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  - Click Print
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  - Choose Black and White from "Color" dropdown

CAPD: An Interdisciplinary Approach – Evaluation and Diagnosis presented in partnership with Salus University

Jennifer Gonzalez, Au.D., Ph.D., CCC-A

Jennifer Gonzalez, AuD, PhD

Jennifer Gonzalez, Au.D., Ph.D., CCC-A, is a Senior Associate Consultant in the Division of Audiology, Department of Otorhinolaryngology at Mayo Clinic in Arizona, and an Assistant Professor of Audiology at Mayo Clinic College of Medicine and Science. Dr. Gonzalez earned her Doctor of Audiology (Au.D.) and Doctor of Philosophy (Ph.D. in Speech, Language, and Hearing Sciences) degrees from the University of Connecticut. Her research and clinical interests focus on central auditory processing; neurodiagnostic applications of auditory evoked responses, including auditory brainstem response, middle latency response, and cortical auditory evoked potentials; and traditional and non-traditional applications of amplification and assistive listening device strategies for the management of central auditory processing disorders and deficits.

Disclosures

- **Presenter Disclosure**: Financial: Jennifer Gonzalez is employed by the Mayo Clinic in Arizona and is an adjunct faculty member at Arizona State University and Salus University. She received an honorarium for presenting this course. Non-financial: Jennifer Gonzalez is a member of American Speech-Language-Hearing Association (ASHA). She holds the Certificate of Clinical Competence in Audiology (CCC-A) from ASHA, is a member of American Academy of Audiology (AAA), American Board of Audiology Certified (ABAC) from AAA, Member-at-Large, ASHA SIG 6 Coordinating Committee and an Editorial Board Member, ASHA Journals (American Journal of Audiology).
- **Content Disclosure**: This learning event does not focus exclusively on any specific product or service.
- **Sponsor Disclosure**: This course is presented by AudiologyOnline in partnership with Salus University.

Learning Outcomes

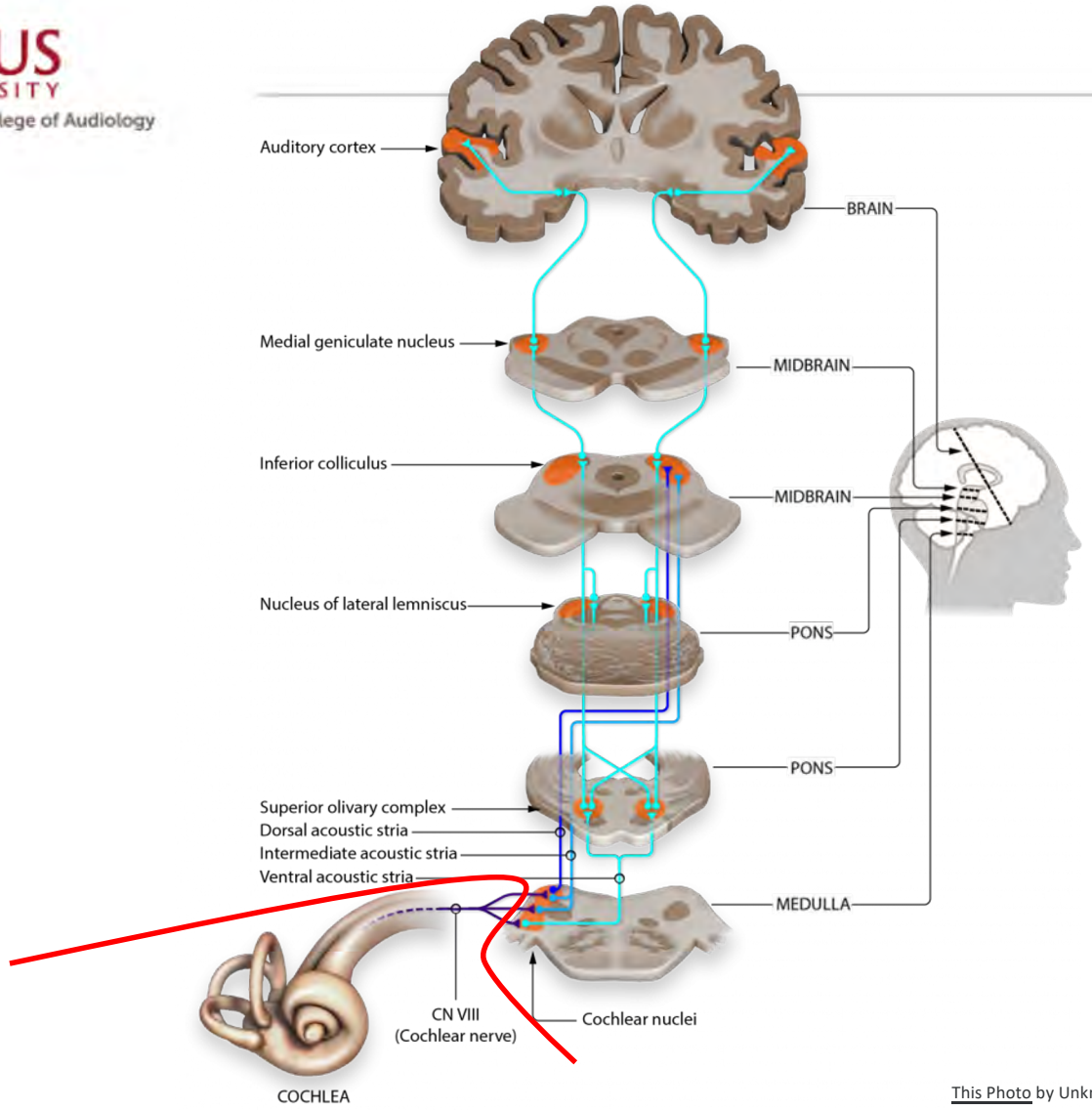
As a result of this course, participants will be able to:

