALLY TRANSFERRED, EITHER BY GIVING FULL ACCESS AND/OR EFFICIENT PROCESSING OF THE SIGNAL, THE BRAIN CANNOT UNDERSTAND THE MESSAGE.

Science of Reading



Five Pillars

"Science of reading" refers to a comprehensive body of research that has supported strategies and methods found to enhance reading. The recommendations that derive from the Science of Reading (SoR) are those that have been consistently supported, over many years, by multiple credible researchers, across multiple settings with a diverse array of students and schools.

Reading scores were poor prior to Covid

Percentage of Fourth Graders at or Above Proficient in Reading and Eighth Graders at or Above Proficient in Math (2000, 2019 and 2022)[1]

Fourth Grade Reading

2000	2019	2022
28%	34%	32%
72% below	66% below	68% below

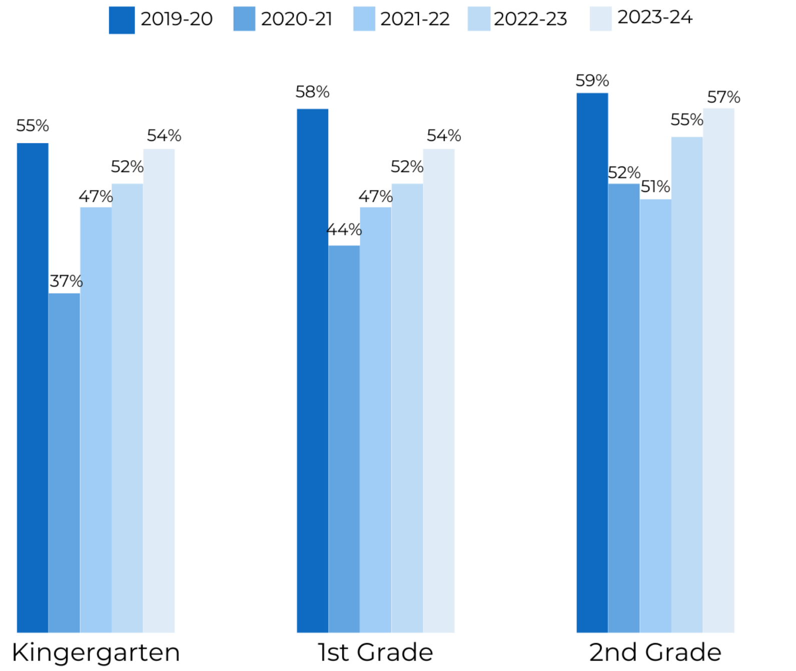
Eigth Grade Math

2000	2019	2022
25%	33%	26%
75% below	67% below	74% below

1 *The Annie E Casey Foundation. 2024 Kid's Count Data Book. www.aecf.org/databook*

Percent of K-2 Students on Track for Reading

DIBELS assessment data includes 300,000 students from 1,400 schools in 43 states.

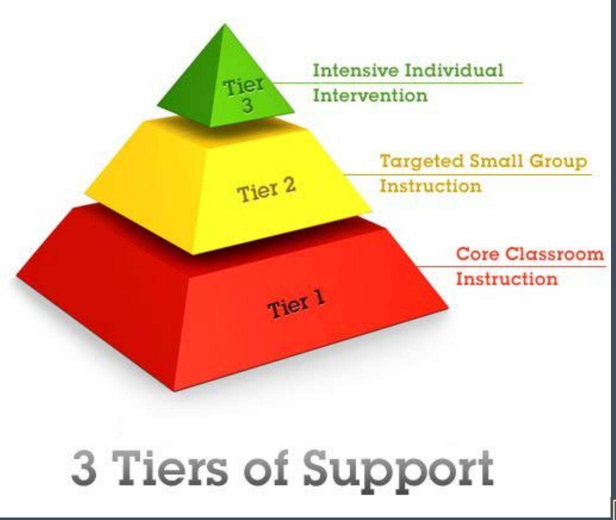


Only about half of students across grades K-2 are on track for learning to read and 3 in 10 students are far behind, data collected from the middle of this school year shows. In recent years, many states and districts have invested in science of reading initiatives to improve literacy rates.

www.k12dive.com/news/half-of-k-2-students-on-track-for-reading/712136/

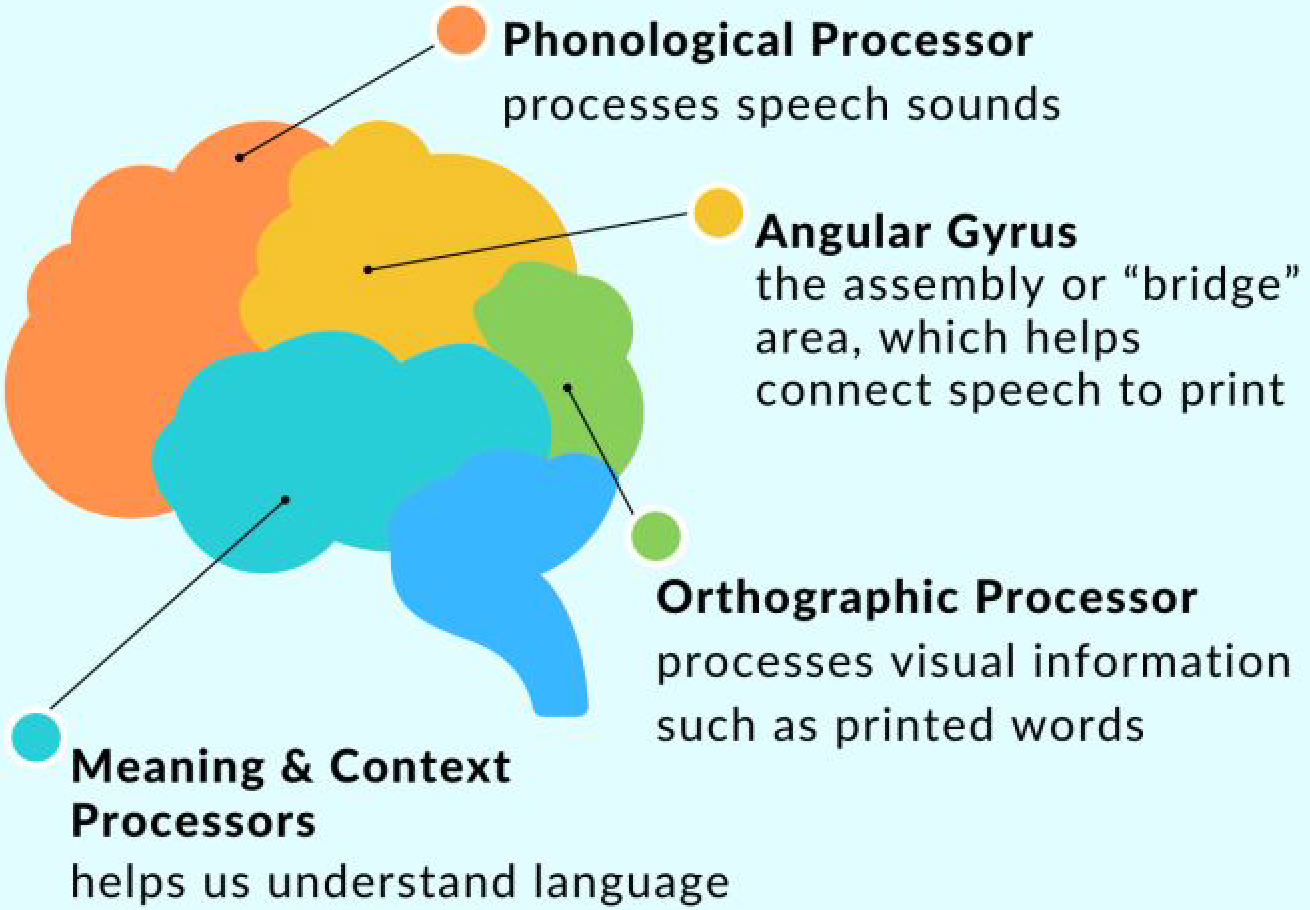
Poor Response to Intervention (RTI)

- Research-driven approaches are not being utilized.
- Children are not getting enough phonemic awareness and phonics instruction in early grades
- Most teachers rather teach reading through leveled books because they find it more appealing.
- The type of corrective feedback when students make errors in reading encourages guessing and memorizing words rather than analysis to figure words out phonetically.
- There are few opportunities for students to apply phonics skills through cumulative practice.
- There is a flawed view of how children learn to read, and many teachers think it is primarily a visual task.
- Resistance to change is a major reason for lackluster performance.
- Mismatched intervention to a child's specific needs
- ***Inadequate assessment of underlying issues***
- Lack of consistent practice outside intervention
- Poor instructional quality
- Underlying learning disabilities like dyslexia
- Insufficient intensity of intervention
- Not addressing the root cause of their reading difficulties



https://theliteracyarchitects.com/

THE READING BRAIN



The Literacy Architects®

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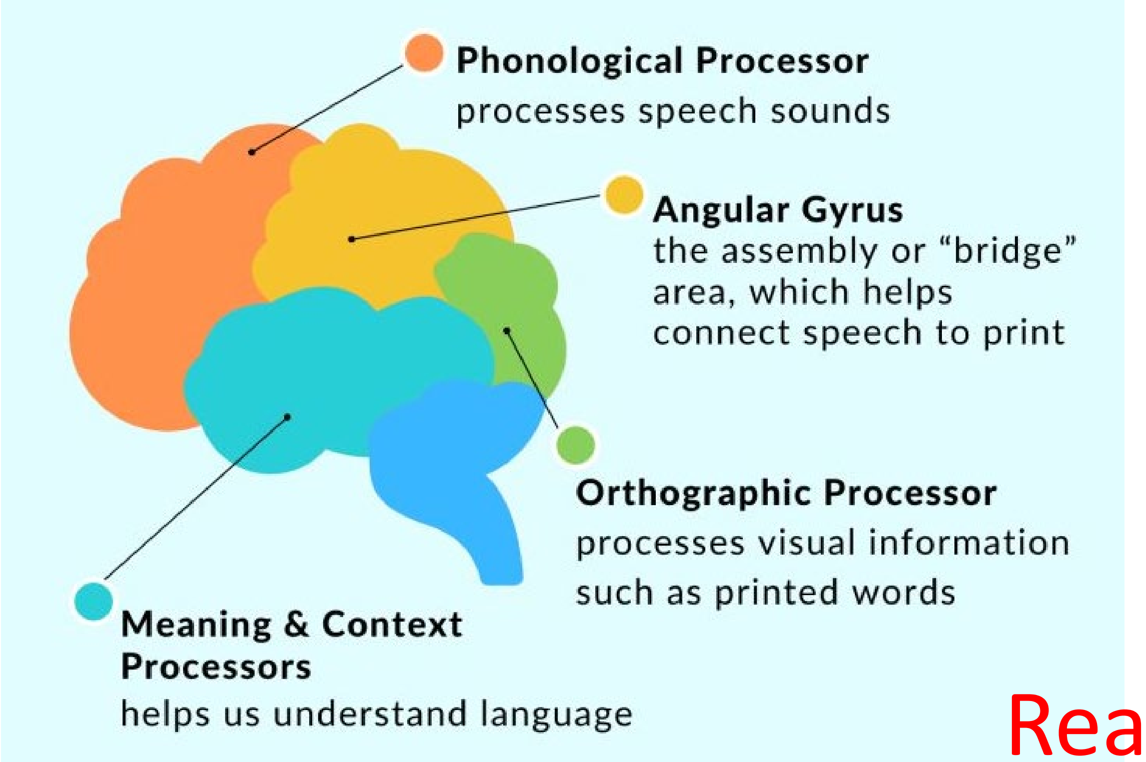
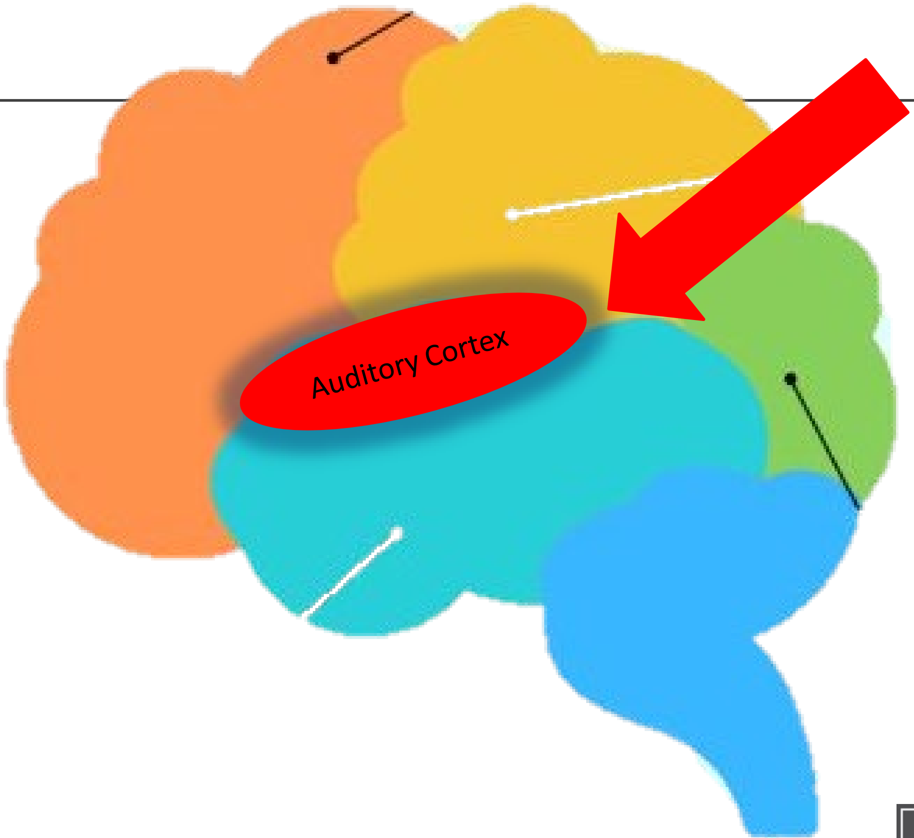
The missing piece





Reading is an auditory skill

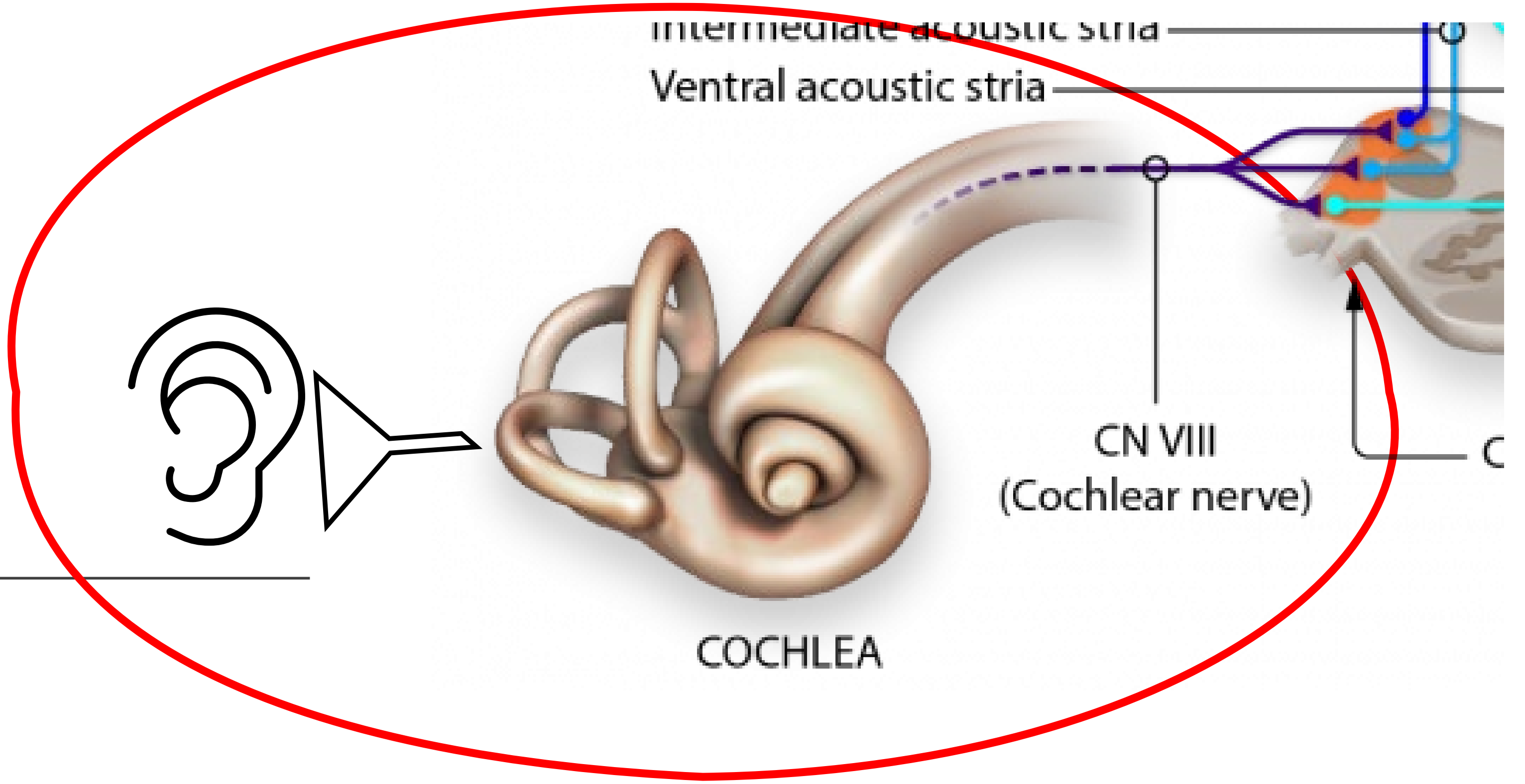
We HEAR in the brain.

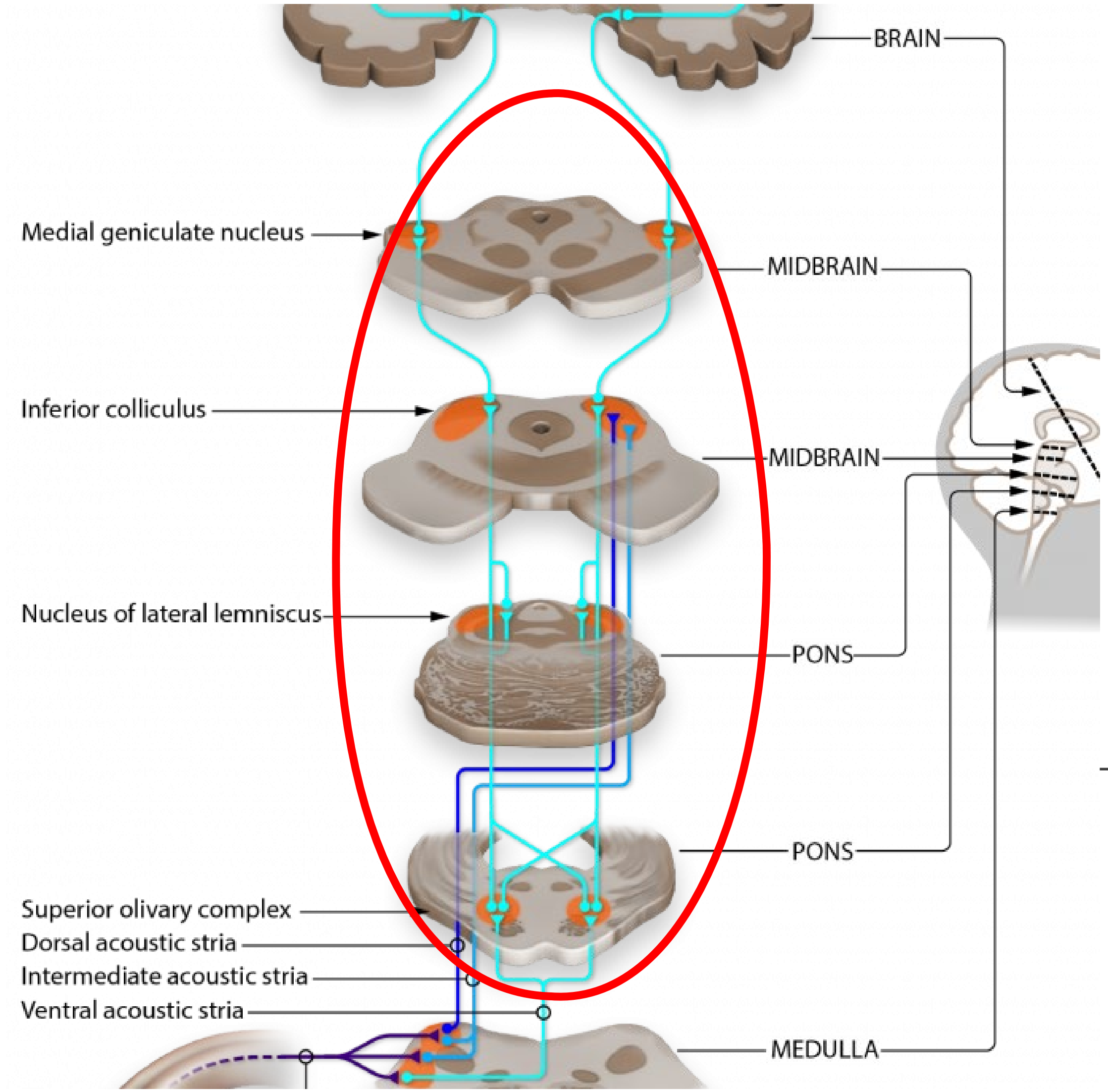
The auditory system consists of 3 parts:

- Access
- Processing
- Hearing

Access

Hardwired System



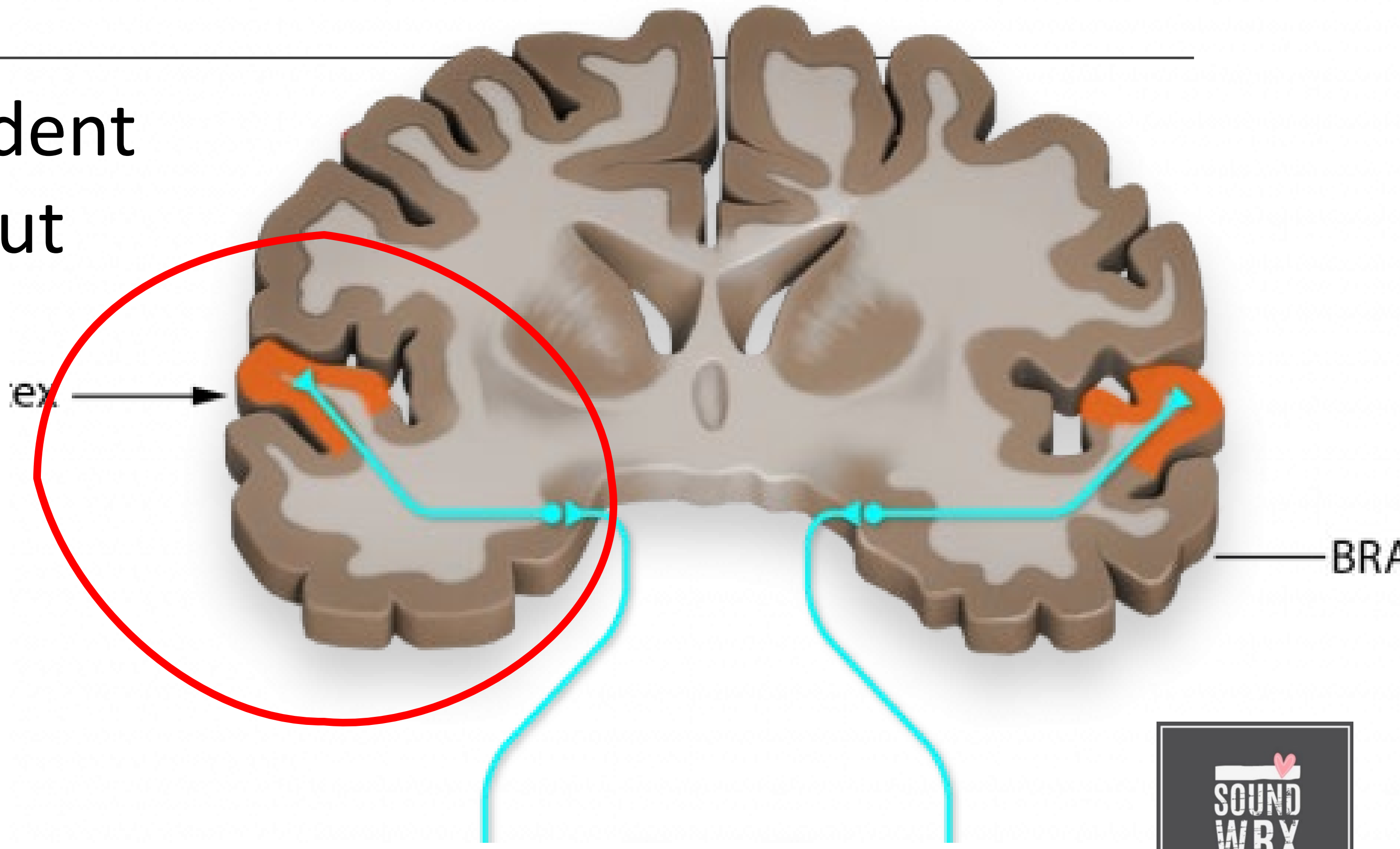


Process/Transfer

Plastic – system can change

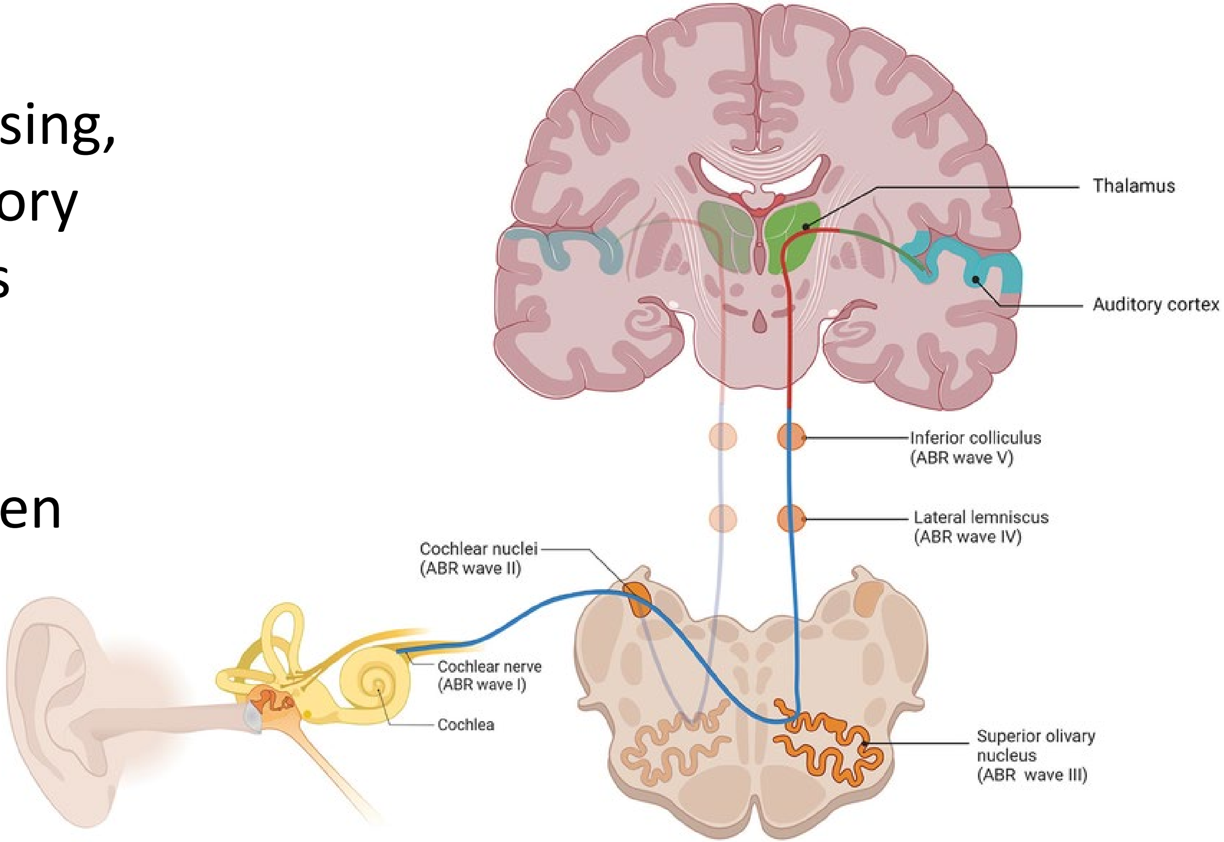
Hear/Recognize

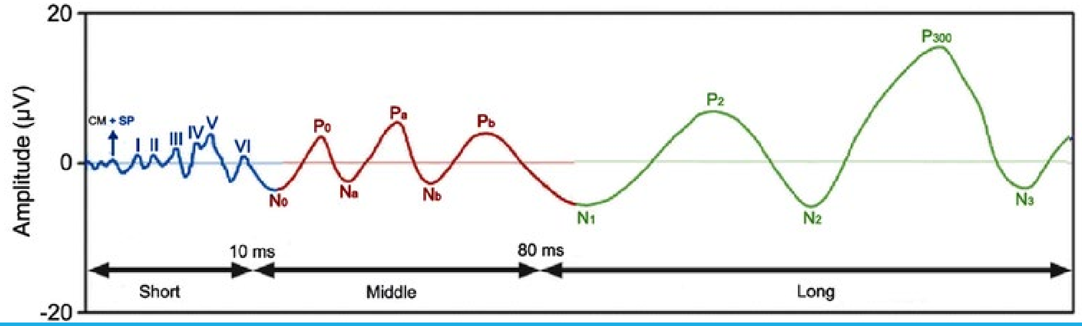
Understanding is dependent on quality of input/output



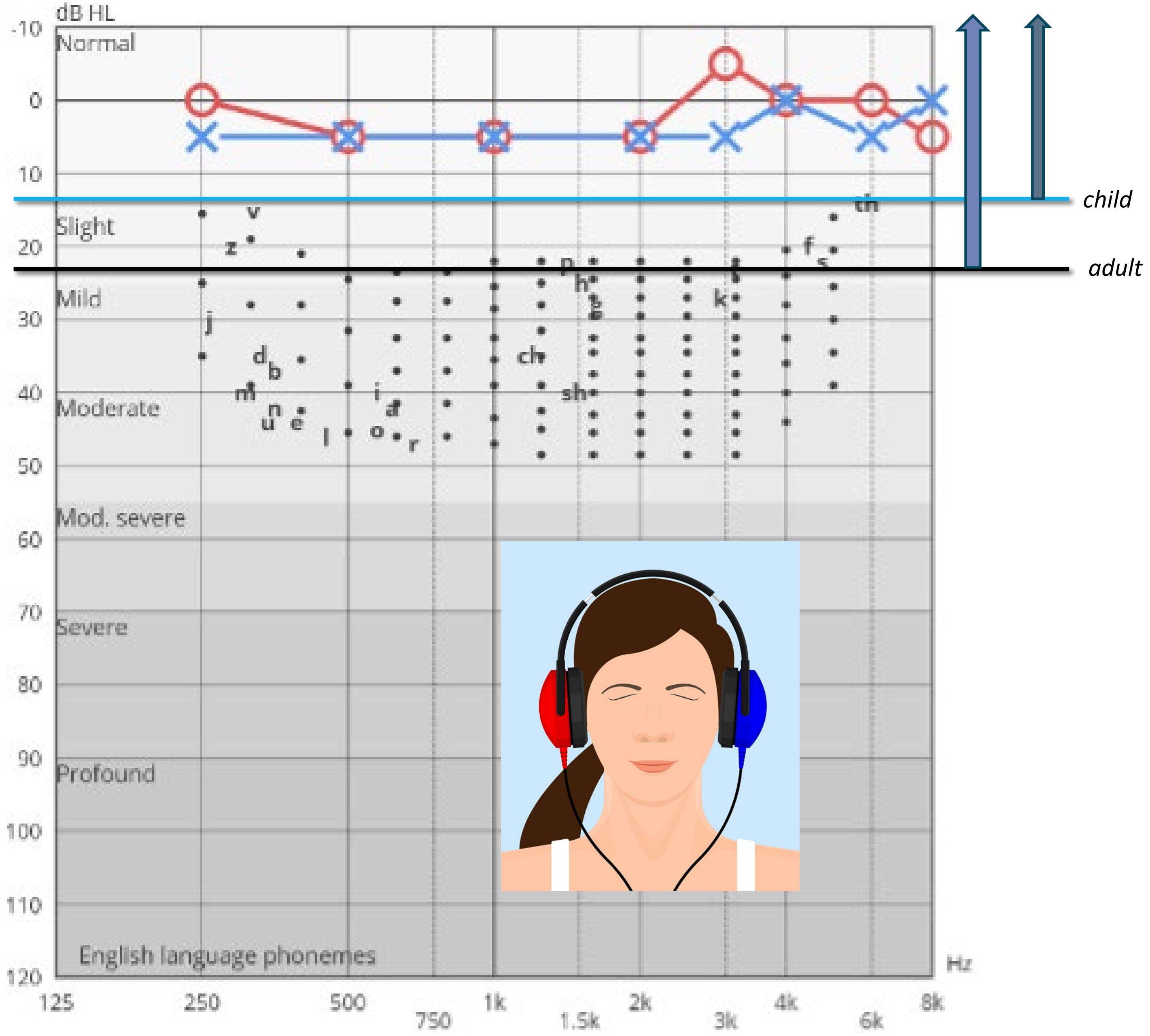
Audiologists are responsible for diagnosing, treating and managing the entire auditory pathway in order to understand what is being heard at the level of the brain.

Audiologists provide full access of spoken language to the brain.





SOUND WRX



Is this normal?

Tone sensitivity better than 20 dBHL does not rule out potential pathology of the cochlea or middle ear (Hidden Hearing Loss)

Can be impaired central auditory processing (CAPD)

Deficits in language comprehension (specific language impairment) or deficits in attention or working memory.

Pienkowski M. On the Etiology of Listening Difficulties in Noise Despite Clinically Normal Audiograms. Ear Hear. 2017 Mar/Apr;38(2):135-148. doi: 10.1097/AUD.0000000000000388. PMID: 28002080; PMCID: PMC5325255.

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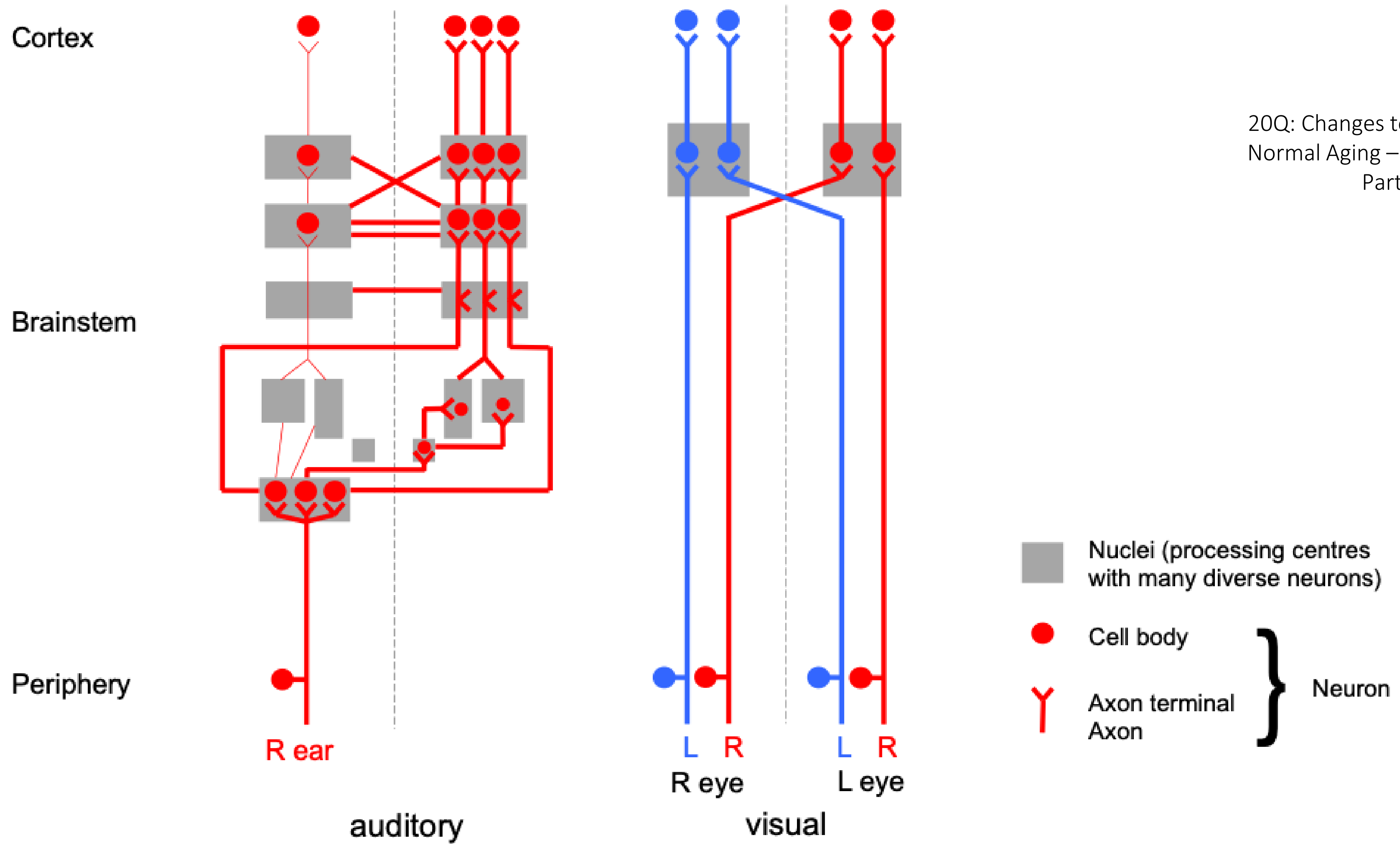
Comparison of Ascending Auditory/Visual Wiring Diagram

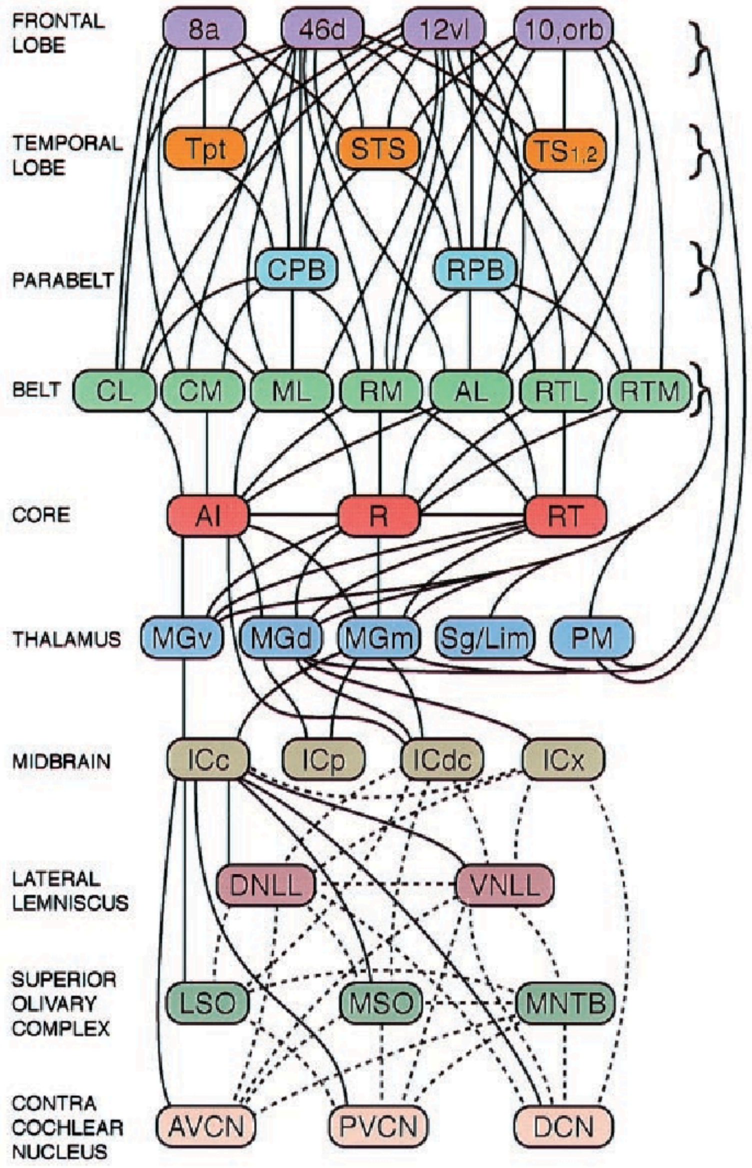


20Q: Changes to Auditory Processing and Cognition During Normal Aging – Should it Affect Hearing Aid Programming?
Part 1 – Changes Associated with Normal Aging

Richard Windle, PhD, MSc, CS

Audiology Online/01-08-2024

Cortical & Subcortical Connections



Kaas JH, Hackett TA. Subdivisions of auditory cortex and processing streams in primates. Proc Natl Acad Sci U S A. 2000 Oct 24;97(22):11793-9. doi: 10.1073/pnas.97.22.11793. PMID: 11050211; PMCID: PMC34351.

Very little cognitive load listening to pure tones

Factors affecting cognitive load

Noise Level

Noise Complexity

Task Complexity

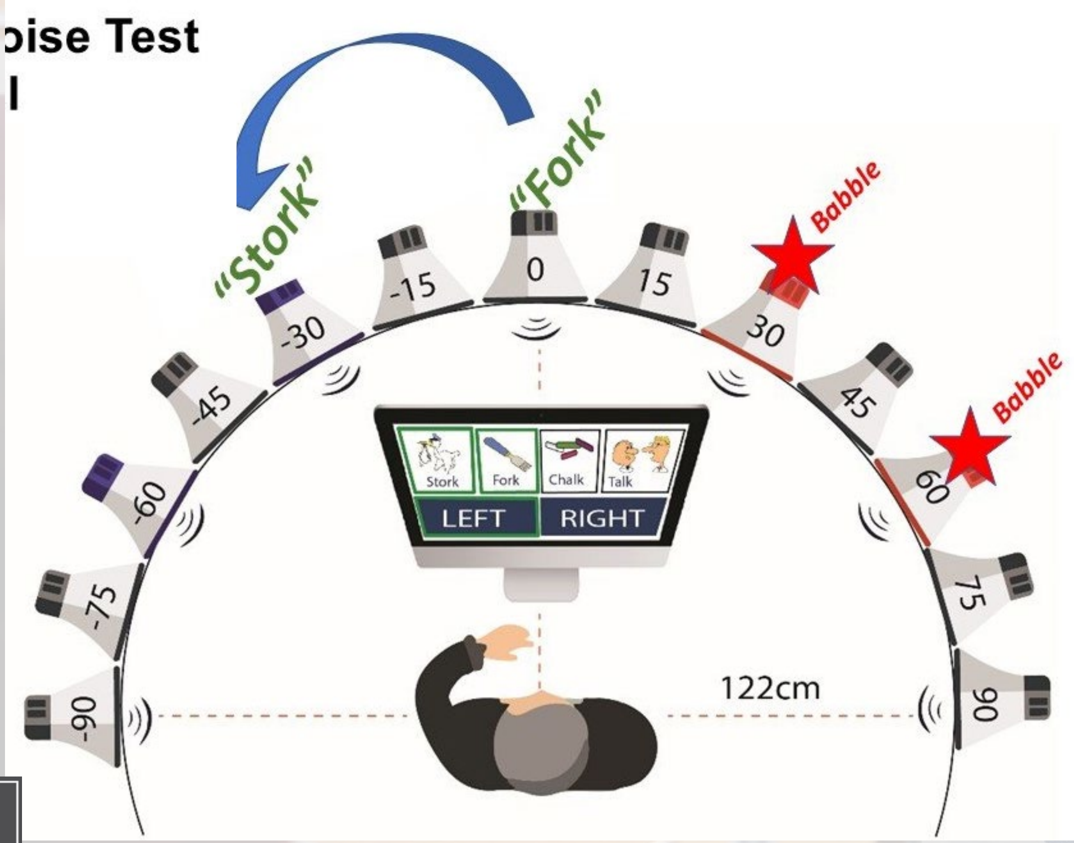
How do we know what the brain is hearing?

Auditory Processing Tests

- Buffalo Model – Jack Katz
- Acoustic Pioneer – Feather Squadron
- SCAN-3
- MAPA
- LiSN-S; LiSN-U; Digispan; DdTP – Harvey Dillon

Subjective

Speech-in-Noise Testing



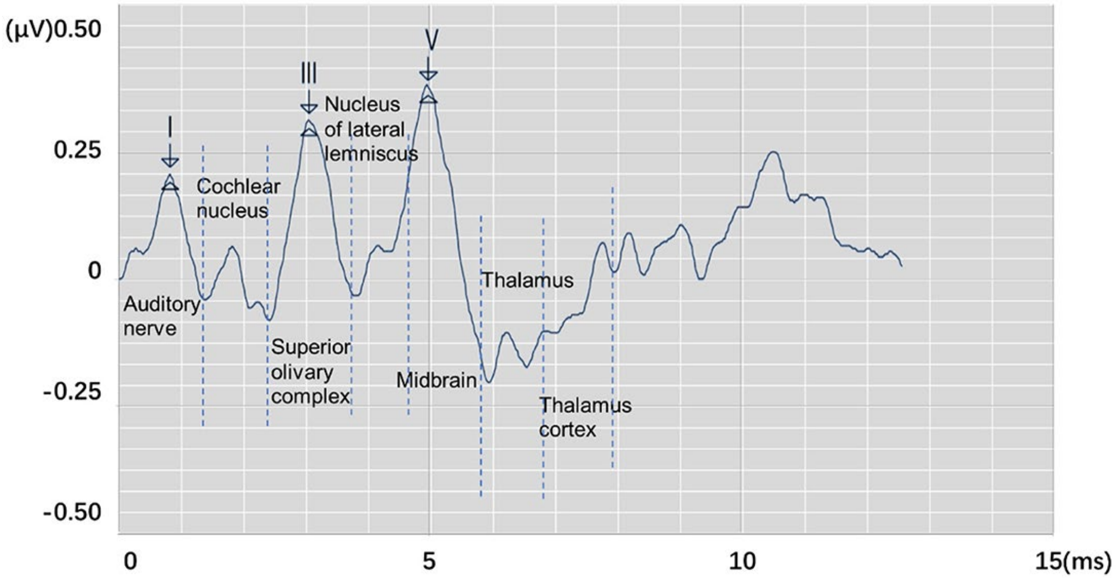
Subjective

Increased mental effort required to understand speech or auditory information when there is background noise present

Brain resource allocation

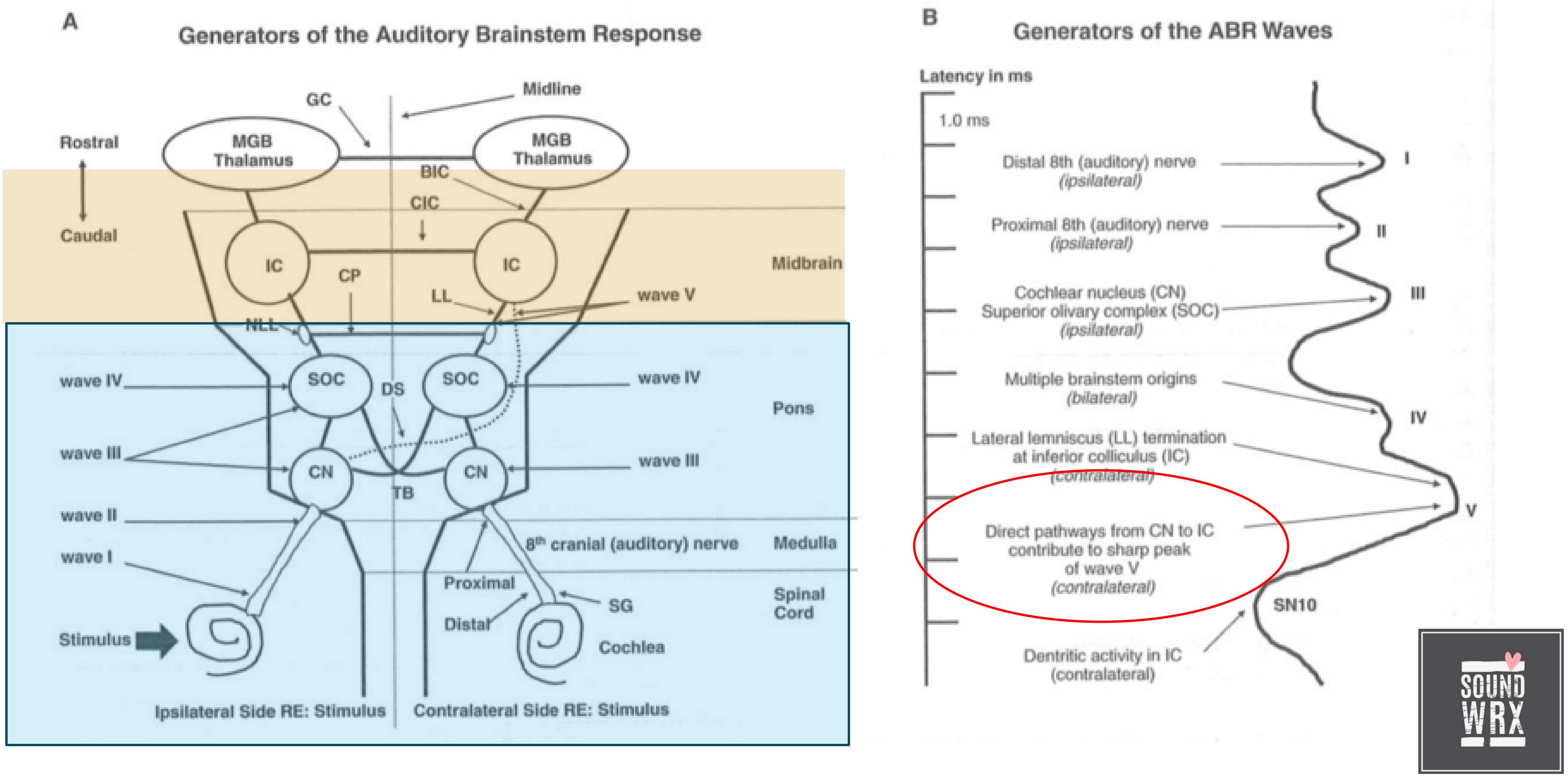
Increased effort leads to stress and mental fatigue, further impairing cognitive performance.