- Describe the skills that underlie central auditory processing and how to evaluate them.
- Explain how to apply knowledge of neuroanatomy and neurophysiology to interpret results of central auditory processing tests.
- Discuss how to synthesize results of the central auditory processing evaluation with patient-reported symptoms in ways that are empowering to patients and meaningful to the experience of everyday life.

CAPD:

- A&P Review
- Central Auditory Processing Skills/Domains
- Behavioral CAPD Testing: Candidacy & Evaluation
- Results: Clinical & Patient-Centered Interpretation
- Clinical Case Review

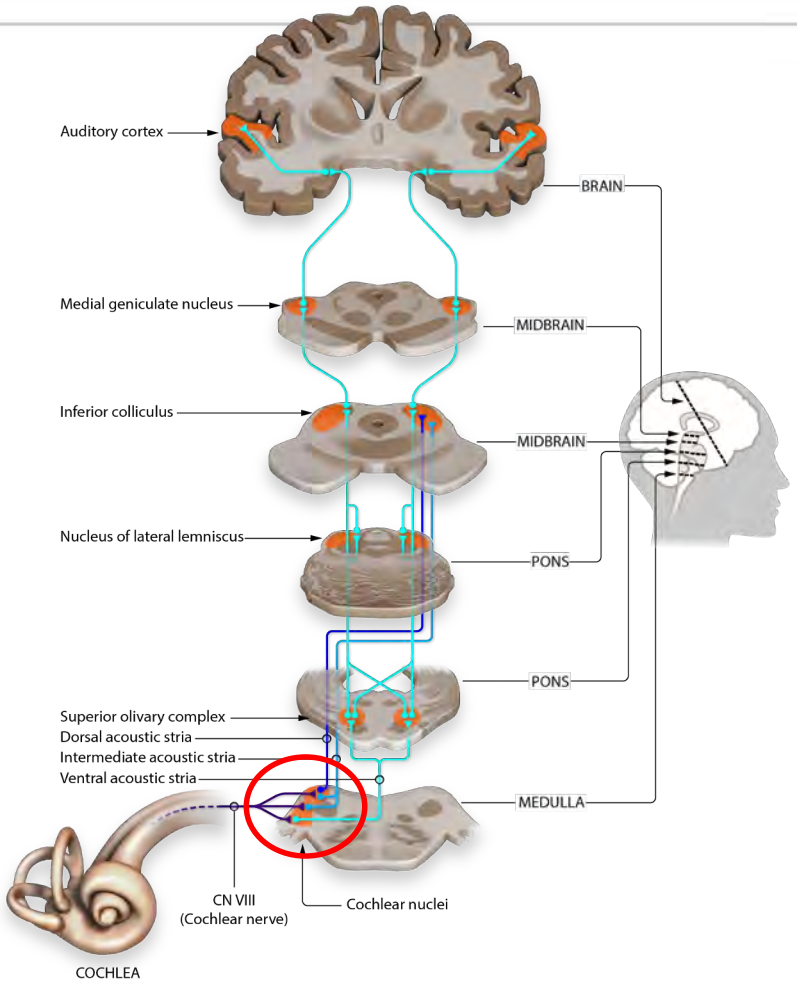
Anatomy & Physiology Review



CANS A&P

Cochlear Nucleus (CN)

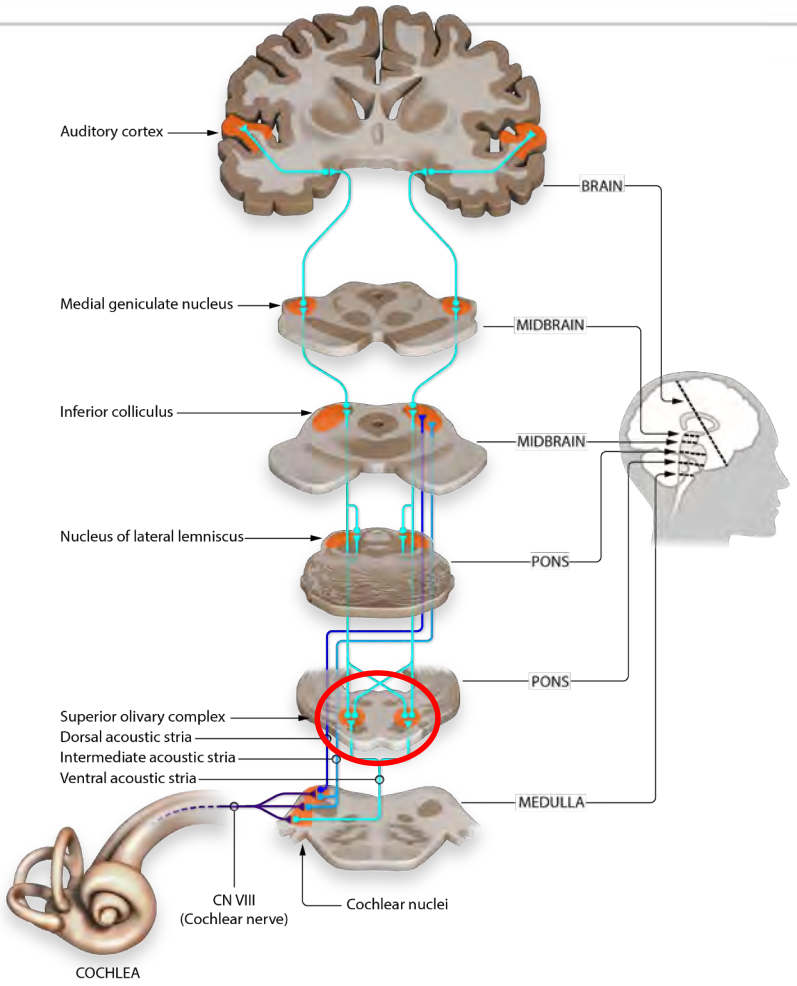
- Ventral (AVCN, PVCN) & Dorsal (DCN) divisions
- Preserves neural coding of auditory information initially performed by auditory nerve
- Enhances/augments the processing of auditory information
- Sets stage for processing of acoustic signal at higher levels