Mimics real world function.



Electrophysiologic Testing

OBJECTIVE


A
Generators of the Auditory Brainstem Response
GC
Midline
Rostral
Caudal
MGB Thalamus
MGB Thalamus
BIC
CIC
IC
IC
CP
LL
NLL
wave V
Midbrain
wave IV
SOC
DS
SOC
wave IV
Pons
wave III
CN
CN
wave III
TB
wave II
wave I
8th cranial (auditory) nerve
Medulla
Proximal
Distal
SG
Spinal Cord
Stimulus
Cochlea
Ipsilateral Side RE: Stimulus
Contralateral Side RE: Stimulus
B
Generators of the ABR Waves
Latency in ms
1.0 ms
Distal 8th (auditory) nerve (ipsilateral)
I
Proximal 8th (auditory) nerve (ipsilateral)
II
Cochlear nucleus (CN) Superior olivary complex (SOC) (ipsilateral)
III
Multiple brainstem origins (bilateral)
IV
Lateral lemniscus (LL) termination at inferior colliculus (IC) (contralateral)
V
Direct pathways from CN to IC contribute to sharp peak of wave V (contralateral)
SN10
Dentritic activity in IC (contralateral)
SOUND WRX

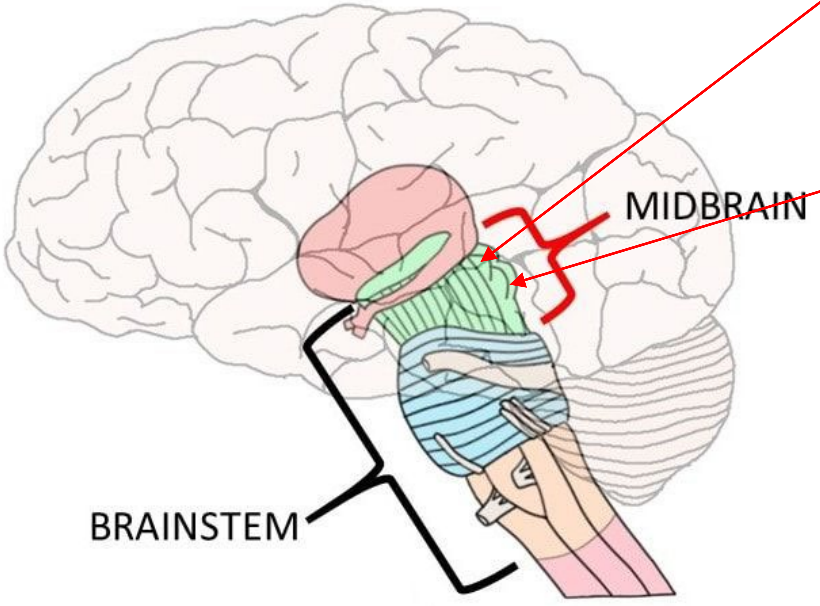
IC: First brain region where visual and auditory information converge – allowing for processing of combined sensory information

Superior Colliculi

Directing behavioral responses toward stimuli in the environment

Inferior Colliculi

Auditory Processing



- **Sound localization**: The IC is the first place where input from both ears about sound location converge.
- **Pitch and rhythm discrimination**: The IC is responsible for discriminating pitch and rhythm.
- **Startle response**: The IC plays a role in generating the startle response.
- **Speech recognition**: The IC is vital for recognizing speech.
- **Acoustic-motor coordination**: The IC coordinates acoustic-motor functions.

https://neuroscientificallychallenged.com/posts/know-your-brain-midbrain

Driscoll ME, Tadi P. Neuroanatomy, Inferior Colliculus. [Updated 2023 Aug 14]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK554468/

Best way to **screen** how the brain hears

Screen how a child listens using a high cognitive load - functional

- Noise level
- Noise Complexity
- Task Complexity

Speech-in-Noise

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APPENDIX A: SUMMARY OF AVAILABLE SPEECH-IN-NOISE TESTS

Acceptable Noise Level (ANL)

Purpose: To measure a patient's tolerance of background noise and estimate their likelihood of successful hearing aid use (Nabelek et al. 1991). May also aid clinicians in determining the level of hearing aid technology a patient requires (Interacoustics n.d.).

Materials: Running speech presented in babble noise.

Administration: The test takes 5–10minutes to administer. First, most comfortable listening level (MCL) is measured in quiet by playing a passage through a loudspeaker, during which the patient is directed to signal to the clinician whether to increase or decrease the volume until the MCL is achieved. Background noise is then added, and the patient is asked to indicate the "maximumlevel of noise that you would be willing to put up with for a long time while following the story."
Scoring: The ANL value is calculated by subtracting the background noise level from the MCL (MCL background noise level = ANL). The smaller the ANL value, the better the predicted outcomes the patient has with hearing aids (Nabelek et al. 1991). (Note: for this calculation to be valid, both ANL and MCL must be quantified on a decibel scale relative to the same reference—e.g., dB HL for both or dB SPL for both, but not one of each.)

Norms: Scores of 7 and below are considered to predict good outcomes (Interacoustics n.d.; Nabelek et al. 2006). A higher value indicates the patient likely needs more counseling and/or noise reduction technology. Scores of 12.5 dB or higher are considered to predict poor outcomes. Using Fig. 2 in Nabelek et al. (2006), clinicians can estimate the likelihood of hearing aid success based on ANL score.

Miscellaneous: The official test from Interacoustics can be found as part of their AC440 audiometry module for multiple systems, but it is not sold separately. Clinicians may use their own clinic-available materials to administer a form of this test, with the caveat that norms may not be comparable. Note: The ANL has inspired the development of a similar test of noise tolerance, Traking of Noise Tolerance Test, developed by Francis Kuk and colleagues (Kuk et al. 2018; the interested reader is also referred to https://www.orca-us.info/en/research for more information about this test).

Speech-in-Noise Testing: An Introduction for Audiologists

Curtis J. Billings, Ph.D., Tessa M. Olsen, B.S., Lauren Charney, Au.D., Brandon M. Madsen, Au.D., and Corrie E. Holmes, Au.D.

Harvey Dillon, Macquarie University
Professor of Auditory Science, Div of Psychology Communication & Human Neuroscience
Doctor of Philosophy, Bachelor of Engineering

Carolyn Mee, Founder & CEO SoundScouts
Women in Digital Innovator of the Year, 2020
2016 Woman of Influence

Sound Scouts™
Hear for your future.

iPad
Headphones
App

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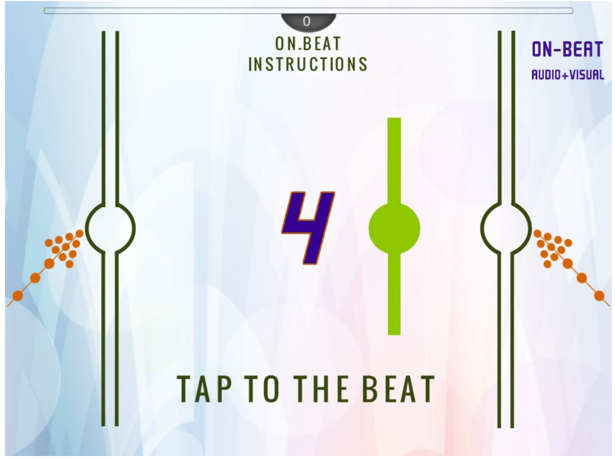
Rhythm

Woodruff Carr K, White-Schwoch T, Tierney AT, Strait DL, Kraus N. Beat synchronization predicts neural speech encoding and reading readiness in preschoolers. Proc Natl Acad Sci U S A. 2014 Oct 7;111(40):14559-64. doi: 10.1073/pnas.1406219111. Epub 2014 Sep 22. PMID: 25246562; PMCID: PMC4210020.

"Beat synchronization and neural encoding of speech reflect precision in processing temporal cues and have been linked to reading skills. In poor readers, diminished neural precision may contribute to rhythmic and phonological deficits."

Neuroscape is a translational neuroscience center at UCSF engaged in technology creation and scientific research to better assess and optimize brain function of both healthy and impaired individuals.



interactive
metronome

Effects of Music Training on Typical Developing Children and Those with Dyslexia

Zanto, T. P., Giannakopoulou, A., Gallen, C. L., Ostrand, A. E., Younger, J. W., Anguera-Singla, R., Anguera, J. A., & Gazzaley, A. (2024). **Digital rhythm training improves reading fluency in children.** *Developmental Science*, 27, e13473. https://doi.org/10.1111/desc.13473

Burland, K. (2020). **Music for all: Identifying, challenging and overcoming barriers.** *Music & Science*, **3**, 1 6. https://doi.org/10.1177/2059204320946950

Kraus, N., Hornickel, J., Strait, D. L., Slater, J., & Thompson, E. (2014). **Engagement in community music classes sparks neuroplasticity and language development in children from disadvantaged backgrounds**. *Frontiers in Psychology*, **5**(DEC), 1403. https://doi.org/10.3389/FPSYG.2014.01403/BIBTEX

Kraus, N., Slater, J., Thompson, E. C., Hornickel, J., Strait, D. L., Nicol, T., & White-Schwoch, T. (2014). **Music enrichment programs improve the neural encoding of speech in at-risk children**. *Journal of Neuroscience*, **34**, 11913–11918. https://doi.org/10.1523/jneurosci.1881-14.2014

White, C., & Wesolowski, B. (2021). **Exploring the effect of rhythmic interventions on first- and second-grade music students' oral reading fluency.** *Visions of Research in Music Education*, **33**(1), 1–34. https://opencommons.uconn.edu/vrme/vol33/iss1/5

Flaugnacco E, Lopez L, Terribili C, Montico M, Zoia S, Schön D (2015) **Music Training Increases Phonological Awareness and Reading Skills in Developmental Dyslexia: A Randomized Control Trial.** PLoS ONE 10(9): e0138715. https://doi.org/10.1371/journal.pone.0138715

Flaugnacco E, Lopez L, Terribili C, Zoia S, Buda S, Tilli S, Monasta L, Montico M, Sila A, Ronfani L, Schön D. **Rhythm perception and production predict reading abilities in developmental dyslexia.** Front Hum Neurosci. 2014 Jun 4;8:392. doi: 10.3389/fnhum.2014.00392. PMID: 24926248; PMCID: PMC4045153.

COHERENCE

Interactive Metronome

[HTTPS://YOUTU.BE/DSHTDHPJCU8](https://youtu.be/DSHTDHPJCU8)

SOUND WRX

Beatsabre

https://youtu.be/3ehSPtWoiuc?t=5

One-on-One Therapy

Study looked at prevalence & **best practice**

Rural & Urban School

Children ages 5-9 years old (learning to read)

Total 150 kids

Used 8 screeners:

- Otoscopy
- Tympanometry
- Acoustic Reflexes
- OAEs
- Kid’s Hearing Games
- Pure Tones @.5, 1, 2, 4, 6, 8kHz
- Sound Scouts
- Rhythmicity

~~Otoscopy~~

Tympanometry

~~Acoustic Reflexes~~

~~OAEs~~

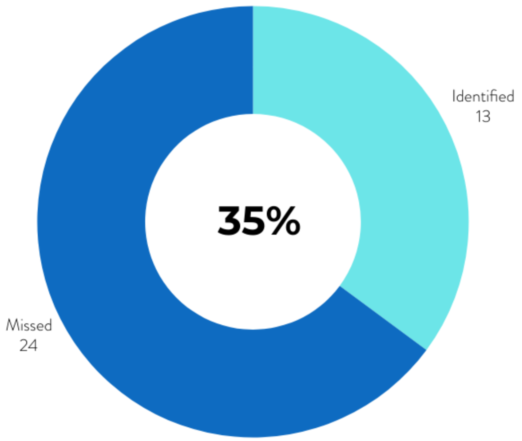
~~Kid’s Hearing Games~~

~~Pure Tones @.5, 1, 2, 4~~, 6, 8kHz

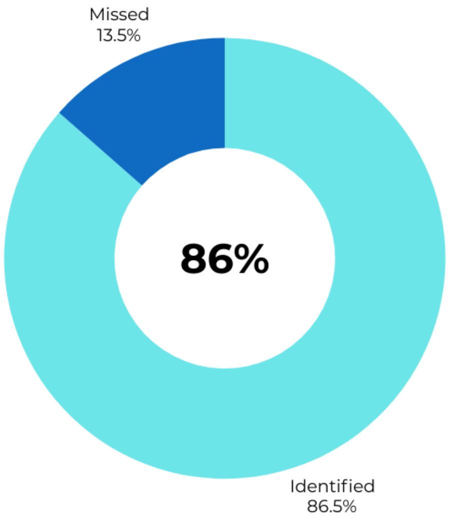
SoundScouts

~~Rhythmicity~~

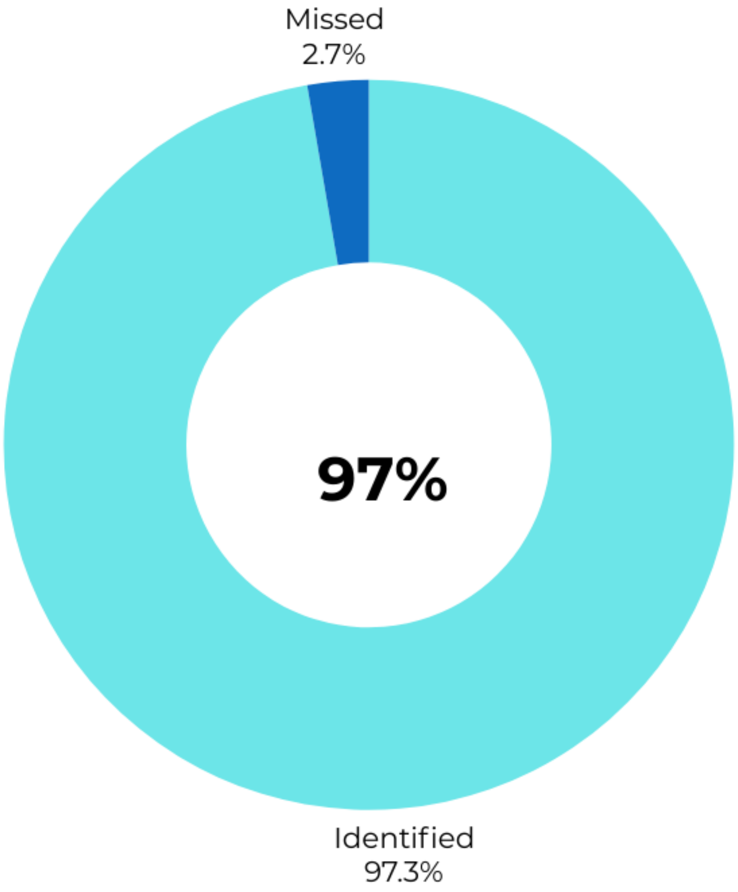
ASHA/AAA Guidelines



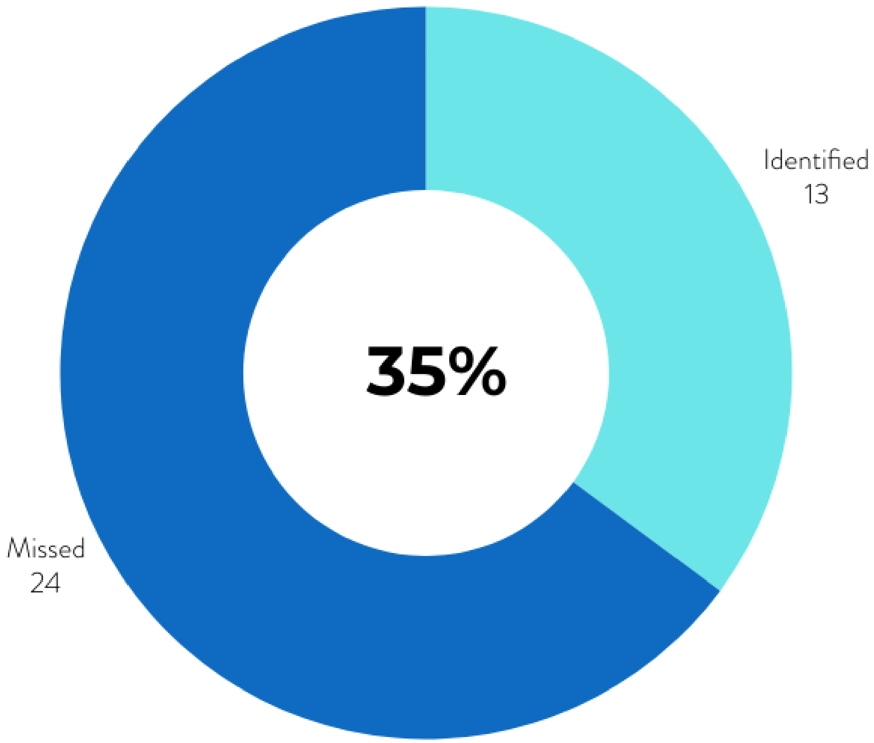
Sound Scouts



Sound Scouts + 4, 6, & 8 kHz



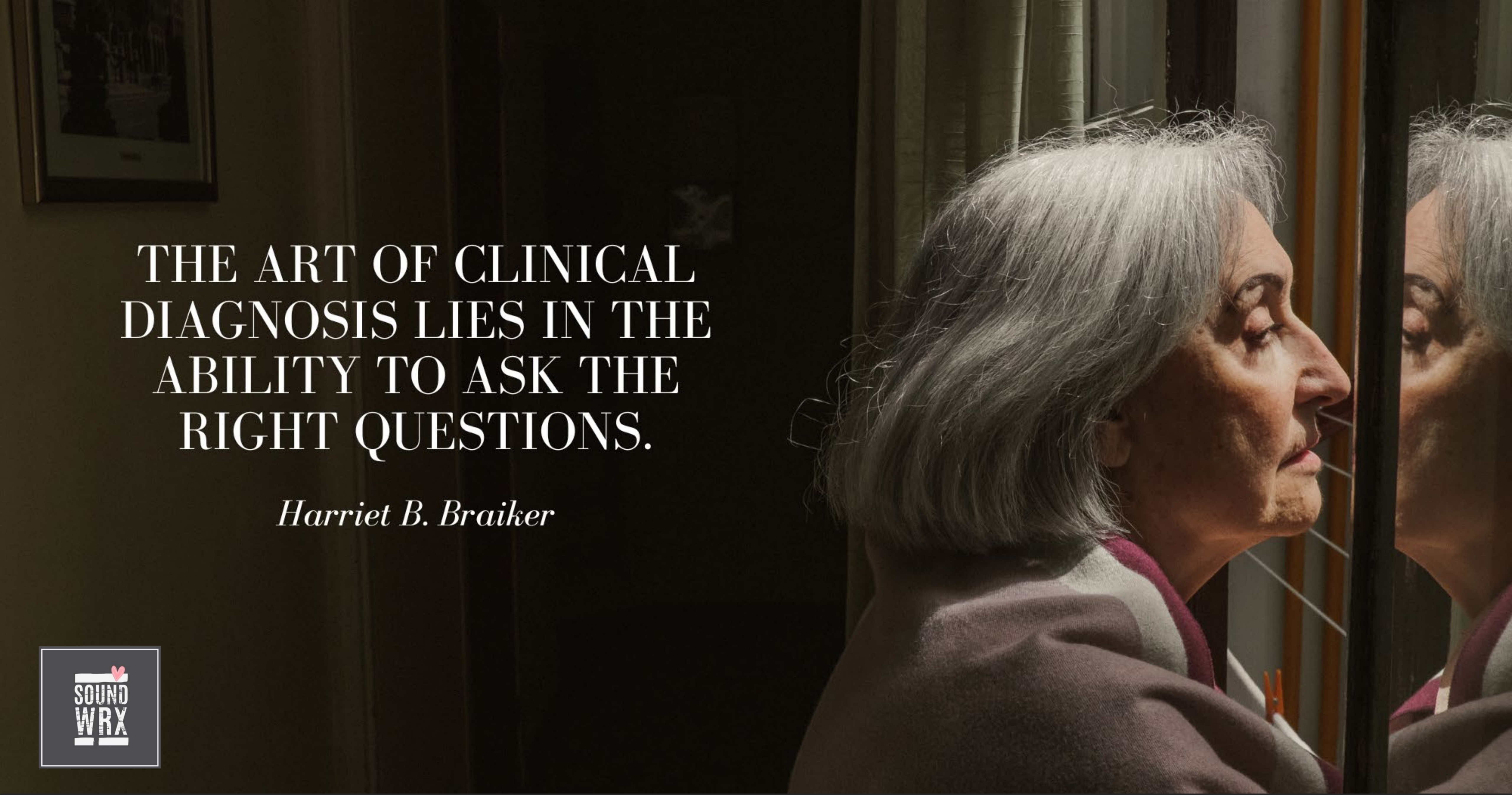
ASHA/AAA Guidelines

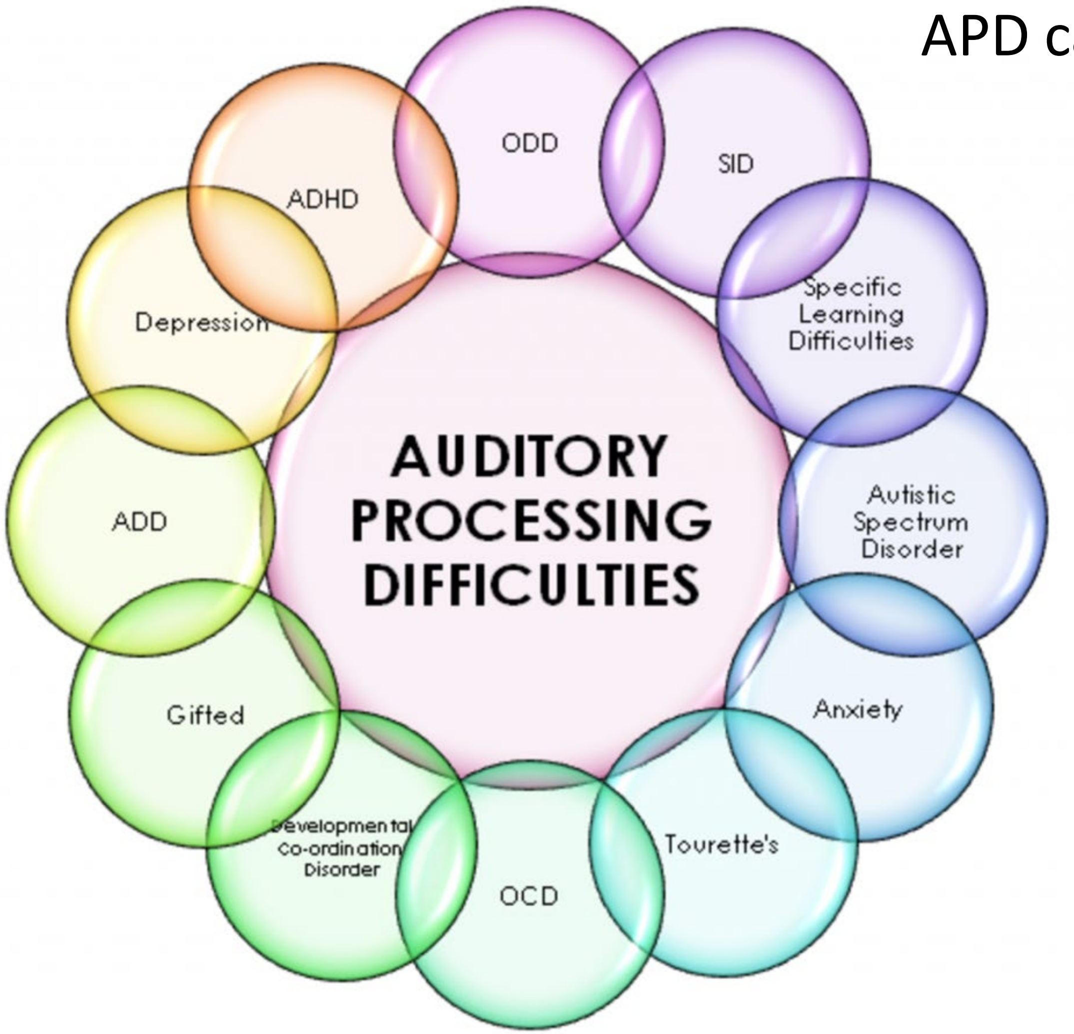


Work space circa 1994

What can you do about it?

Are you providing the diagnosis or the intervention?


THE ART OF CLINICAL DIAGNOSIS LIES IN THE ABILITY TO ASK THE RIGHT QUESTIONS.
Harriet B. Braiker
SOUND WRX

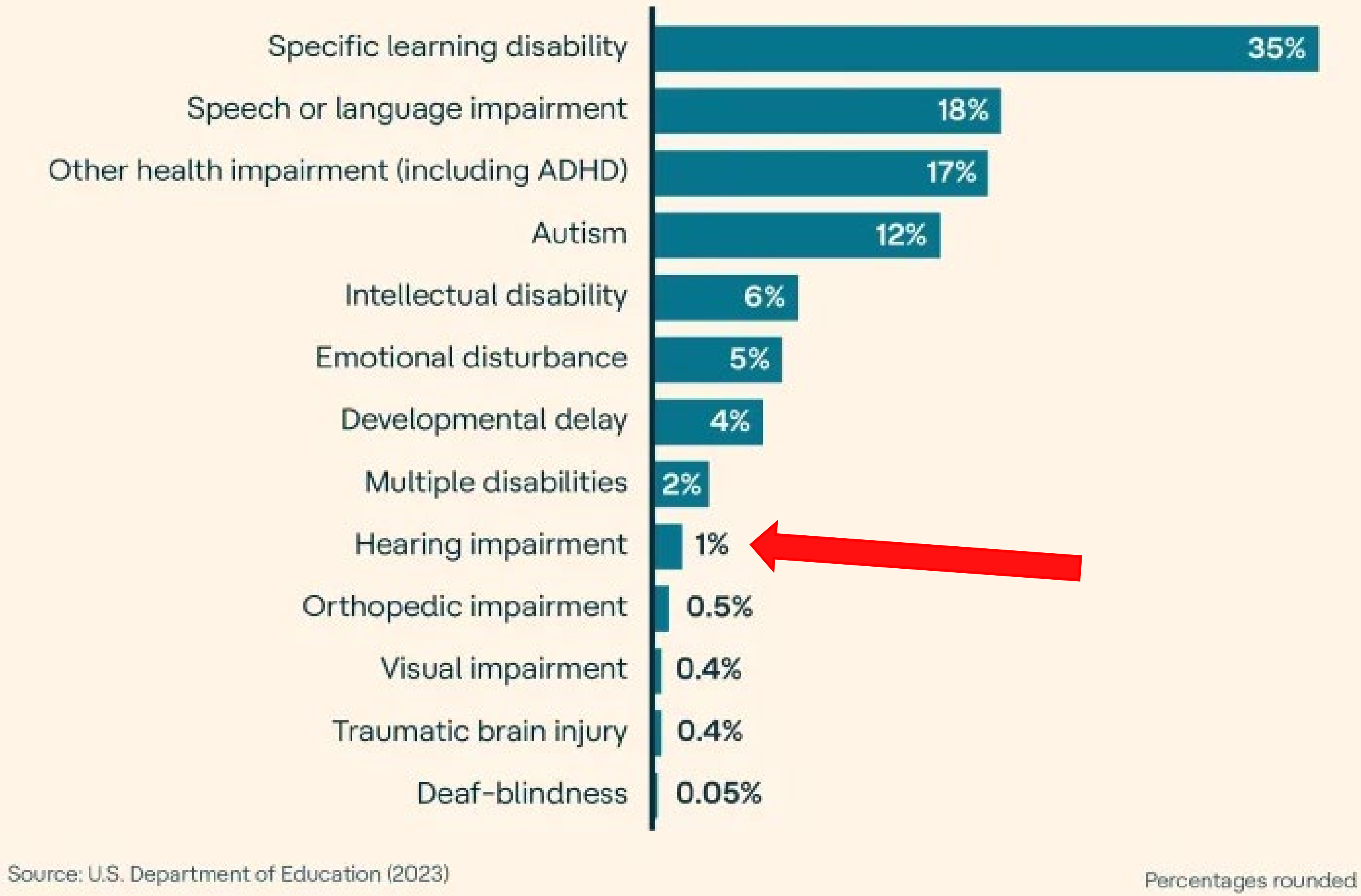


APD can coexist with many other learning disabilities.

Research indicates up to 70% of individuals with dyslexia have an underlying auditory processing disorder.

Why doesn't reading intervention work for everyone?

Disability categories for school-age kids with IEPs



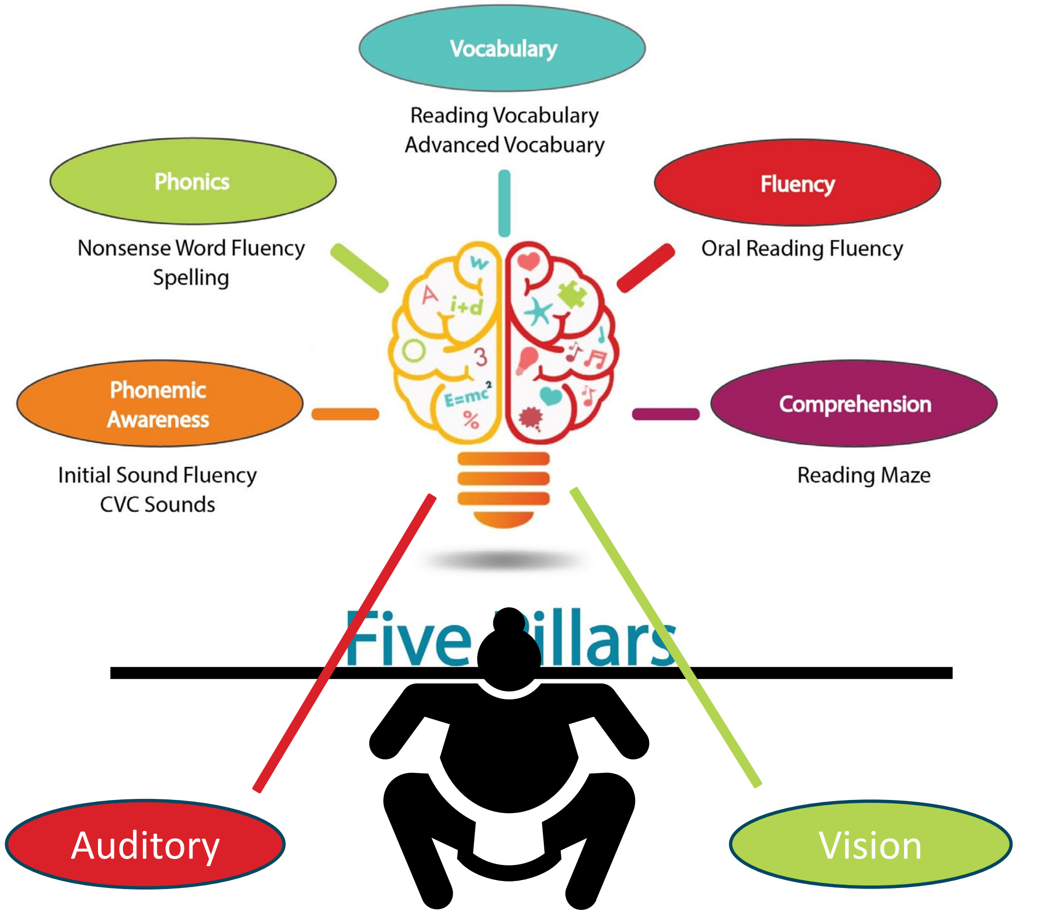
Misdiagnosed
not identified

1.8M

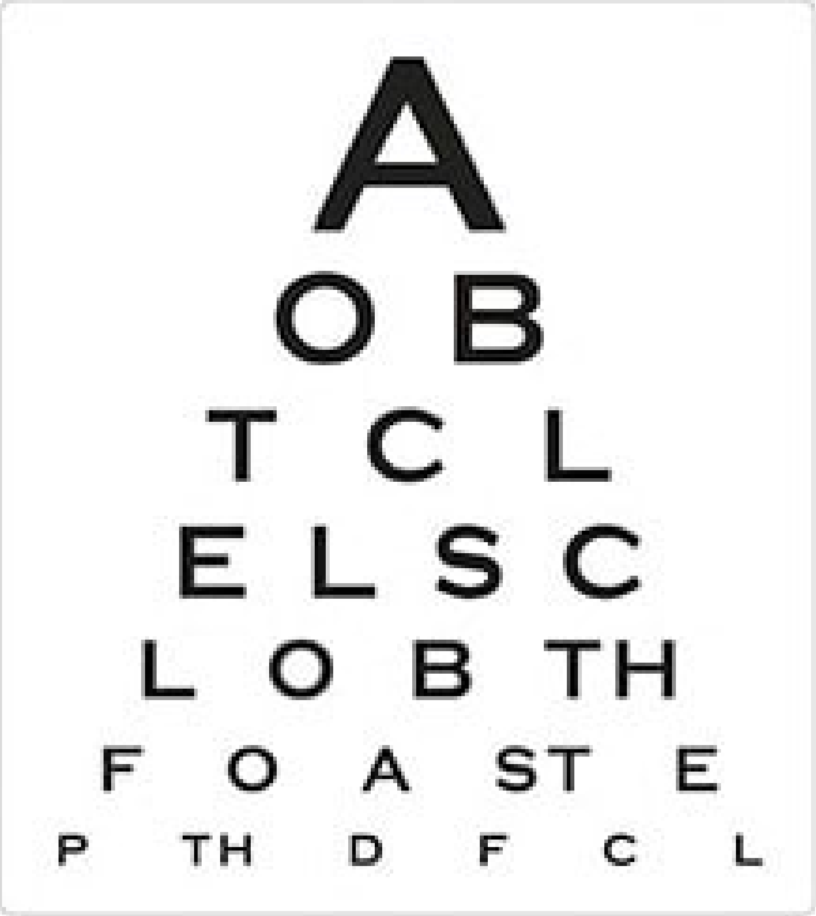
The right diagnosis mean the right intervention

Science of Reading

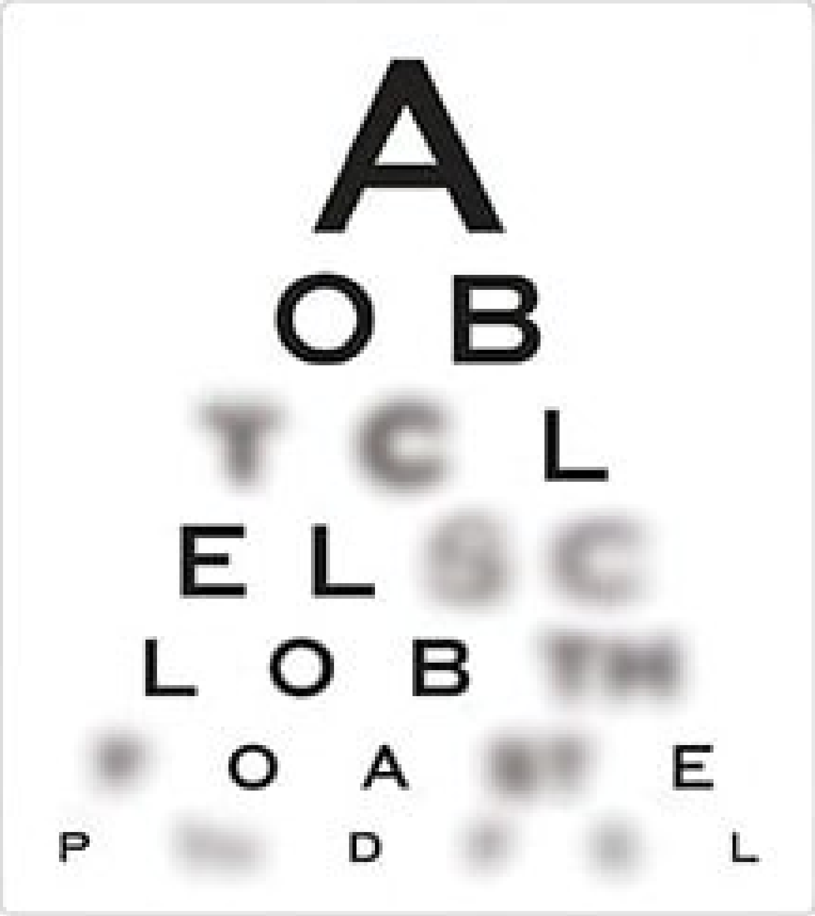
The brain must receive authentic representations of auditory and visual signals in order to think, speak and read.



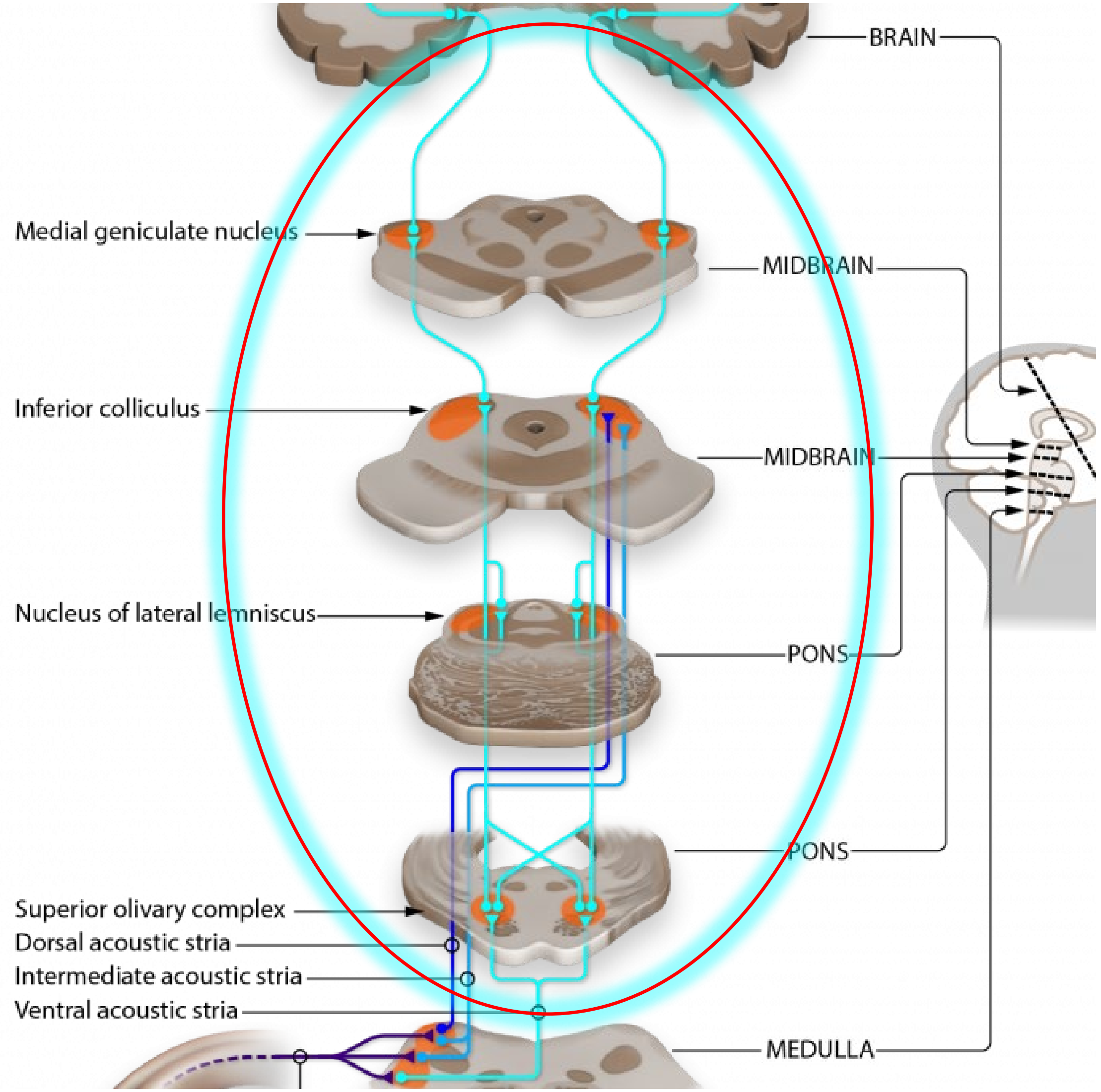
The Science Behind Reading



Normal hearing



Hearing loss



neuroplasticity, capacity of neurons and neural networks in the brain to change their connections and behaviour in response to new information, sensory stimulation, development, damage, or dysfunction.

Intervention is defined by the diagnosis and driven by the deficit

“Science means constantly walking a tightrope between

blind faith and **curiosity**;

between **expertise** and **creativity**;

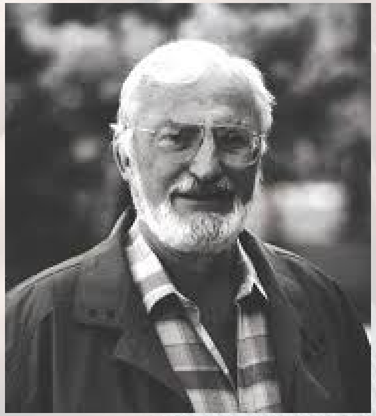
between **bias** and **openness**;

between **experience** and **epiphany**;

between **ambition** and **passion**;

and between **arrogance** and **conviction** –

in short, between an **old today** and a **new tomorrow**.”



--Heinrich Rohrer

Intervention

Language & Compensatory Strategies

- Reduce background noise
- Acoustic modifications (carpet, curtains, bookcases)
- Note-taking aid
- Attention prompts and cueing
- Eye contact
- Comprehension checks
- Visual aids
- Listening breaks
- Pre-teaching of new concepts, vocabulary

Intervention/Training

- Auditory skills training - computer
- One-on-one therapy with a clinician
- Phonemic awareness training
- Phoneme discrimination
- Listening in noise training
- Pitch pattern awareness
- Temporal resolution training
- Binaural integration training
- Localization/lateralization of sound
- Dichotic listening training – amblyaudia
- ‘Ear advantage’ training

Amplification/Technology

- Personal FM system
- Soundfield system
- Low-gain hearing aids (LGHAs)
- Assistive listening devices
- Laptop/tablet with word processing capabilities
- Custom ear filters and noise cancelling ear pieces

Final tips & takeaways

The math doesn’t work

- We are missing and/or misdiagnosing many kids with auditory issues

Best practice for 2024 & beyond

- Technology & research show us what we can’t see – we must open our eyes.

The auditory pathway can change

- Deficit driven intervention supports the Science of Reading

We must know what the brain is hearing

- Increase the cognitive load to understand what the brain hears

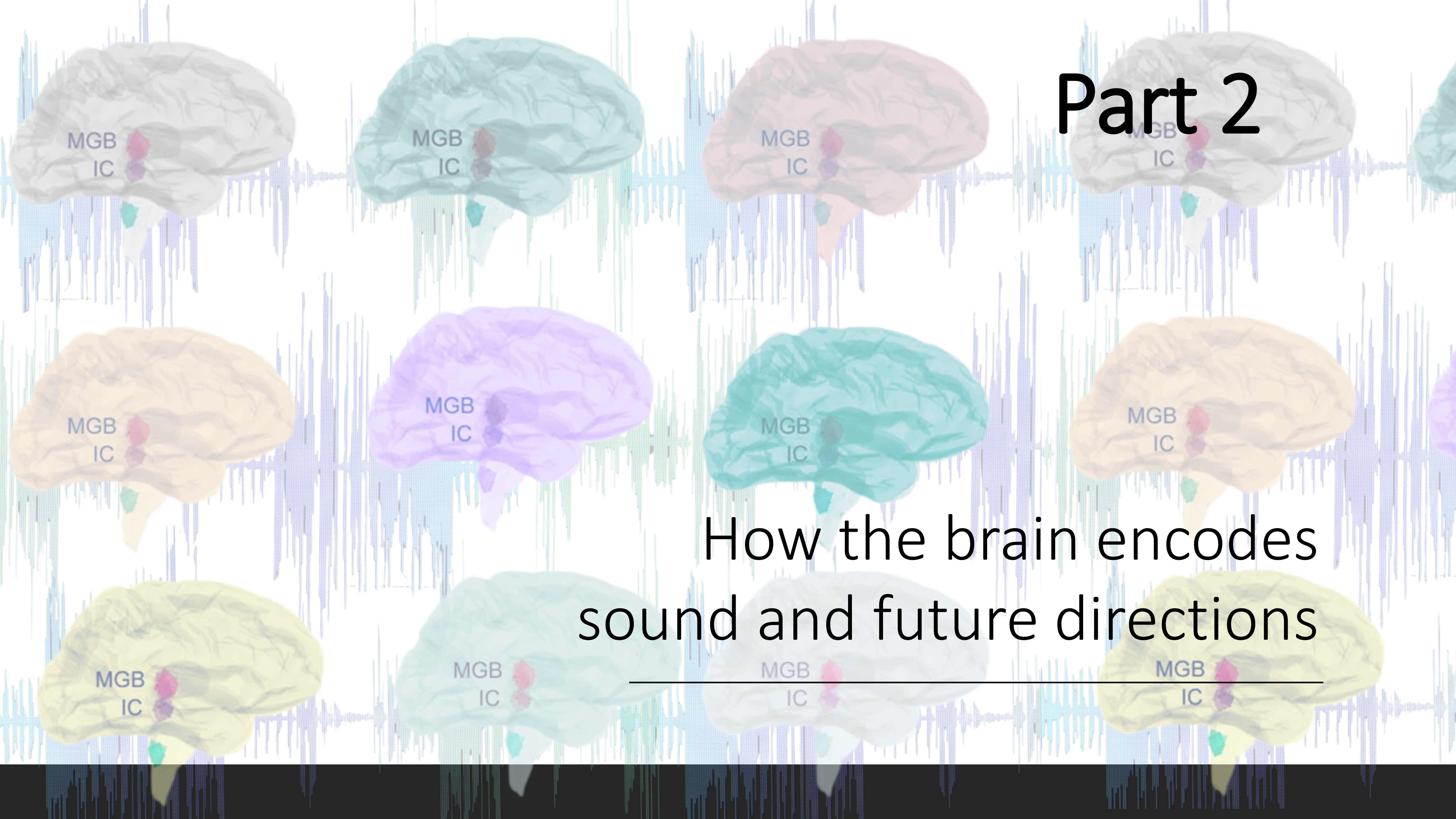
1. Do the math
2. Open your eyes
3. Change the pathway
4. Test appropriately
5. Never stop being curious

SOUND WRX


BREAK TIME
SOUND
WRX

Part 2

How the brain encodes sound and future directions



What tools do we have to test how the brain encodes sound?

Otoacoustic Emissions (OAEs)

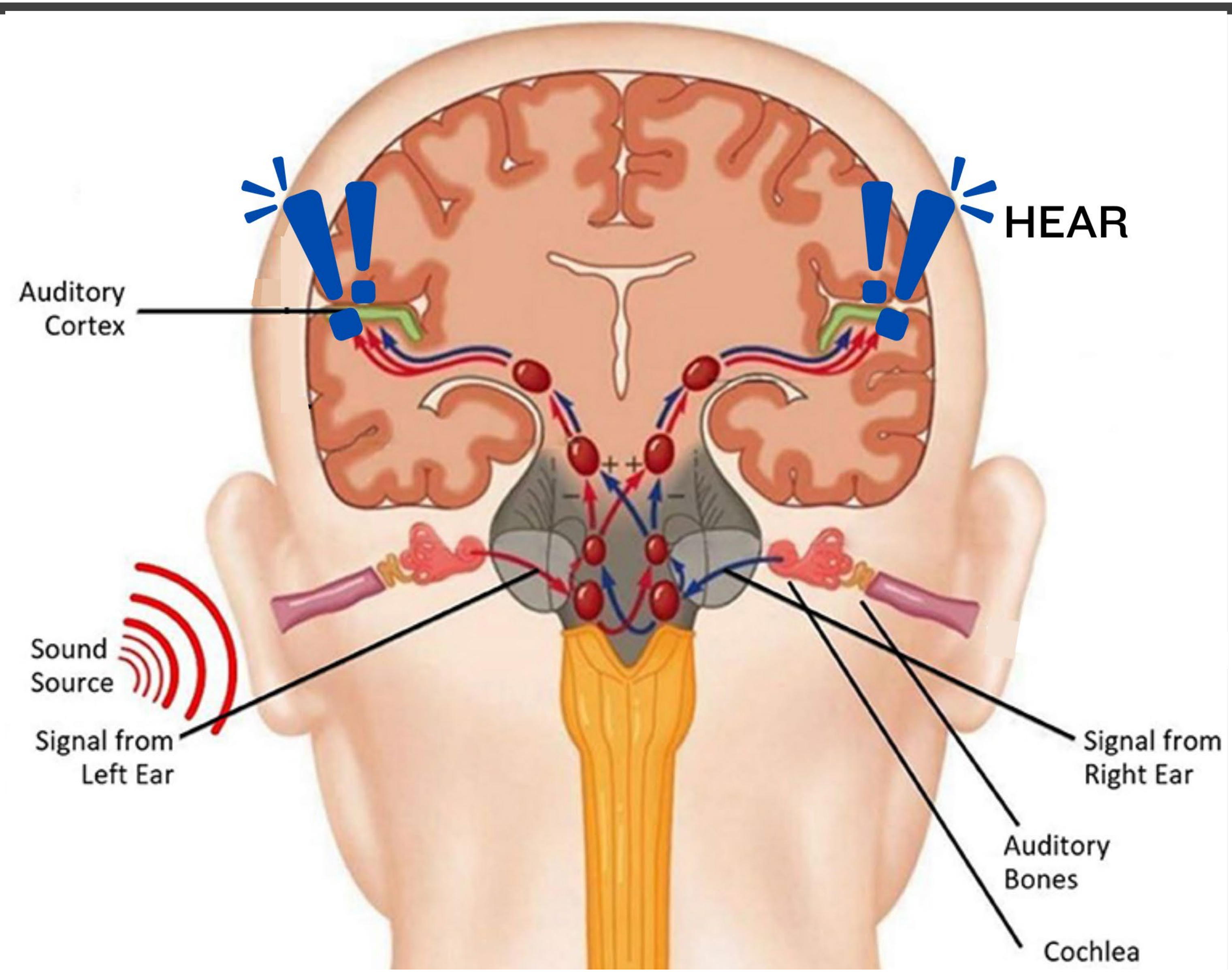
Auditory Brainstem Response (ABR)