CANS A&P

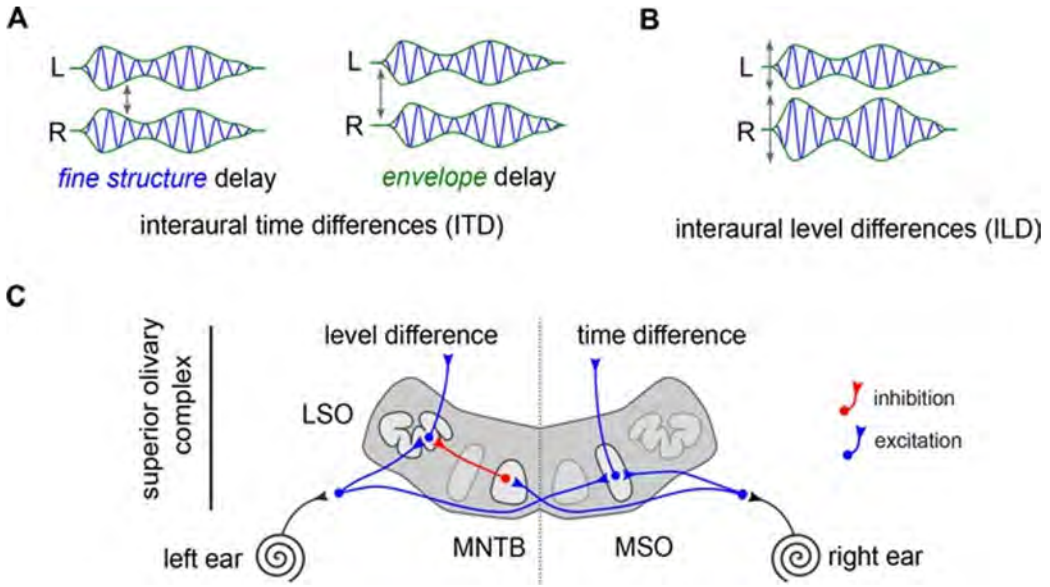
Superior Olivary Complex (SOC)

- First location in the auditory system that receives input from both ears
- Lateral superior olive (LSO)
- Medial superior olive (MSO)
- Contralateral inhibition via medial nucleus of the trapezoid body (MNTB)
- Tonotopically organized



CANS A&P

Superior Olivary Complex (SOC)



Medial Superior Olive (MSO)

- Interaural time difference (ITD)
- *All about that phase*
- Low-frequency dominant (up to ~1000 Hz)

TIME PATHWAY

Lateral Superior Olive (LSO)

- Interaural level difference
- Intensity difference cues
- Head shadow effect
- Mid- to high-frequencies (active above ~1000 Hz)

INTENSITY PATHWAY

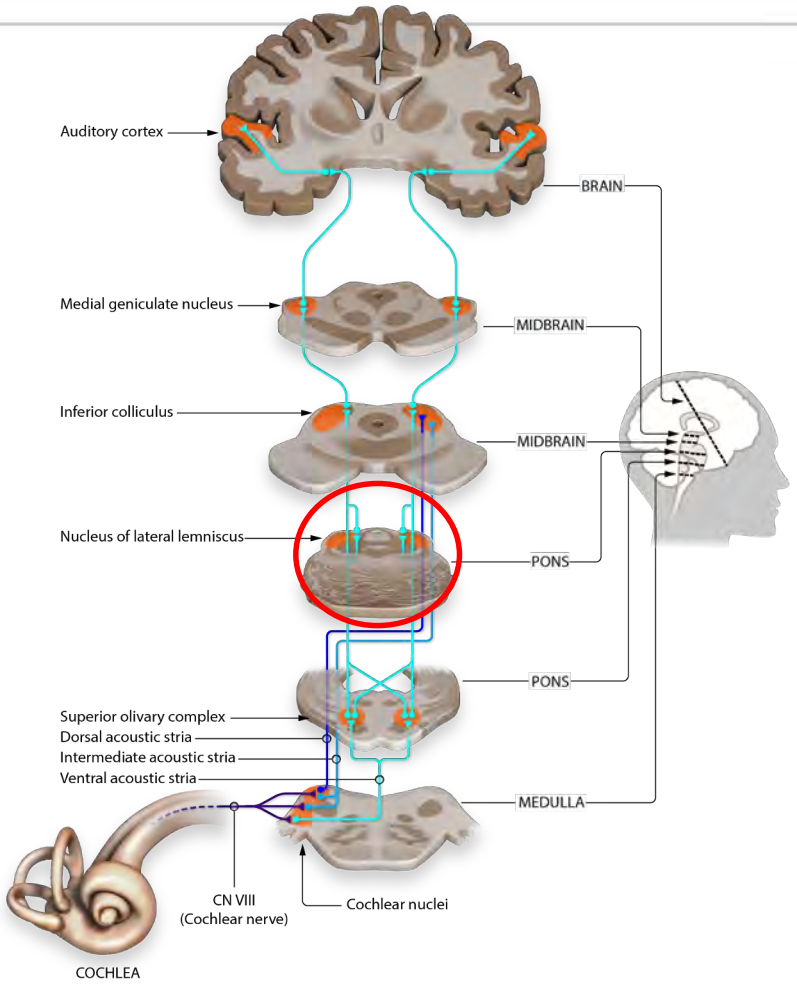
CANS A&P

Lateral Lemniscus (LL)

- Lateral lemniscus tract is a major brainstem pathway for the auditory system

- Two nuclei
  - Ventral nucleus of the lateral lemniscus (VNLL)
  - Dorsal nucleus of the lateral lemniscus (DNLL)

- Formed by fibers arising from the contralateral CN that combine with fibers running from the ipsilateral SOC