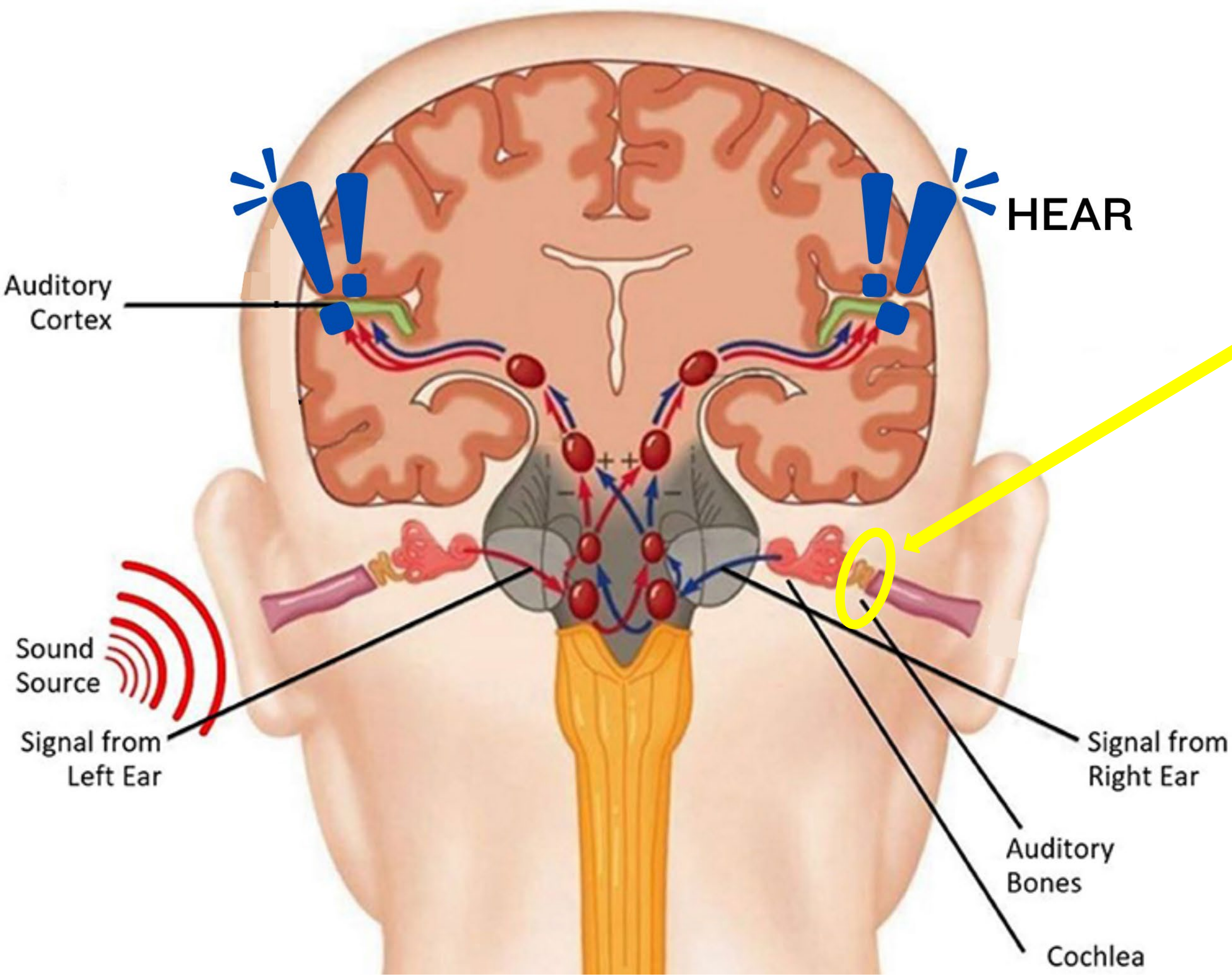
Tympanometry/Acoustic Reflexes

Screening Audiometer

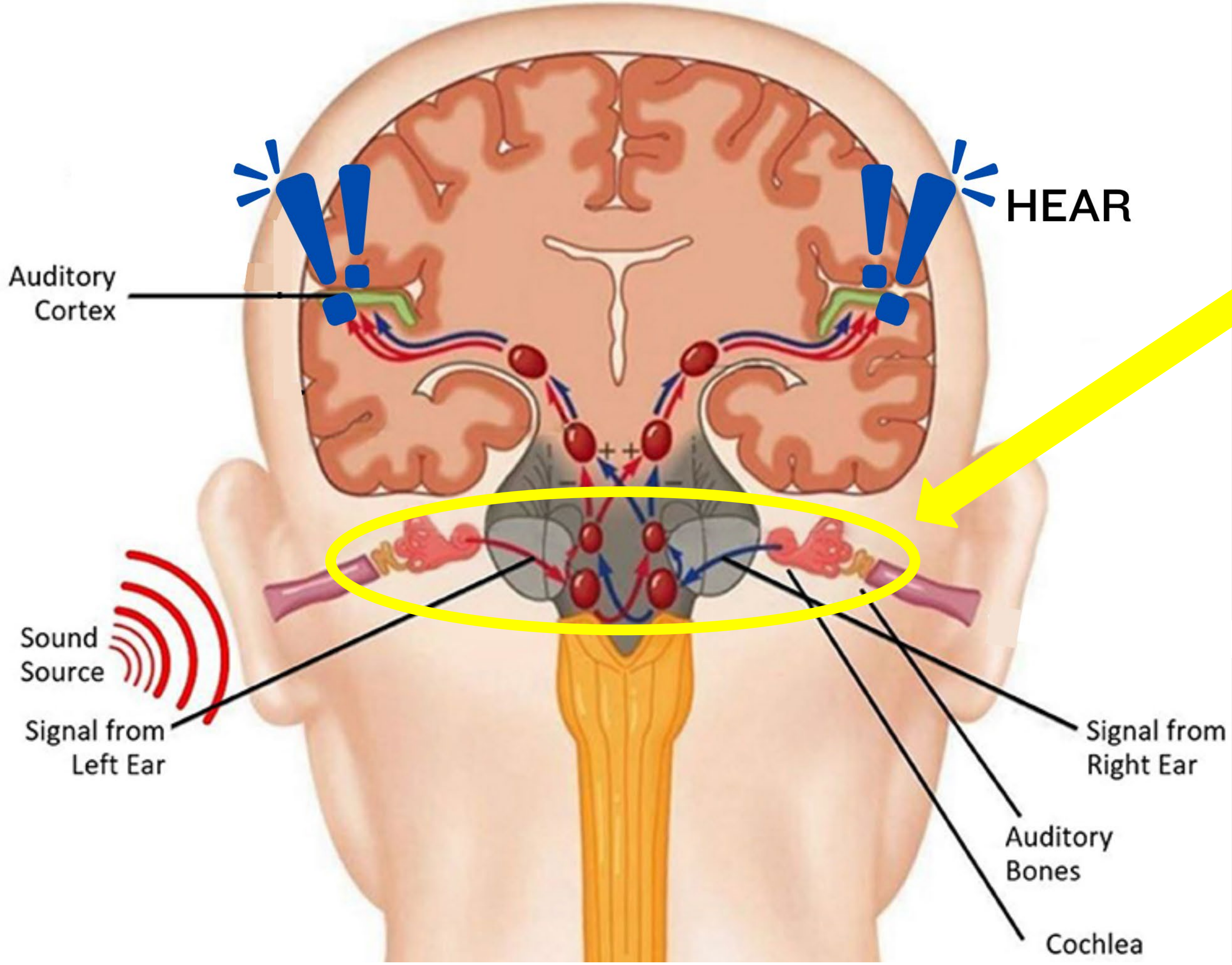
Diagnostic Audiometry

Portable Audiometry


HEAR
Auditory
Cortex
Sound
Source
Signal from
Left Ear
Signal from
Right Ear
Auditory
Bones
Cochlea

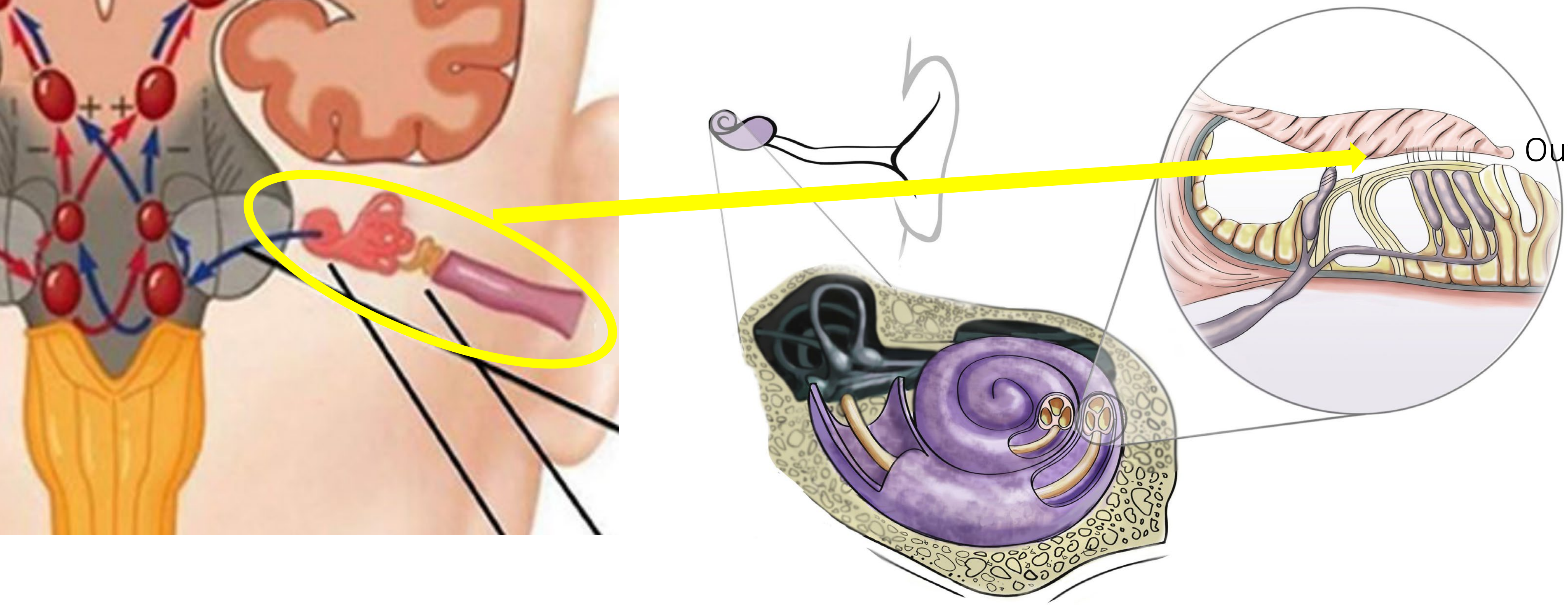


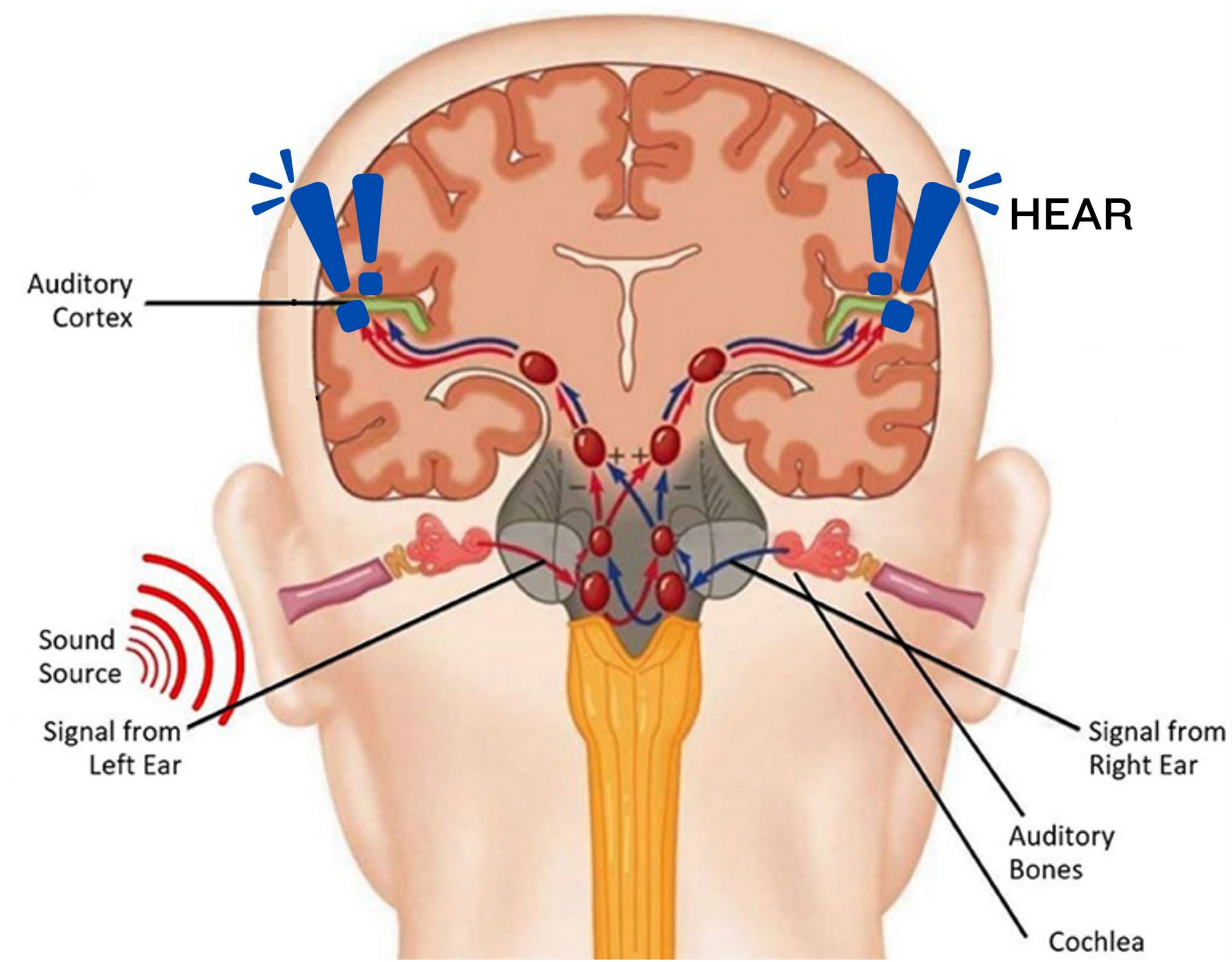
Tympanometry



Acoustic Reflexes

OAEs





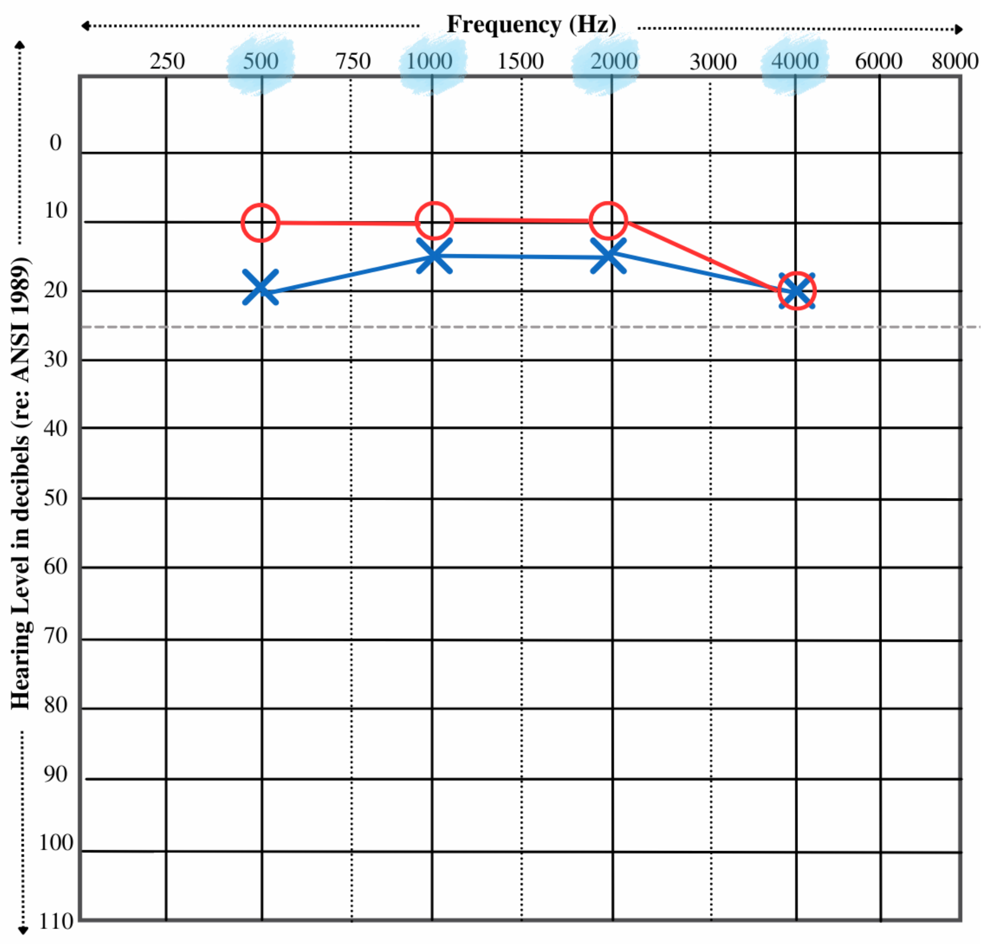
Diagnostic Audiometry

Recognition of a sound and speech in a quiet condition

Gives good information about if the brain is receiving sound and if the integrity of the pathway allows for understanding speech in quiet.

Screening

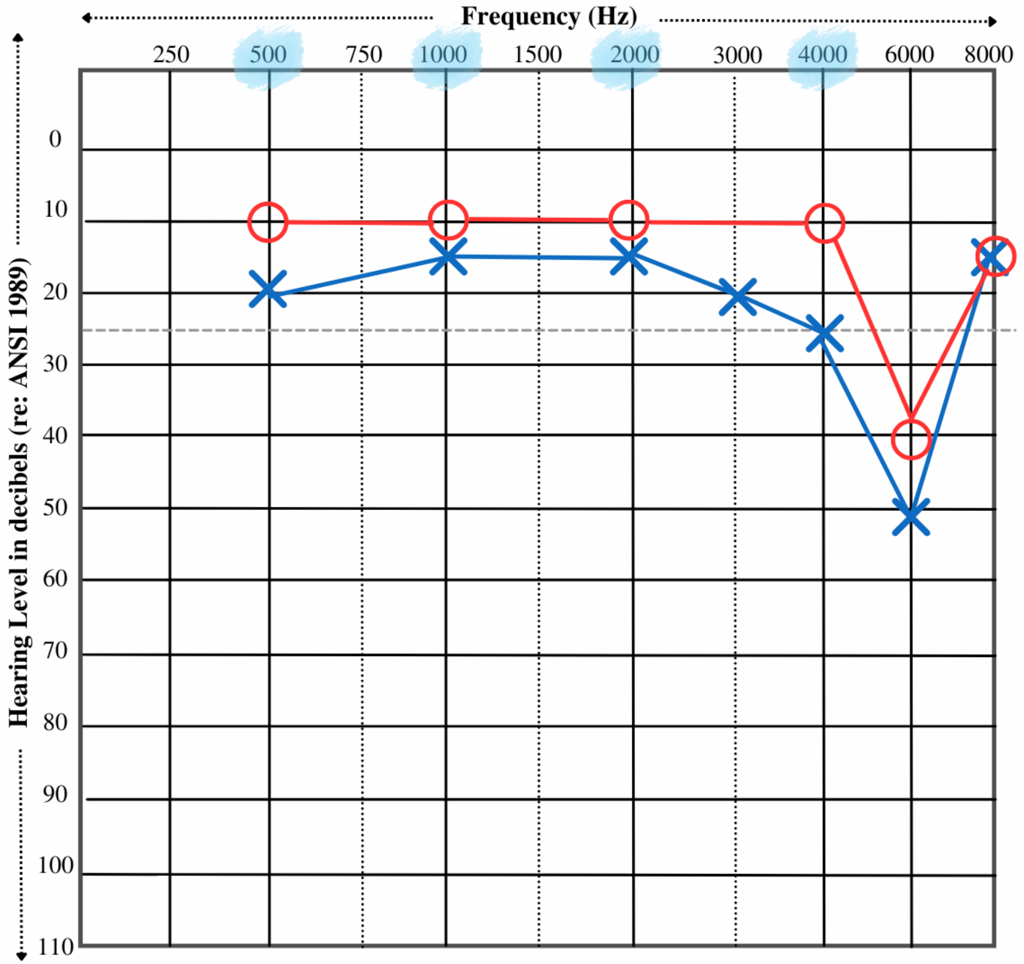
ASHA/AAA



Recommend screen children at 20dBHL at frequencies .5, 1. 2, 4kHz

Screening

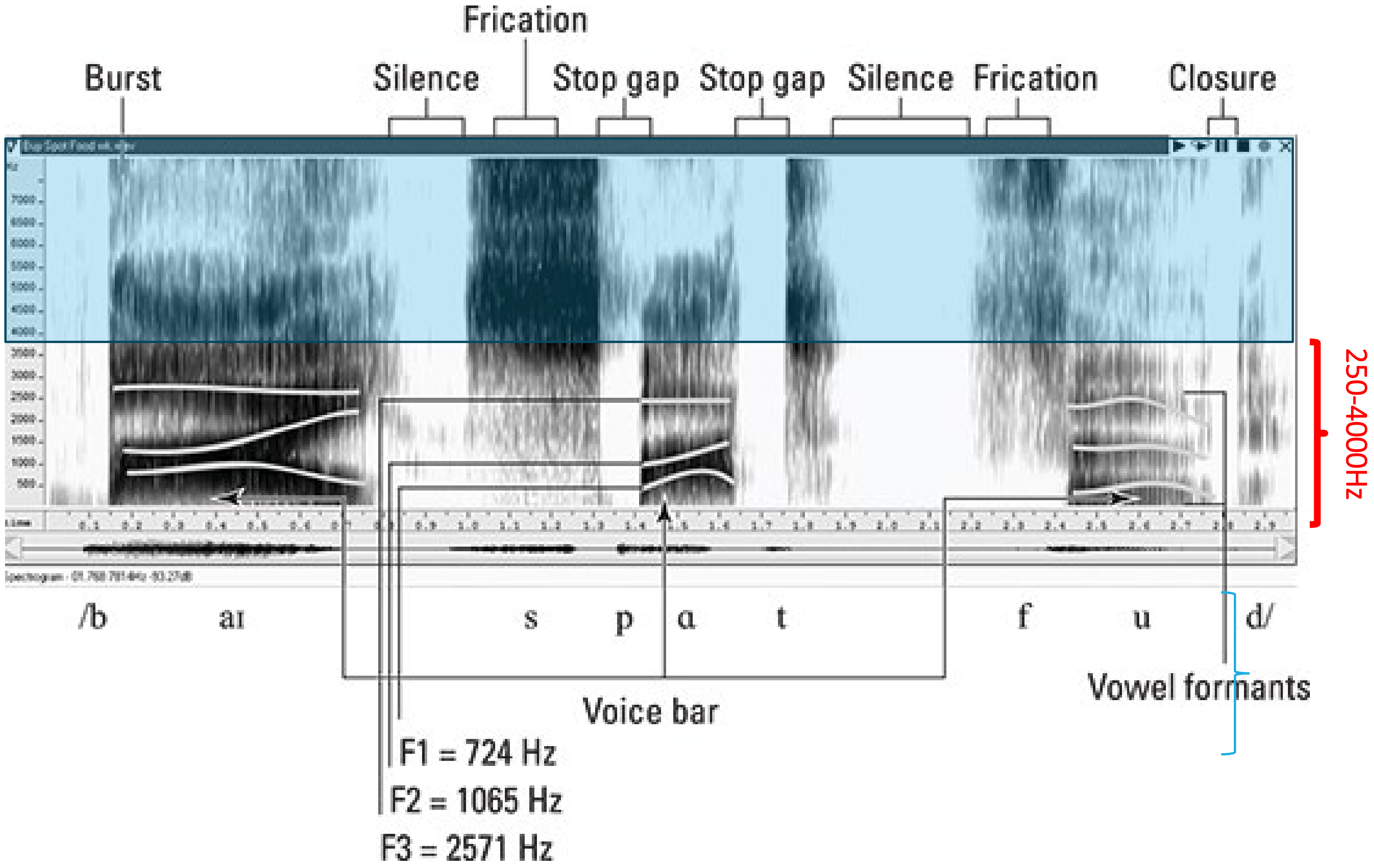
ASHA/AAA



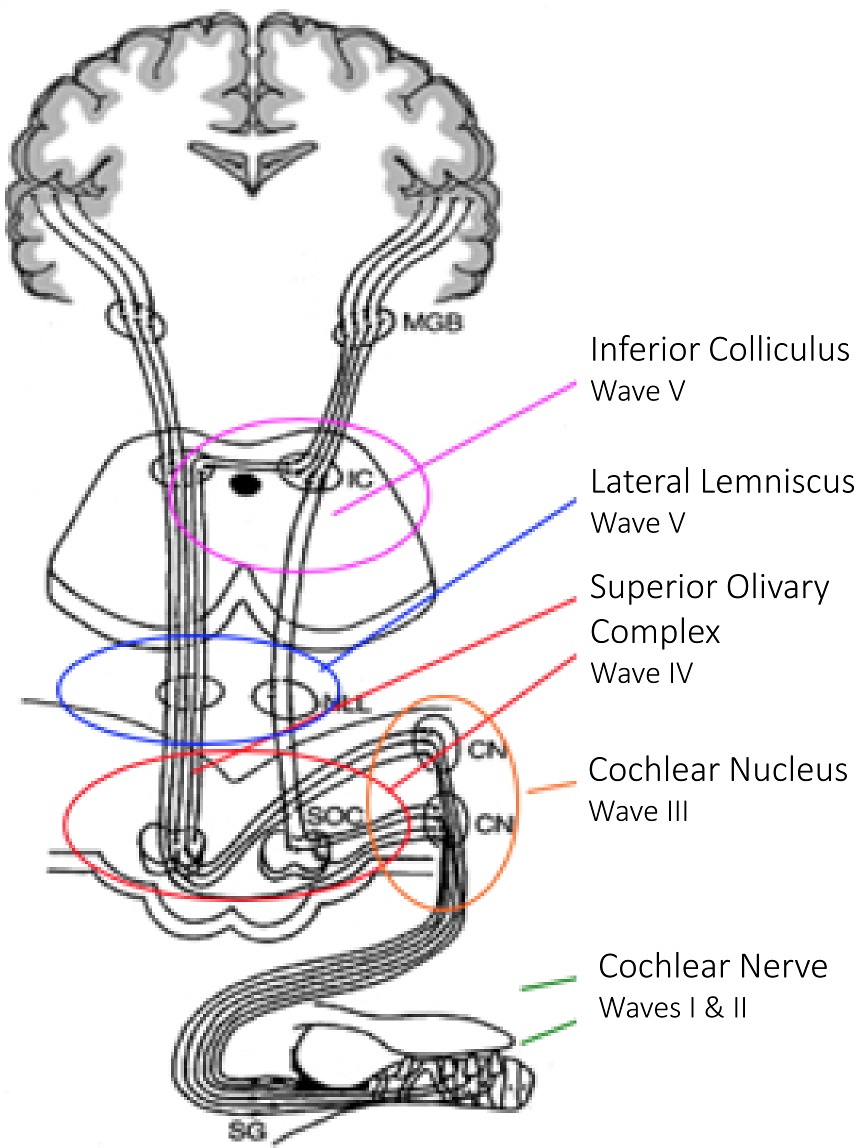
Ling Sounds & Formant Spectrum

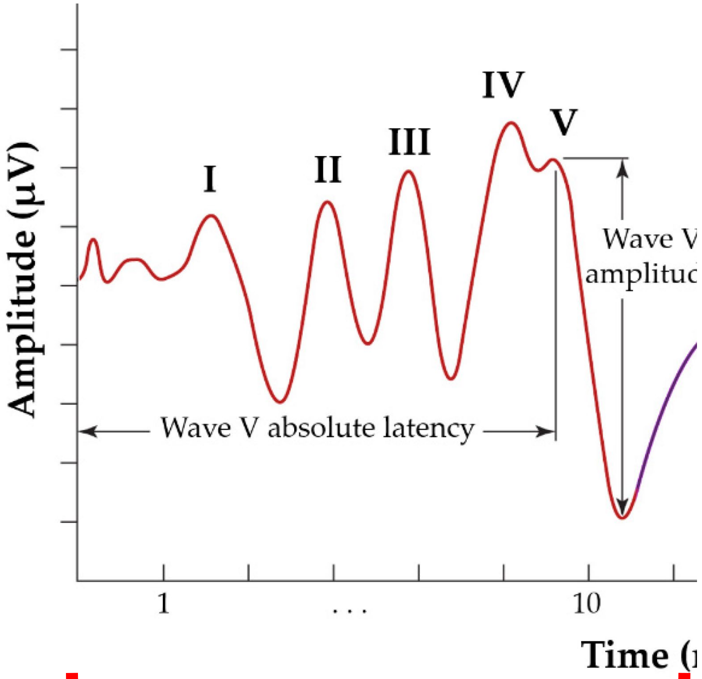
LING SOUND	1ST FORMANT	2ND FORMANT	3RD FORMANT	4TH FORMANT
OO	200-500	650-1100		
AH	525-775	825-1275		
EE	150-450		2300-2900	
SH			1500-2000	4500-5500
S				5000-6000
TH				6000
M	250-350	1000-1500	2500-3500	

Reading delay
School considering retaining him in first grade
Tinnitus
Dizziness
Thick glasses



To be able to understand speech clearly, it is therefore important to have good hearing across the entire range of frequencies from 125 – 8,000 Hz, but especially in the range of the unvoiced consonants.





0 - 15 ms

ABR/AABR

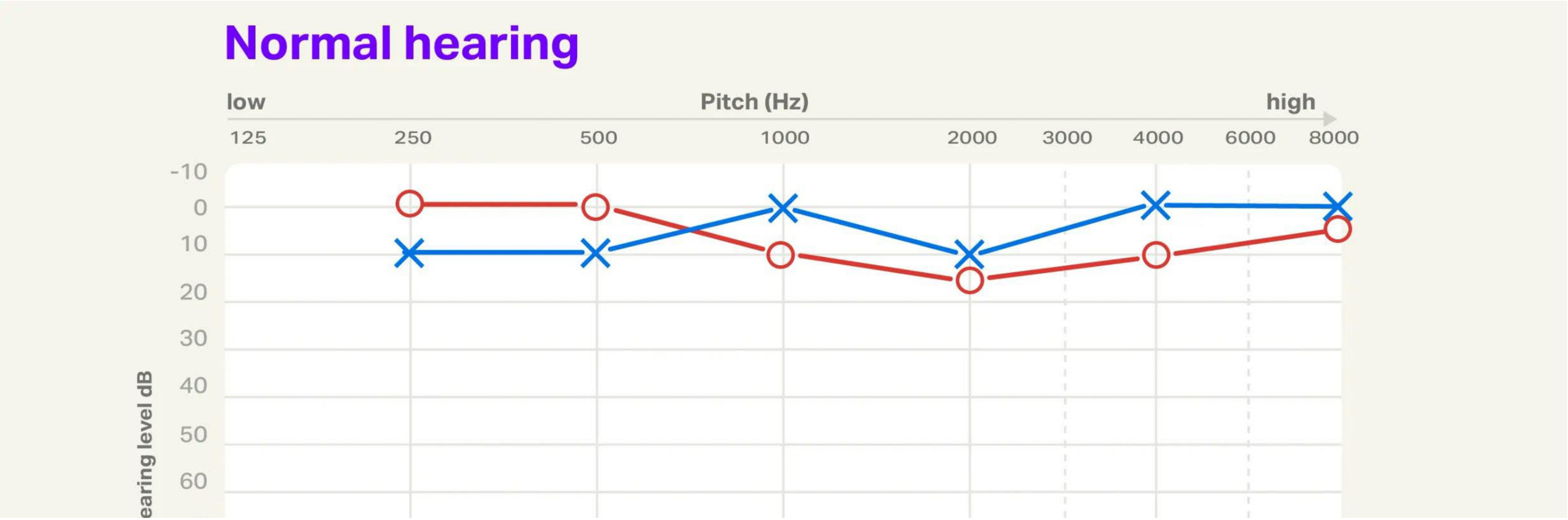
A test of hearing thresholds

To assess the functional status of the auditory neural pathway

Important information, but only tests for hearing sensitivity

Do any of these tests tell us what we're hearing in the brain?

Do they tell us how someone functions in the world?



Is this normal hearing?

Hidden Hearing Loss

"Recent studies provide evidence that changes in the peripheral auditory system (the cochlea) induced by noise, drugs, peripheral neuropathy, or aging can also alter the neural sound-evoked output of the auditory nerve (AN) independently of hair cell loss and changes in hearing thresholds.

This form of hearing loss has been referred to as "hidden hearing loss" (HHL) to reflect that the dysfunction is not revealed by standard tests of auditory thresholds."

SPEECH IN NOISE

C Kohrman D, Wan G, Cassinotti L, Corfas G. Hidden Hearing Loss: A Disorder with Multiple Etiologies and Mechanisms. Cold Spring Harb Perspect Med. 2020 Jan 2;10(1):a035493. doi: 10.1101/cshperspect.a035493. PMID: 30617057; PMCID: PMC6612463.

Auditory Processing Disorders (APD)

Problems in processing auditory stimuli due to central nervous system abnormalities despite intact peripheral auditory structures.

Fundamental auditory skills are compromised such as:

- sound localization
- sound discrimination
- pattern recognition
- temporal analysis of sound signals
- temporal integration of sounds

Konopka AK, Kasprzyk A, Pyttel J, Chmielik LP, Niedzielski A. Etiology, Diagnostic, and Rehabilitative Methods for Children with Central Auditory Processing Disorders-A Scoping Review. Audiol Res. 2024 Aug 21;14(4):736-746. doi: 10.3390/audiolres14040062. PMID: 39194418; PMCID: PMC11351927.

Many different types of tests available to assess auditory processing disorders.

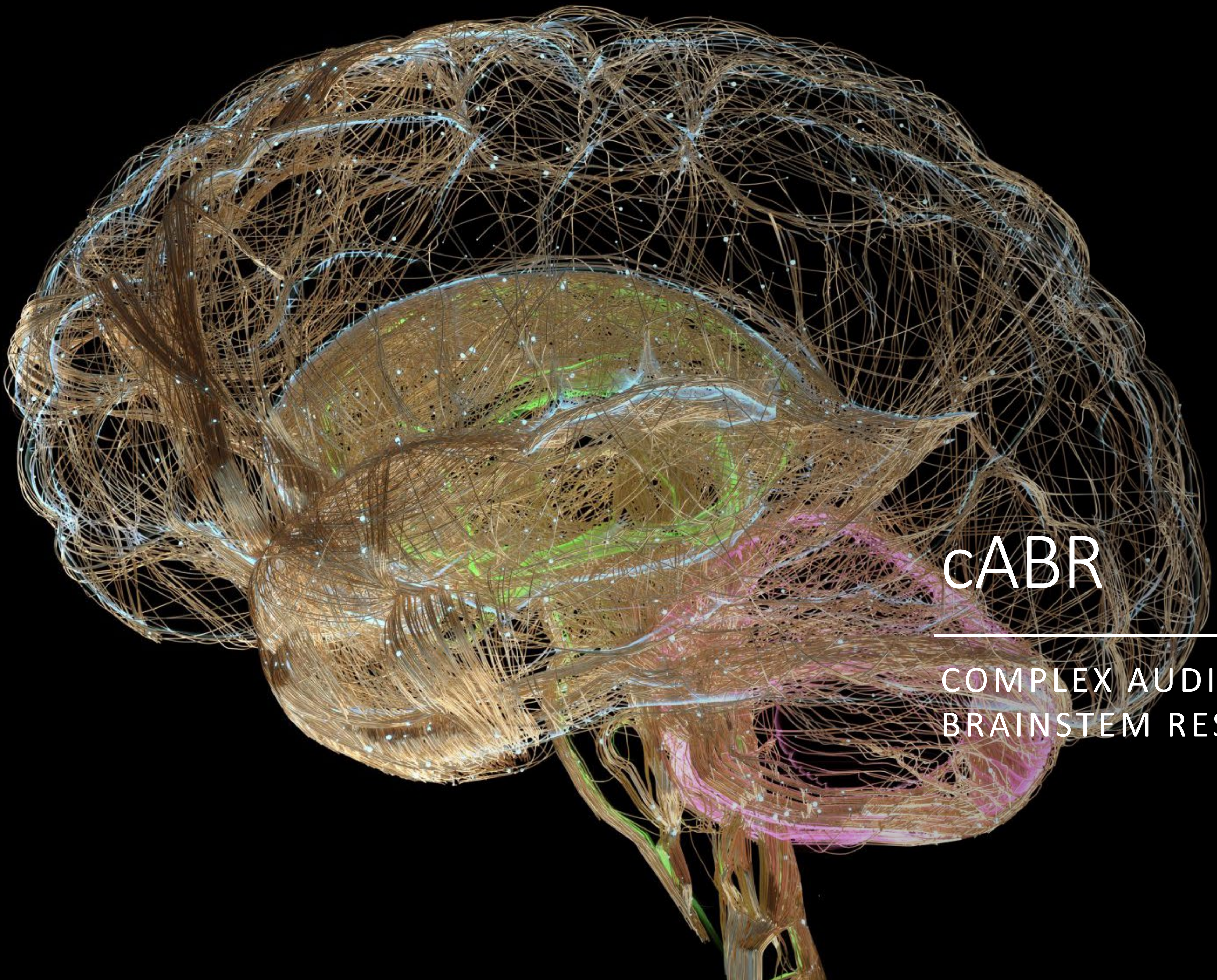
SUBJECTIVE

Auditory Evoked Potentials

Auditory Brainstem Response

References	N(ears), age, and gender	Diagnostic criteria	ABR rep rate	ABR intensity	ABR findings
Hurley (2004)	N: 48 non-APD, 48 APD Age: 7–12 yo Gender: Male	Screened for auditory processing disorders using SCAN-C and two language tests: Peabody Picture Vocabulary Test-III (PPVT-III) and Oral and Written Language Scales (OWLS)	11.1/s	70 dB peak SPL	- No significant difference in ABR latency between APD and non-APD group - Non-APD group displayed greater ABR amplitudes (for waves I, III, and V) than the APD group
Filippini and Schochat (2009)	N: 20 non-APD, 20 APD Age: 7–24 yo Gender: N/A	Auditory processing assessment (information on specific tests unclear)	19/s	80 dB nHL	- No significant difference between the APD and non-APD group on ABR amplitude and/or latency
Morlet et al. (2019)	N: 48 non-APD, 38 APD Age: 7–12 yo Gender: 12M/7F (APD), 10M/14F (non-APD)	Referred specifically for an APD evaluation based on APD related symptoms; diagnosed by audiologists based on the APD test battery from AAA and ASHA based on abnormal scores on SCAN-3, Bamford-Kowal-Bench Sentences in Noise, Dichotic Digits Test, Frequency Pattern Test/Pitch Pattern Sequence Test, Staggered Spondaic Words Test, Random Gap Detection Test, Phonemic Synthesis Test (PST), and Auditory Continuous Performance Test	27.7/s	80 dB nHL	- No significant difference between the APD and non-APD group on ABR amplitude and/or latency
Allen and Allan (2014)	N: 23 non- APD, 40 APD Age: 7–17 yo Gender: 39M/24F Both groups were referred for testing due to their reported listening difficulties	Abnormal scores on 5 central auditory processing tests: gap detection task (AFT-R), dichotic test (SSW), temporal patterning test (PPS), speech in noises task (WIC), filtered speech task (FS)	27.7/s, 57.7/s	<110 dB HL	- No significant difference between APD and non-APD groups on absolute wave latencies
Jirsa (2001)	N: 60 non-APD, 74 APD Age: 9.2–13.6 yo Gender: 20M/17F (APD); 17M/13F (TD)	Diagnosis of APD based on abnormal scores on the Dichotic Digits Test (DD), Dichotic Sentence Identification Test (DSI), Frequency Pattern Test (FP), Auditory Duration Pattern Test (DP), Time Compressed Speech Test, Synthetic Sentences Identification Test with Ipsilateral Competing Message (SSI-ICM)	11.1/s	75 dB nHL	- APD group significantly differed from the non-APD group on ABR latency measures.
Ankmnal-Veeranna et al. (2019)	N: 44 non-APD, 216 sAPD Age: 4.11–35 yo (TD); 5.25–15.7 yo (sAPD) Gender: N/A	Referrals due to concerns with hearing/listening in noisy conditions; behavioral checklists for auditory processing problems and educational risk indicating need for central auditory processing assessment	13.3/s	80 dB nHL	- APD group significantly differed from the non-APD group on ABR latency measures.
Gopal and Pierel (1999)	N: 18 non-APD, 18 APD Age: 7–13 yo Gender: N/A	Diagnosed with auditory processing difficulties by certified speech-language pathologists based on CELF-R and TAPS; failed the SCAN or SCAN-A test	11.1/s	<5 dB nHL (ABR thresholds), 55 dB above monaural threshold for ABR peak V (5)	- No significant differences between APD and non-APD groups on latency and amplitude for right, left, and binaural ABRs
Gopal et al. (2002)	N: 20 non-APD, 20 CAPD Age: 9.2–15.7 yo Gender: 6M/4F in non-APD; 7M/3F in experimental	Experimental/CAPD group all failed the SCAN or SCAN-A test	11.1/s 81.1/s	60 dB nSL	- APD group significantly differed from the non-APD group on ABR amplitude

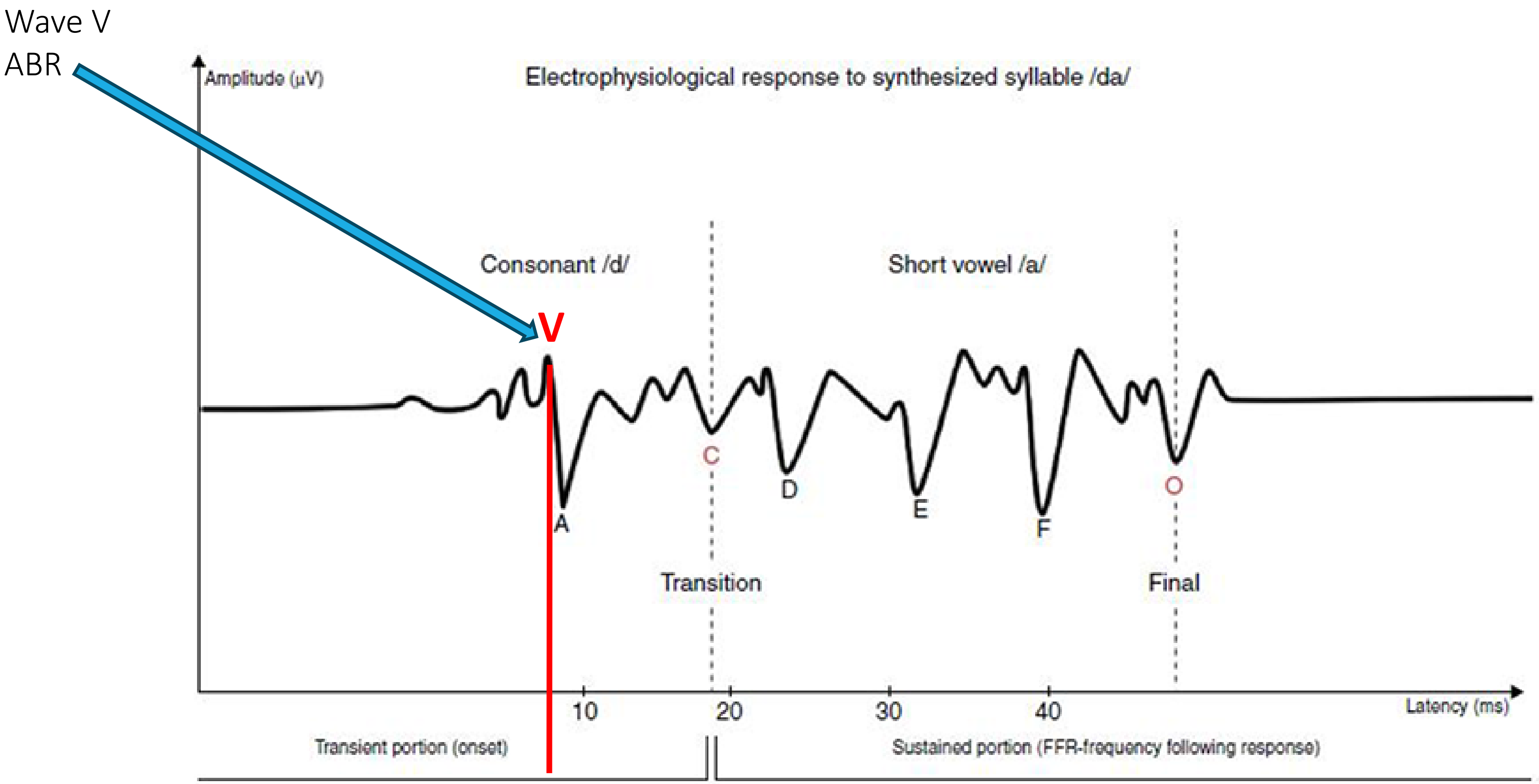
APD, auditory processing disorder; sAPD, suspected auditory processing disorder; TD, typically developing; SCAN-C, screening test for auditory processing in children; SCAN-A, screening test for auditory processing in adults; CAPD, central auditory processing disorder; SSW, staggered spondaic word test; PST, phonemic synthesis test; PPVT, Peabody picture vocabulary test; PPS, pitch pattern sequencing test; WIC, words-in-competition test; FS, filtered speech task; DD, dichotic digits test; DSI, dichotic sentence identification test; DP, duration pattern test; SSI-ICM, synthetic sentences identification test with ipsilateral competing message; TAPS, test for auditory processing skills; CELF-R, clinical evaluation of language fundamentals—revised.



cABR

COMPLEX AUDITORY BRAINSTEM RESPONSE

40ms short /da/



How the brain processes aspect of and reflects our individual experience in sound


Fundamental Frequency

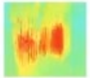

Harmonics

Frequency domain; strength of fundamental frequency & harmonics.

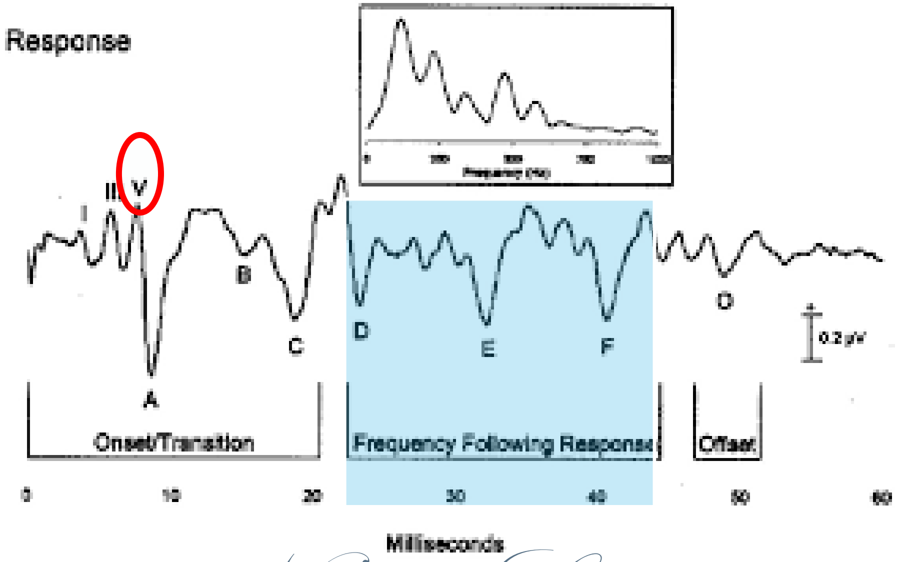

Stim/Resp — Tells how accurate the response is – stim-to-response correlation (closer to 1 is a better correlation)


Timing — Gives important information regarding timing of the response to the stimulus. Especially important for consonants


Stability — How stable is the response from trial to trial.


Phase — Phase is another form of measuring timing – this measure compares the brain's timing response to consonants using the phase differences between /ga/ and /ba/. The red indicates larger timing differences (i.e., better ability to distinguish between consonants)


Noise — Not a direct ingredient of a FFR, the presence of background noise can affect the quality and strength of an FFR by interfering with the neural synchronization to a target sound's periodic features.

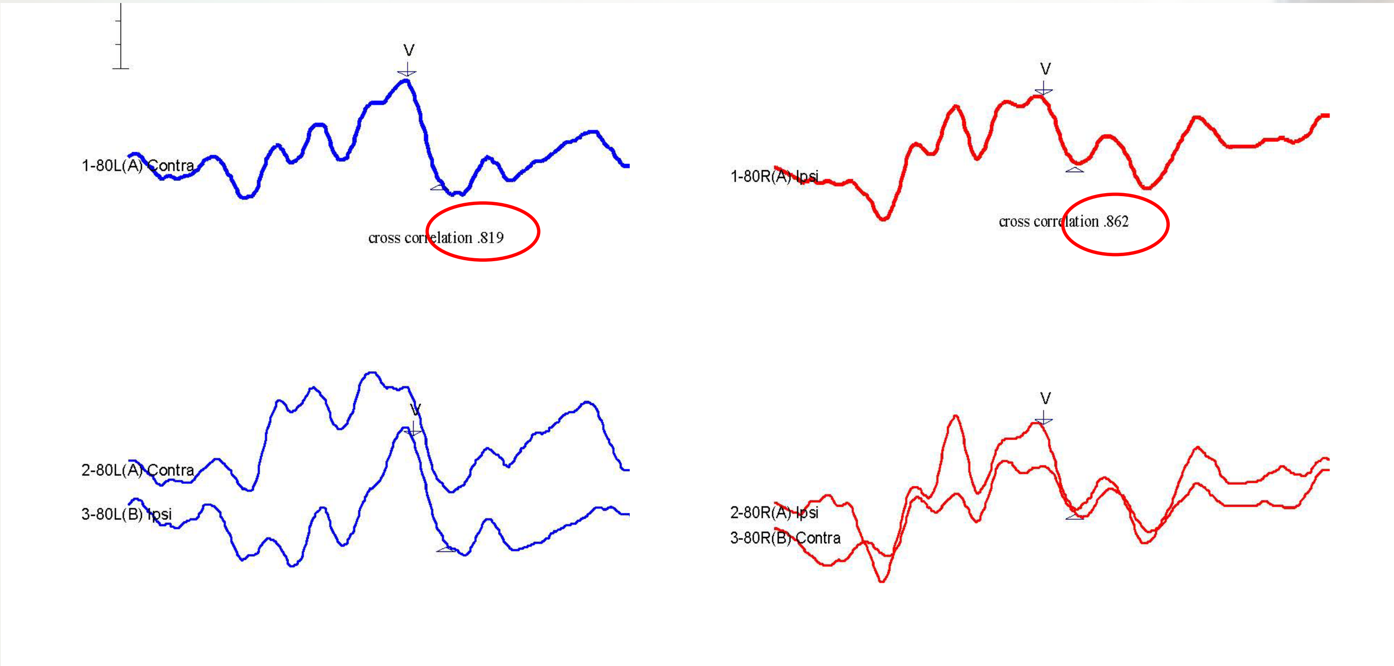


Neural Signature

The FFR is a snapshot of how the brain processes sound.


Nick

Early Response - ABR



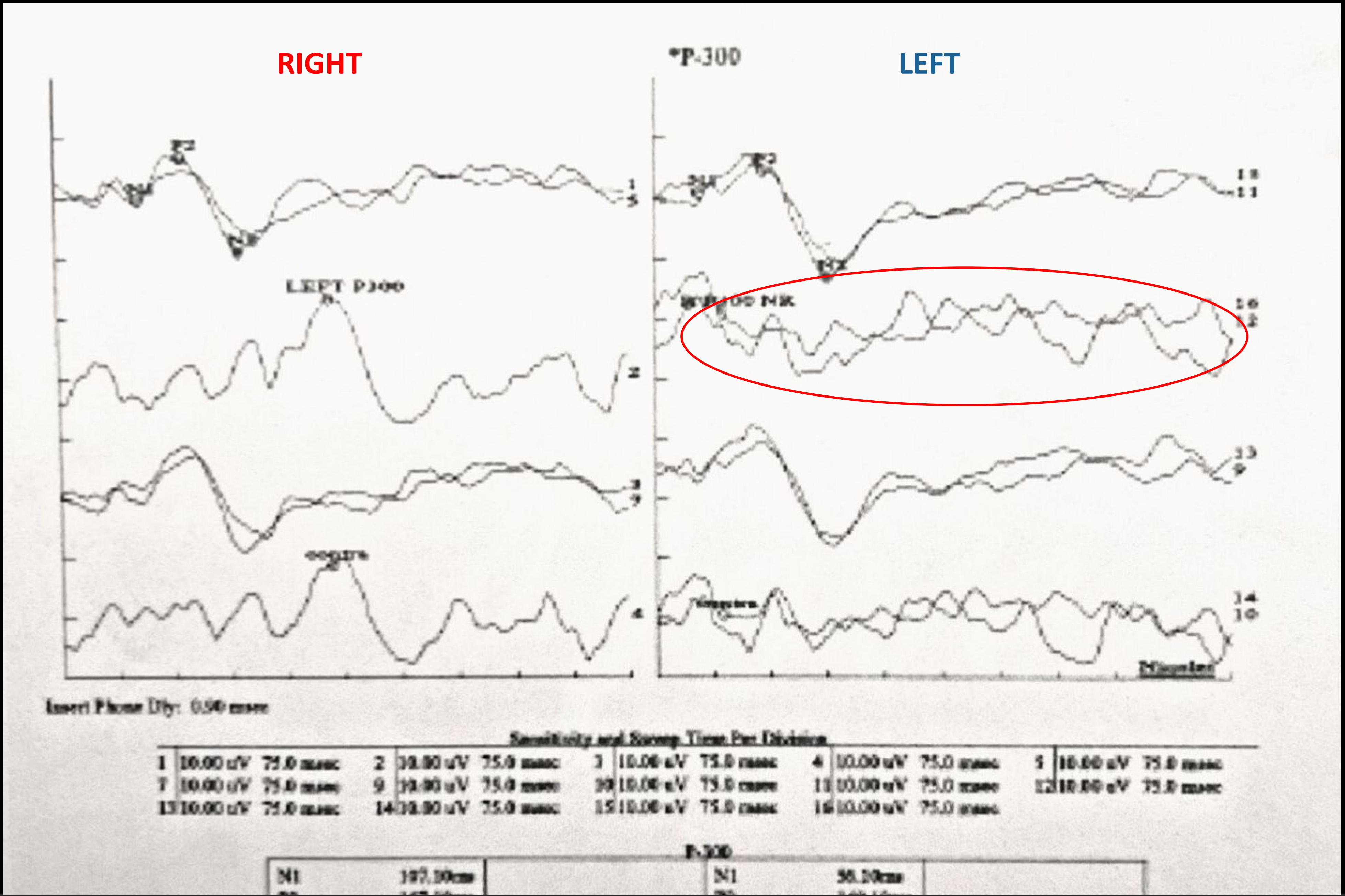
Good cross-correlation: (the measurement of how well two independent signals resemble each other, a concept also known as cross-similarity).

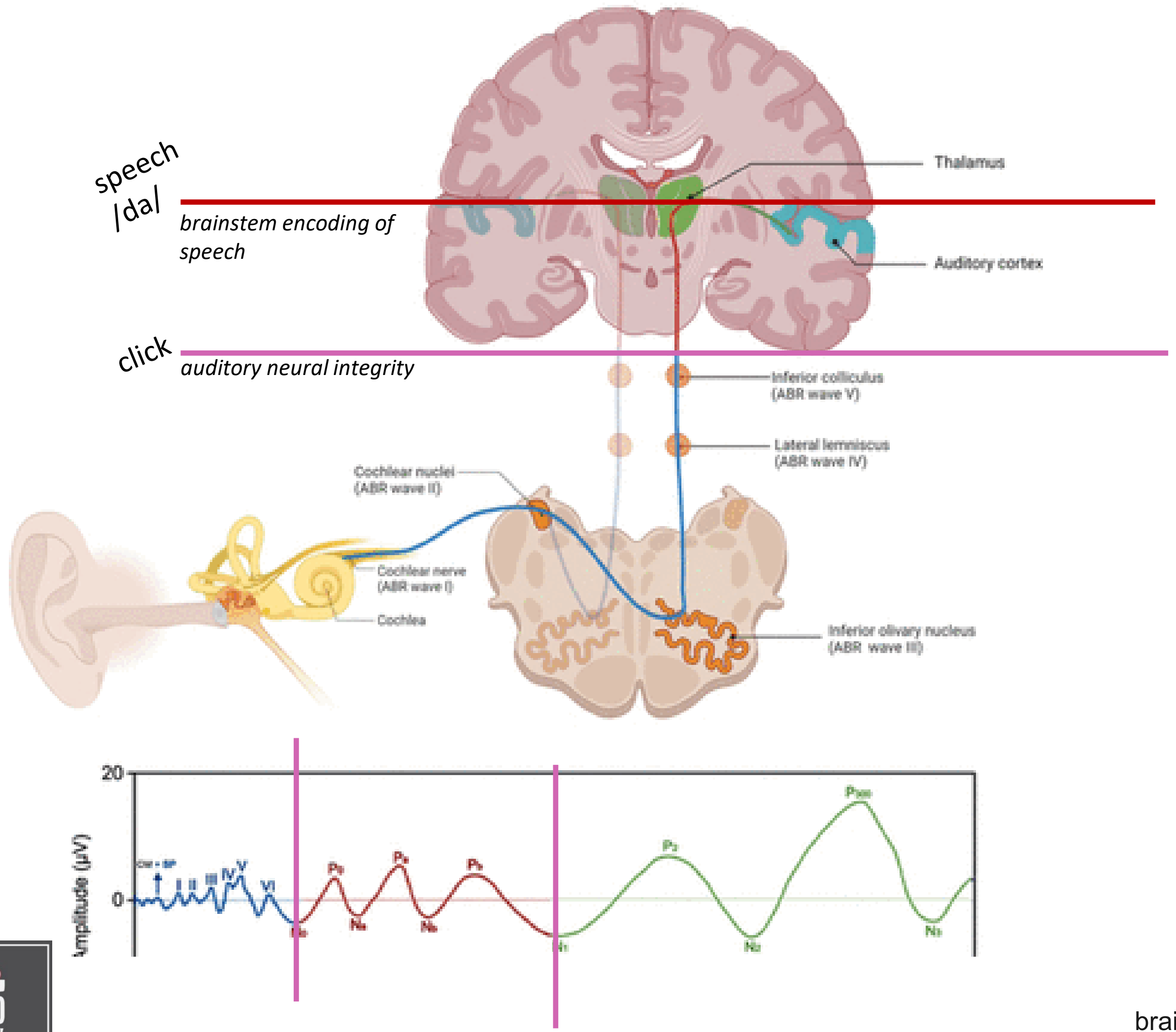
Nick

- Normal Birth Hx
- Normal developmental milestones
- Concussion at age 3 years
- Dx with ADHD
- Rx made him "feel funny"
- High IQ – couldn't read
- Sensory issues
- Poor handwriting
- Poor organizational skills
- Difficulty with multi-step directions
- Sensitive to loud sounds

Late latency P300

NR = Right Side





Change the signal to Speech

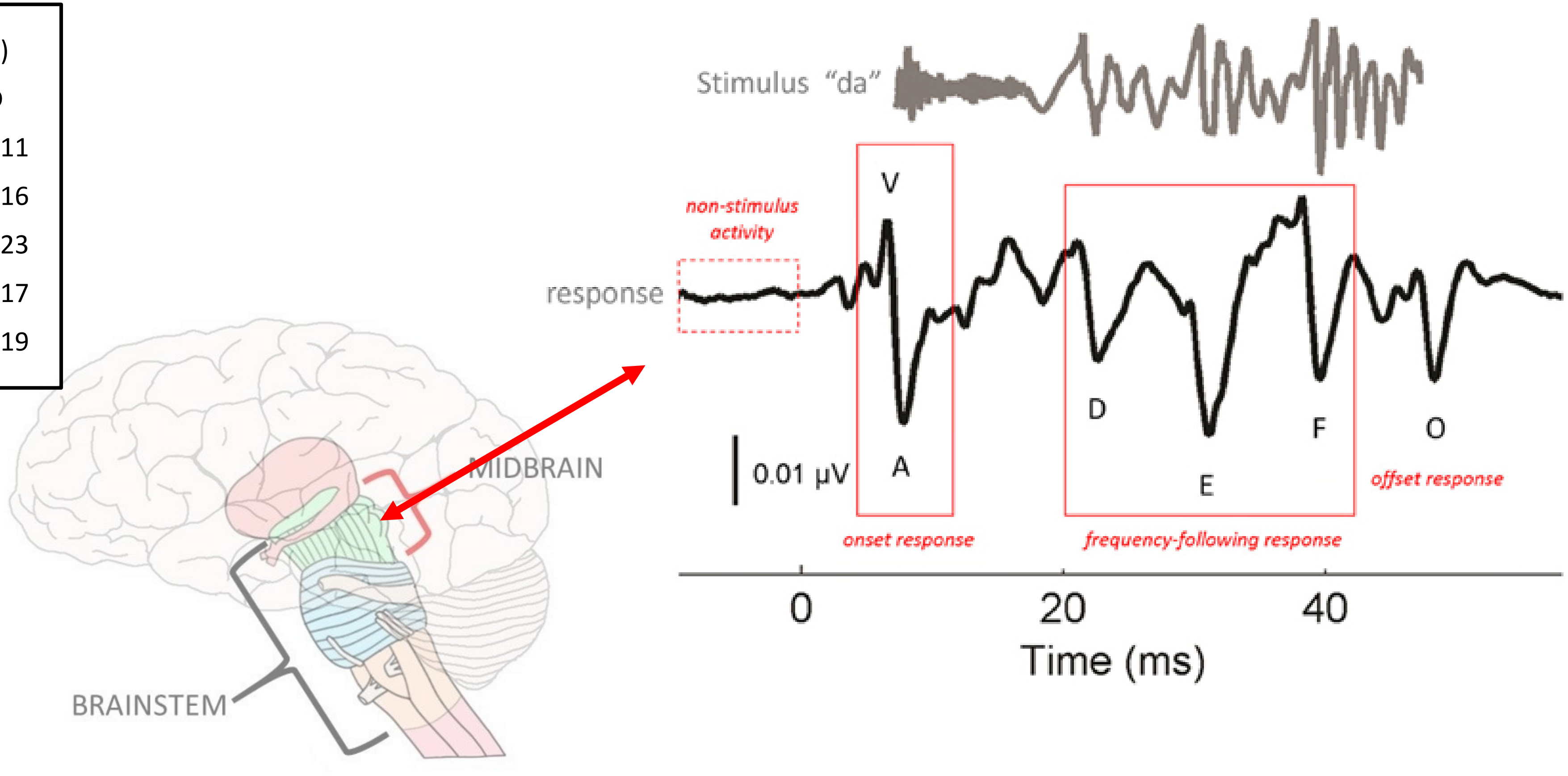
A complete description of how the auditory system responds to speech can only be obtained by using speech stimuli.

Sinha SK, Basavaraj V. Speech evoked auditory brainstem responses: a new tool to study brainstem encoding of speech sounds. Indian J Otolaryngol Head Neck Surg. 2010 Oct;62(4):395-9. doi: 10.1007/s12070-010-0100-y. Epub 2011 Jan 11. PMID: 22319700; PMCID: PMC3266097.

Neuro-bio markers of APD cABR/FFR

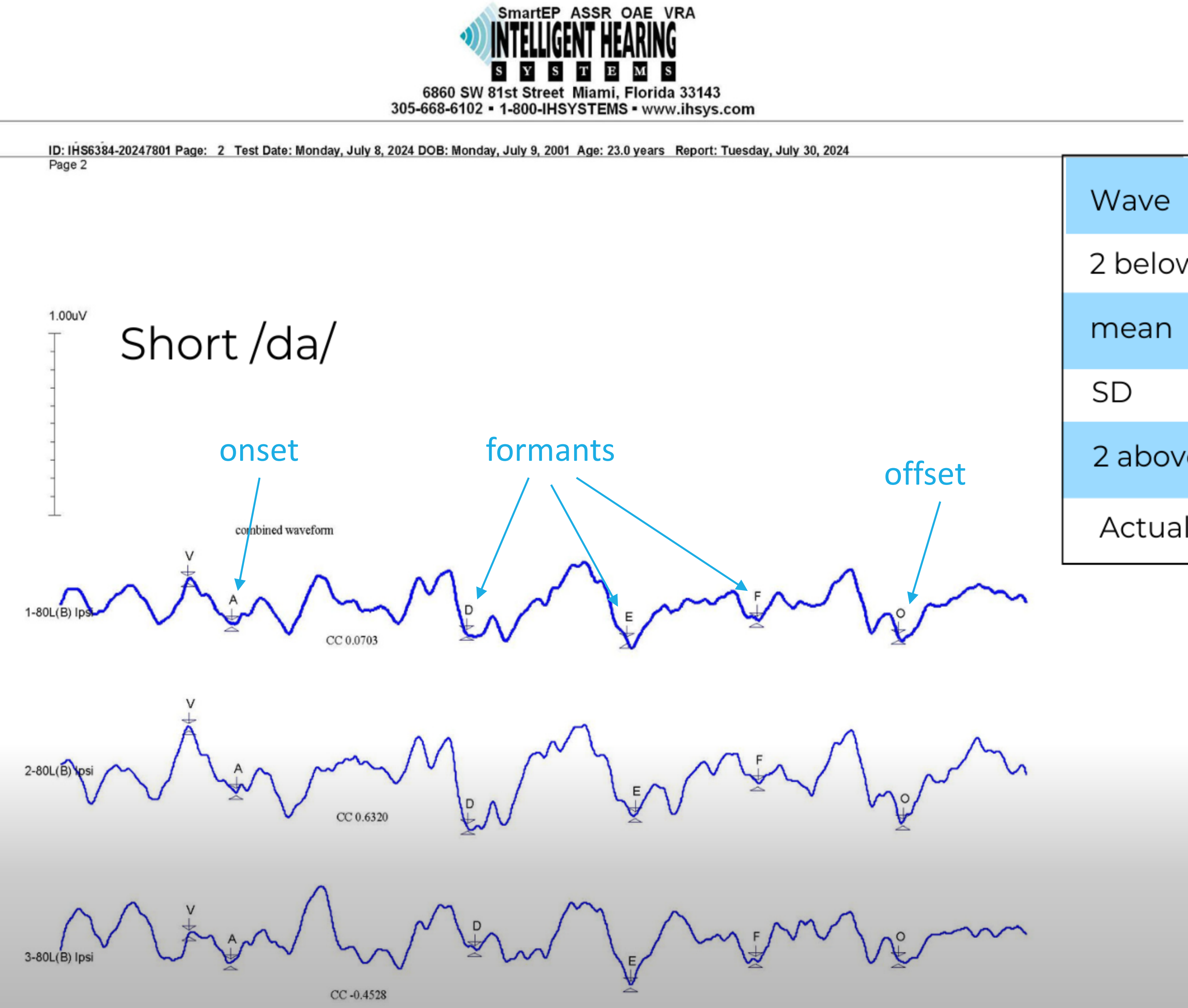
Phase locking is a phenomenon that occurs in the auditory system, where the neural response of the auditory nerve precisely synchronizes with the phase of a periodic sound stimulus. This synchronization allows the auditory system to encode important information about the frequency and timing of sounds, which is crucial.

Peaks	Latency (ms)		Amplitude (μv)	
	Mean	SD	Mean	SD
V	6.81	0.44	0.19	0.11
C	16.82	1.93	0.24	0.16
D	24.75	1.02	0.32	0.23
E	31.36	0.77	0.37	0.17
F	40.04	1.09	0.29	0.19



Short /da/ Left

Wave	V	A	D	E	F	O
2 below	7.17	8.28	23.94	32.54	40.85	49.79
mean	6.65	7.60	22.60	31.12	39.61	48.33
SD	0.26	0.34	0.67	0.71	0.62	0.73
2 above	6.13	6.92	21.26	29.70	38.37	46.87
Actual		9.93	23.50	32.80	40.30	48.50

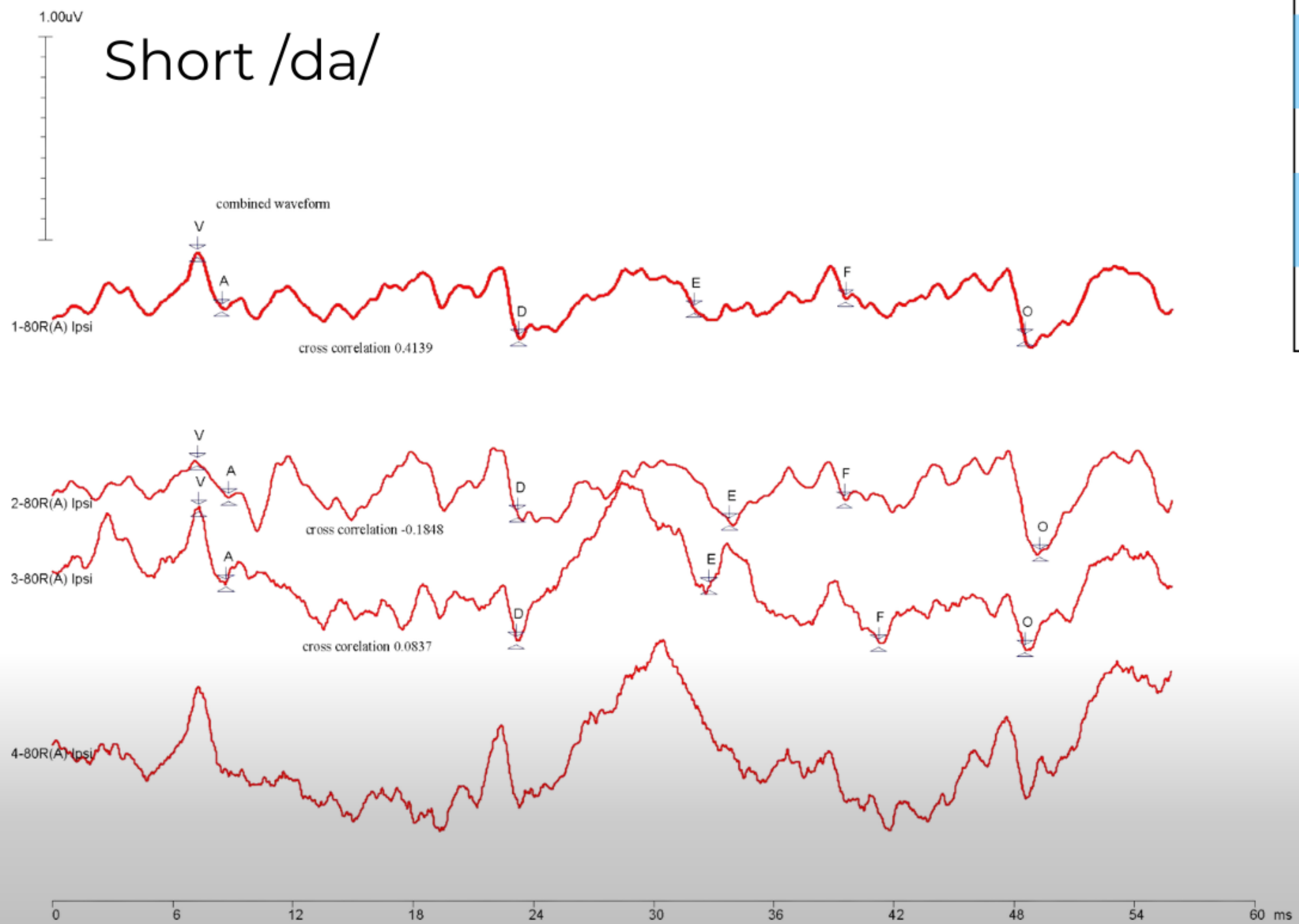


SOUND WRX

INTELLIGENT HEARING SYSTEMS

6860 SW 81st Street Miami, Florida 33143
305-668-6102 • 1-800-IHSYSTEMS • www.ihsys.com

ID: IHS6384-20247801 Page: 2 Test Date: Monday, July 8, 2024 DOB: Monday, July 9, 2001 Age: 23.0 years Report: Tuesday, July 30, 2024
Page 2

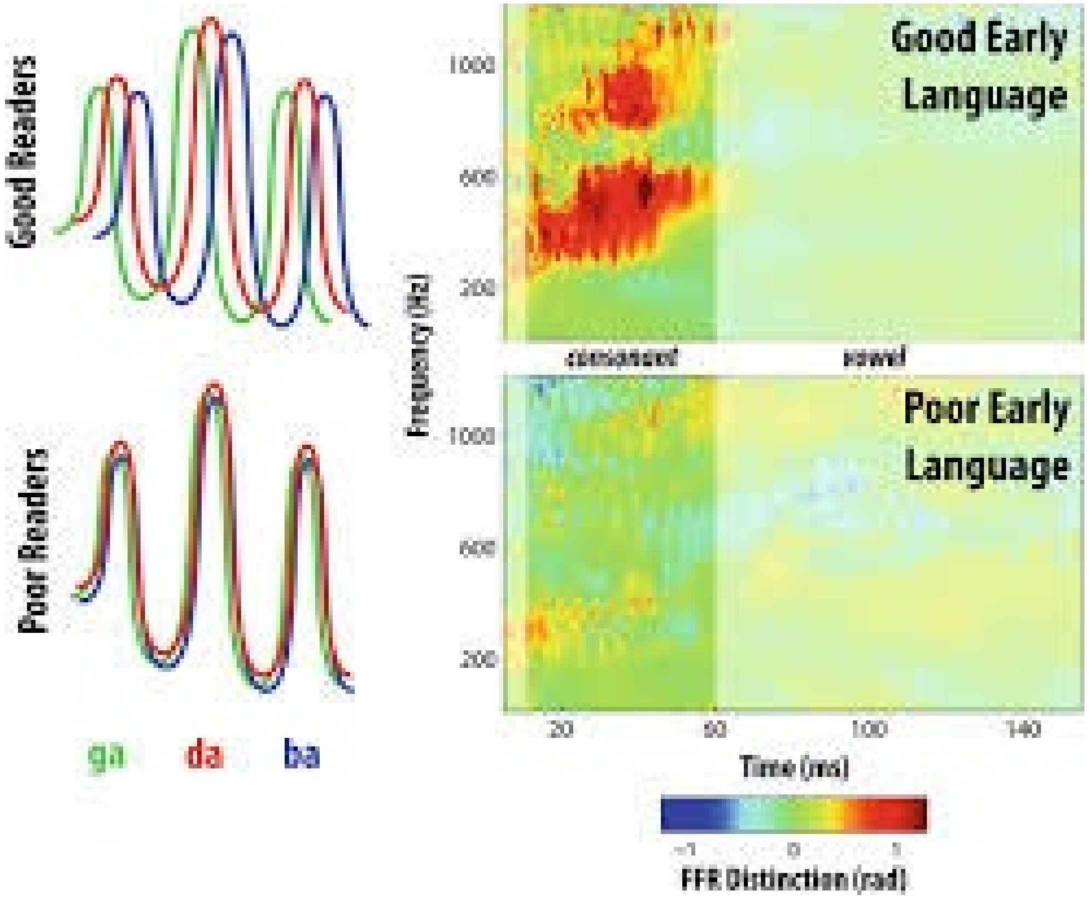


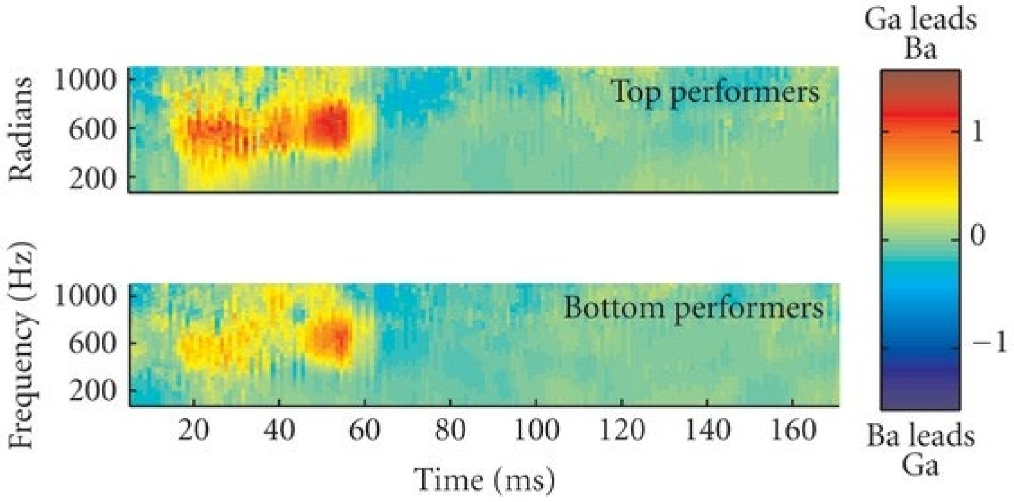
Num	Filename	Int	Ear	Stim.	Type	Swps/Art	Rate	Mode	PP Amp	SNR	RN	Gain	Filters	Masking(SPL)
1	NEW	80SPL	R	Inst	cABR_DA_40ms	4863/2	10.9	AXXX	0.46	0.74	0.236	100	30-3000Hz	
2	NEW	80SPL	R	Inst	cABR_DA_40ms	2000/1	10.9	AXXX	0.52	0.42	0.295	100	30-3000Hz	
3	81RC80A.7	80SPL	R	Inst	cABR_DA_40ms	2000/1	10.9	AXXX	0.82	0.54	0.371	100	30-3000Hz	

Wave	V	A	D	E	F	O
2 below	7.17	8.28	23.94	32.54	40.85	49.79
mean	6.65	7.60	22.60	31.12	39.61	48.33
SD	0.26	0.34	0.67	0.71	0.62	0.73
2 above	6.13	6.92	21.26	29.70	38.37	46.87
Actual		8.50	23.30	32.05	39.63	48.55
			(-1 SD)	(-1+ SD)		

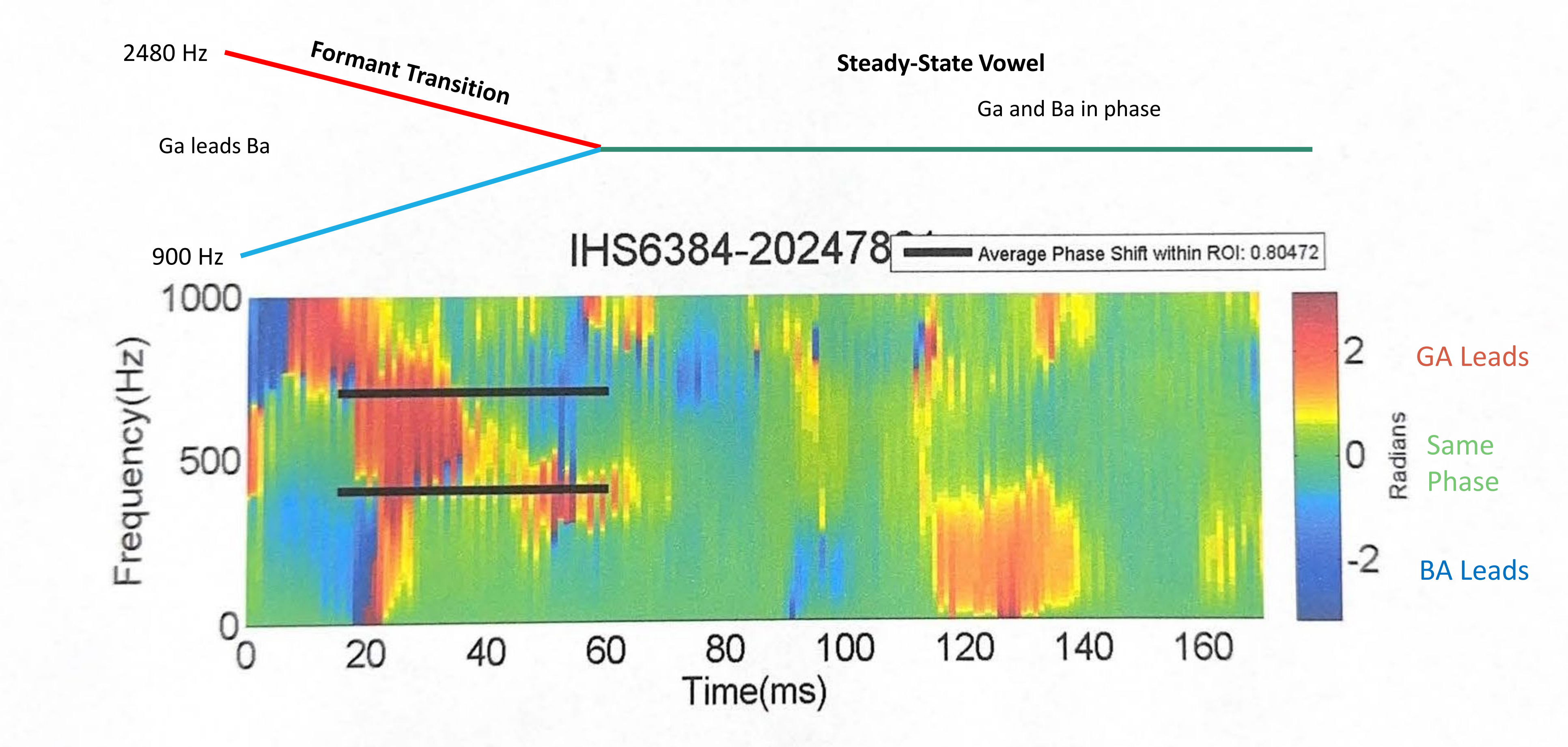
Short /da/ Right

SOUND WRX


Good Readers
Poor Readers
ga
da
ba
Good Early Language
Poor Early Language
Frequency (Hz)
1000
600
200
consonant
vowel
20
60
100
140
Time (ms)
FFR Distinction (rad)

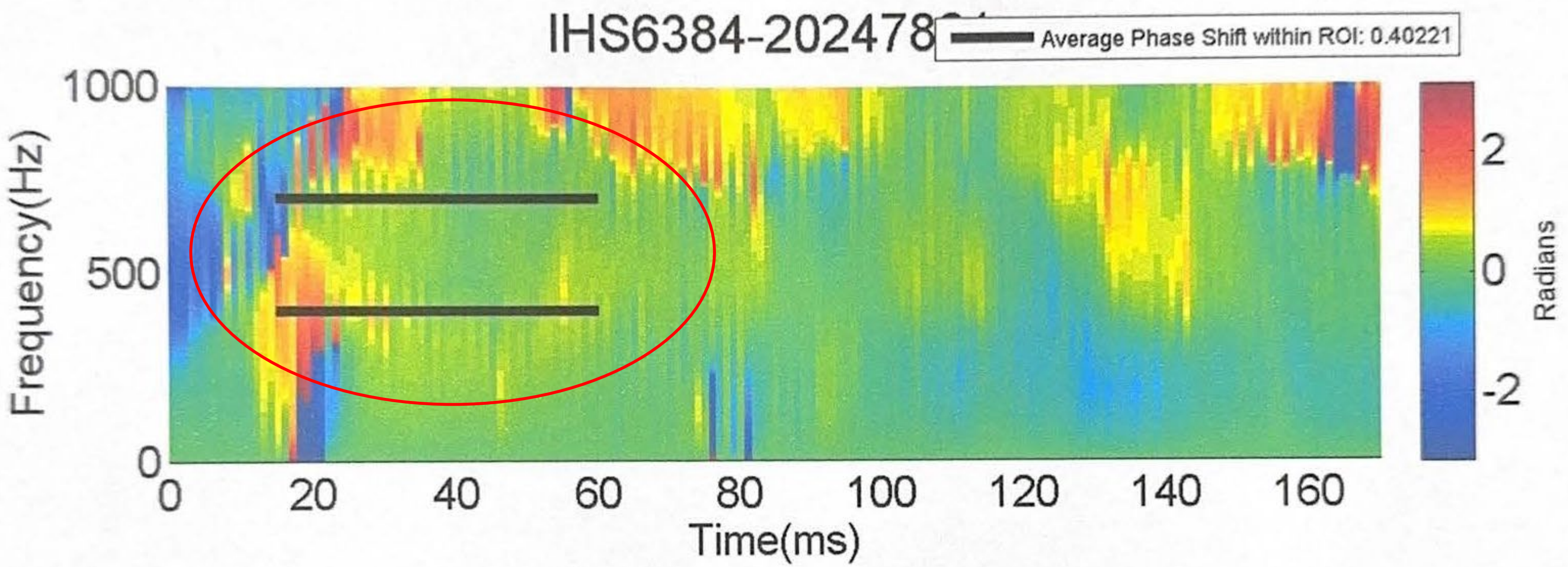

Ga leads Ba
Radians
1000
600
200
Top performers
Frequency (Hz)
Bottom performers
20
40
60
80
100
120
140
160
Time (ms)
1
0
−1
Ba leads Ga

Crossphaseogram Left



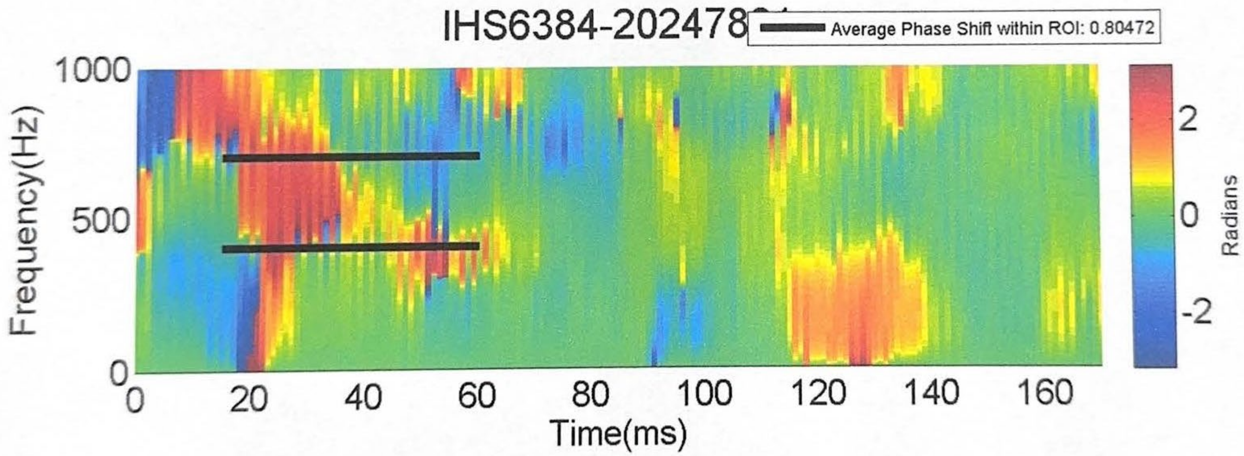
The cross-phaseogram is a measure of relative timing between FFRs elicited by two different stimuli. We can apply this knowledge to investigate subcortical speech-sound differentiation in individuals by recording their FFRs to minimally contrastive speech sounds.

Crossphaseogram Right

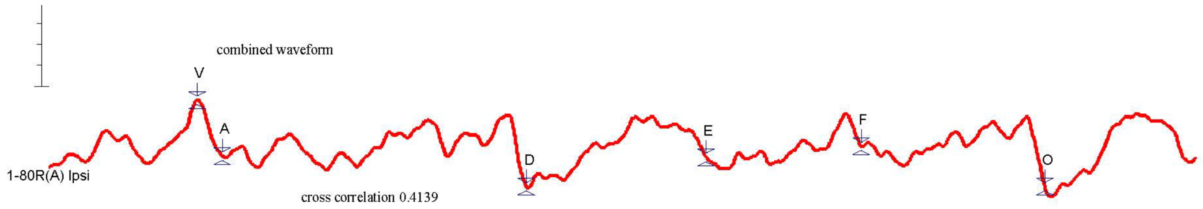


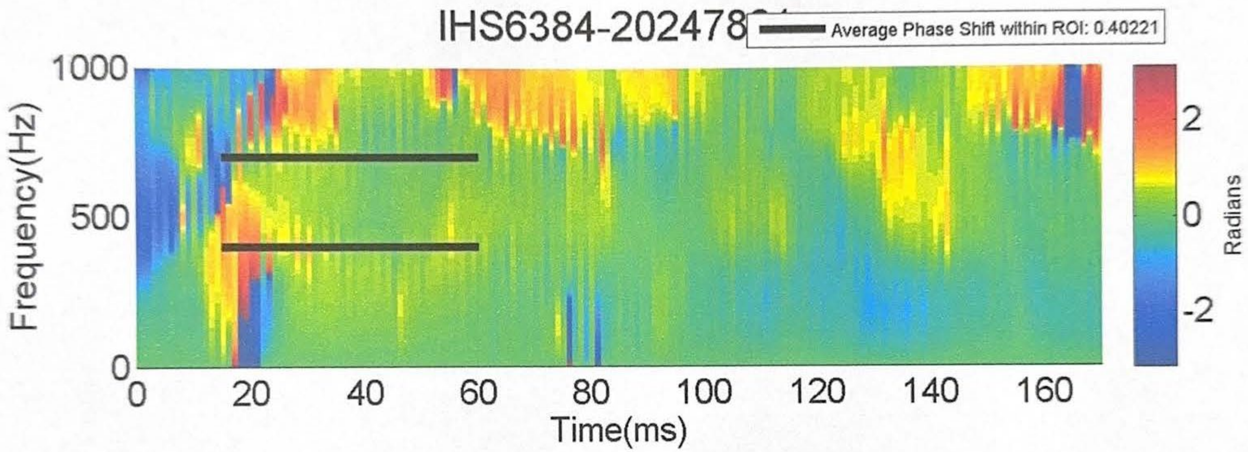
Left


V
A
D
E
F
O
1-80L(B) Ipsi
CC 0.0703


IHS6384-202478
Average Phase Shift within ROI: 0.80472
Frequency(Hz)
1000
500
0
Time(ms)
0
20
40
60
80
100
120
140
160
Radians
2
0
-2

Right


combined waveform
V
A
D
E
F
O
1-80R(A) Ipsi
cross correlation 0.4139

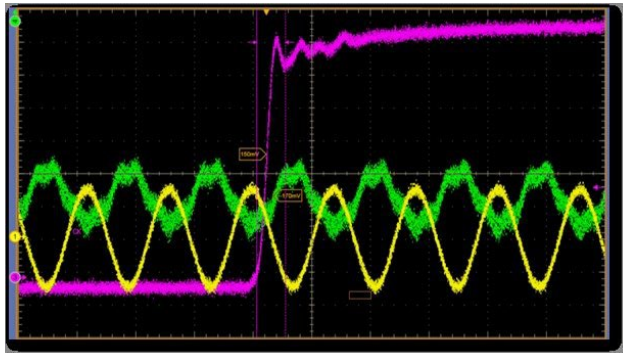

IHS6384-202478
Average Phase Shift within ROI: 0.40221
Frequency(Hz)
1000
500
0
Time(ms)
0
20
40
60
80
100
120
140
160
Radians
2
0
-2

Jitter

Jitter is the deviation in time between when a signal is supposed to be sent and when it is actually sent.

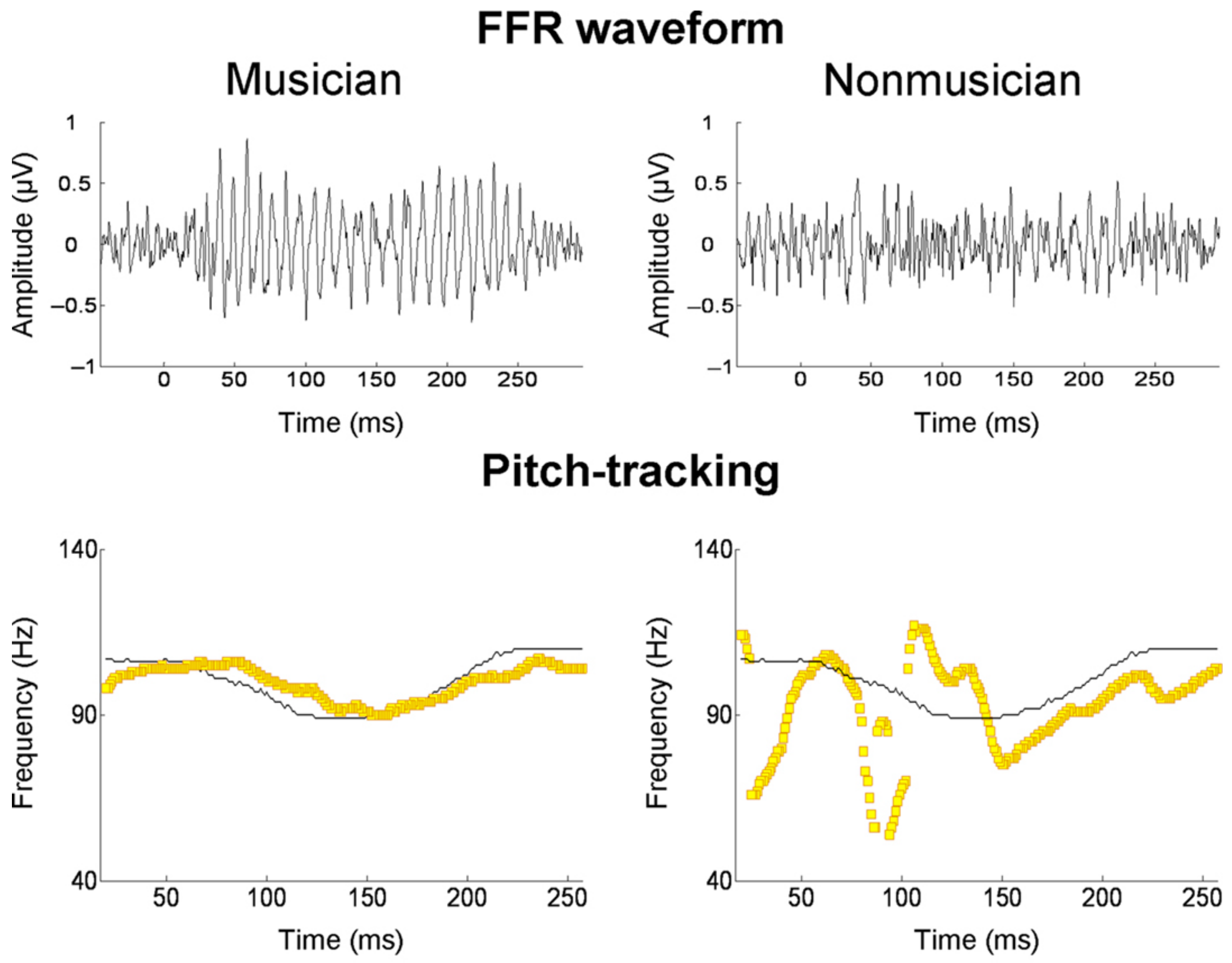
- **Clocking errors** – timing is not precise.
- **Noise** – fluctuation in the voltage that affects the timing of the signal.
- **Electromagnetic Interference** – noise in the signal that affects the timing.

Degrades the signal which results in loss of *detail, clarity and overall fidelity*.



Dreesen, Wendi & Browder, Mark & Wood, Rick & Carlson, Carl & Kallas, Nick & Kruschwitz, Craig & Schwellenbach, David & Thiemann, Sara & Tibbitts, Aric. (2014). Development of an X-ray Radar Imaging Technique for 3-D Scene Scanning.


PGA
SOUND
WRX



FFR waveform
Musician
Nonmusician
Amplitude (μV)
1
0.5
0
−0.5
−1
0
50
100
150
200
250
Time (ms)
Pitch-tracking
Frequency (Hz)
140
90
40
50
100
150
200
250
Time (ms)

Future Directions

Complex Sound Analysis

Studying how FFR encodes the pitch and timing of natural speech sounds, including variations in intonation and speaker identity, to better *understand neural mechanisms underlying speech perception*.

Real-World Applications

Developing portable EEG systems to record FFRs in natural listening environments, enabling investigations into how ***auditory processing adapts to different listening conditions and noise levels***.

Neurofeedback Potential

Exploring the use of FFR as a neurofeedback signal to train individuals *to improve their auditory processing abilities*, particularly in cases of hearing loss or developmental disorders.

Developmental Studies

Further investigating how FFR changes across the lifespan, particularly in early development, to understand the *maturation of auditory processing pathways*.

Advanced Signal Processing

Employing sophisticated analysis techniques like time-frequency decompositions to extract detailed information about the FFR's temporal dynamics and frequency components, allowing for a more *nuanced understanding of neural encoding*.

Machine Learning Integration

Using machine learning algorithms to *identify patterns in FFR data* that could be used to diagnose auditory disorders, monitor treatment progress, or predict individual differences in auditory perception.

Multimodal Integration

Combining FFR with other neuroimaging techniques like fMRI or MEG to gain a more *comprehensive picture of the neural sources contributing to the FFR*, including cortical involvement.

Binaural Hearing Research

Studying the FFR in binaural listening situations to explore how the brain integrates information from both ears, potentially providing *insights into spatial hearing abilities.*

Developmental Trajectory of the Frequency-Following Response During the First 6 Months of Life

Ribas-Prats et al.
University of Barcelona, Spain

During the first 6 months of life, rapid and sustained maturation of the neural machinery necessary for phoneme discrimination takes place.

Within the first month, a significant improvement in F1 neural encoding

F1 important for identifying and distinguishing vowels

Neonatal Frequency-Following Responses: A Methodological Framework for Clinical Applications

Gorina-Careta N, Ribas-Prats T, Arenillas-Alcón S, Puertollano M, Gómez-Roig MD, Escera C. Neonatal Frequency-Following Responses: A Methodological Framework for Clinical Applications. Semin Hear. 2022 Oct 26;43(3):162-176. doi: 10.1055/s-0042-1756162. PMID: 36313048; PMCID: PMC9605802.

Early identification of future language disorders and the opportunity to leverage brain plasticity during the first 2 years of life. Thus, proving early intervention to prevent or alleviate sound and language encoding disorders.

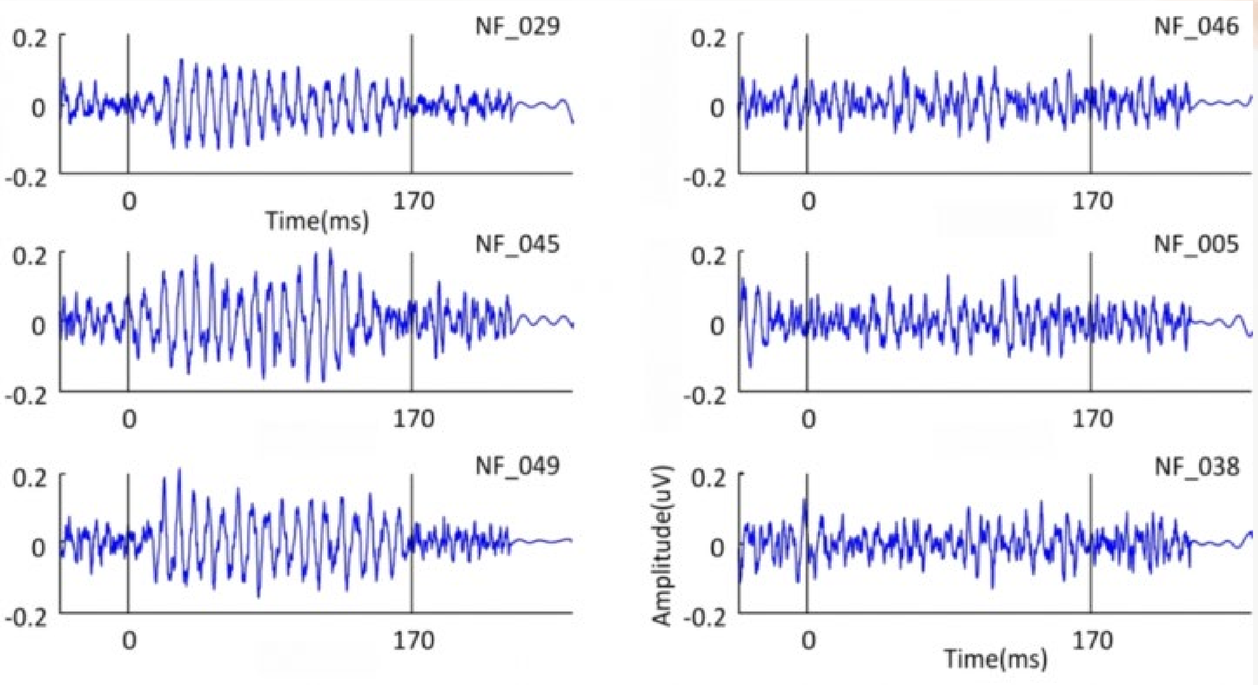
Encoding of speech sounds in newborns: the Frequency-Following Response (FFR) as a biomarker for neurocognitive development

PI: Carles Escera

Sant Joan de Déu Barcelona · Hospital

UNIVERSITAT DE BARCELONA

How speech sounds are encoded in the neonate's brain and whether defective neuronal speech encoding can predict neurocognitive impairment




FFR @32-36 weeks


top down, bottom up and this whole idea of.
Holistic processing, which is something that Jen and
Thank You