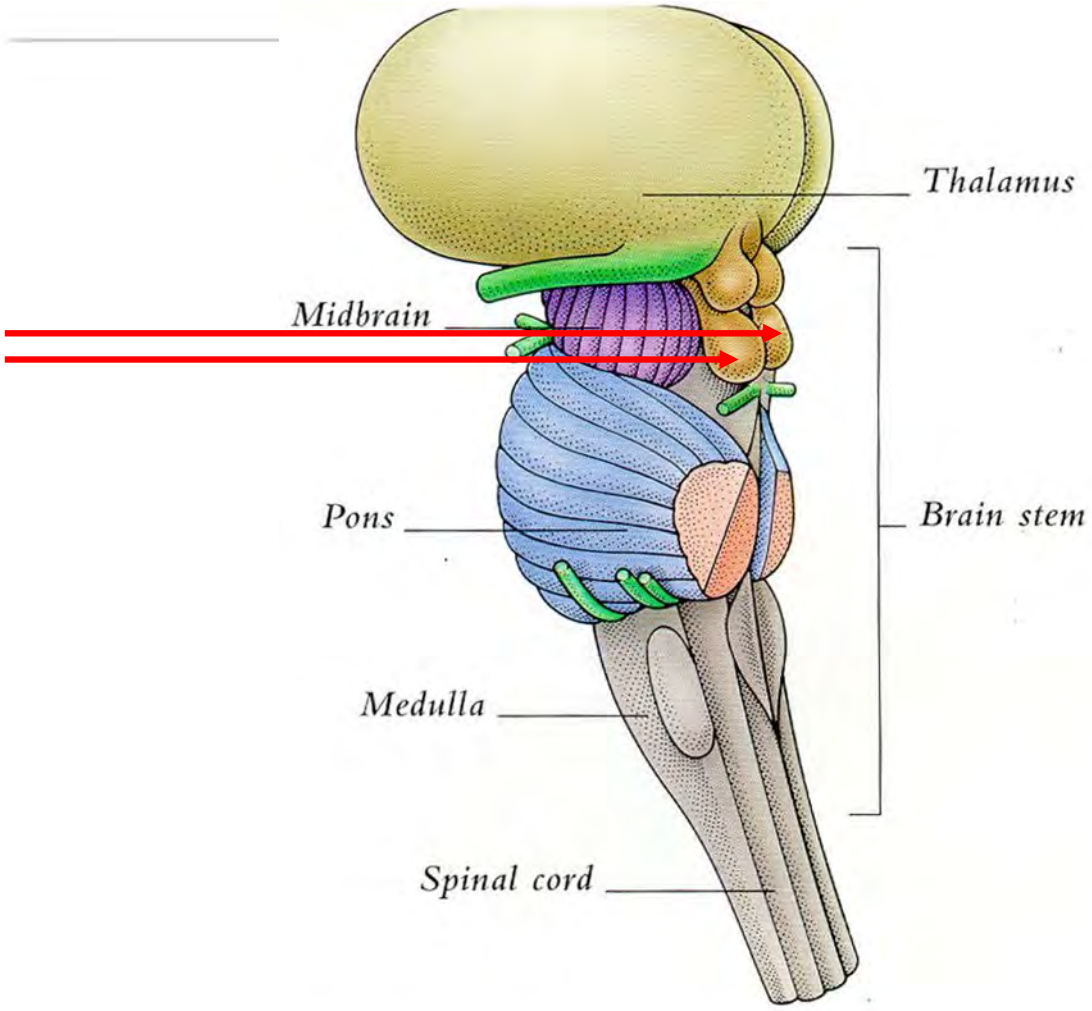
CANS A&P

Inferior Colliculus (IC)

- Bottom two of four spherical mounds in the dorsal midbrain

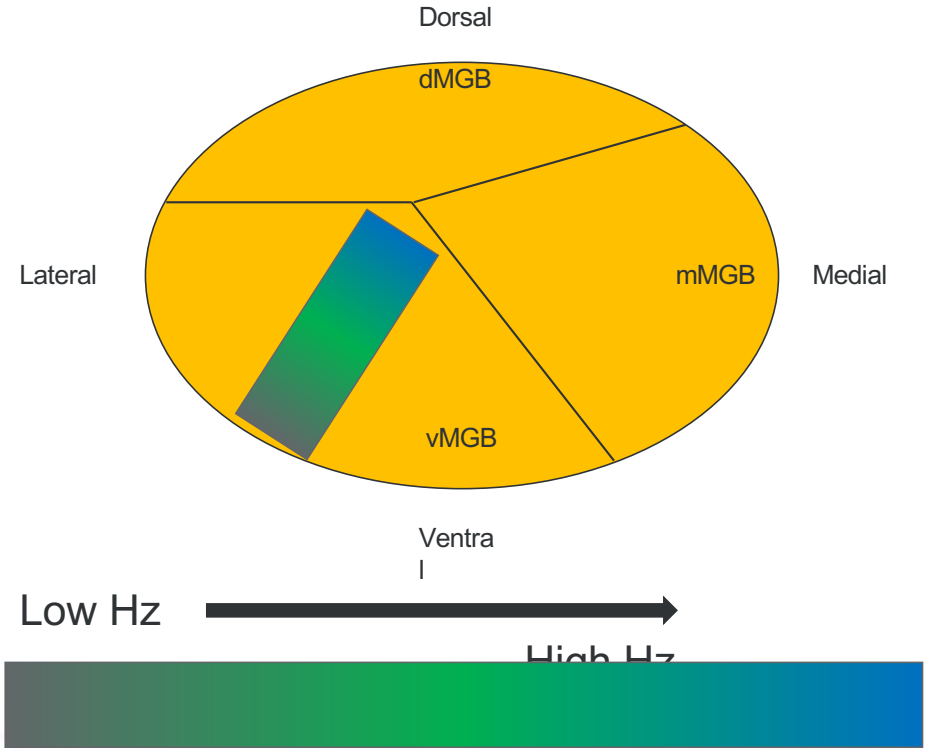
- Three main divisions
  - Central nucleus (CNIC, or ICC) (tonotopically organized)
  - Lateral division/cortex
  - Dorsal division/cortex

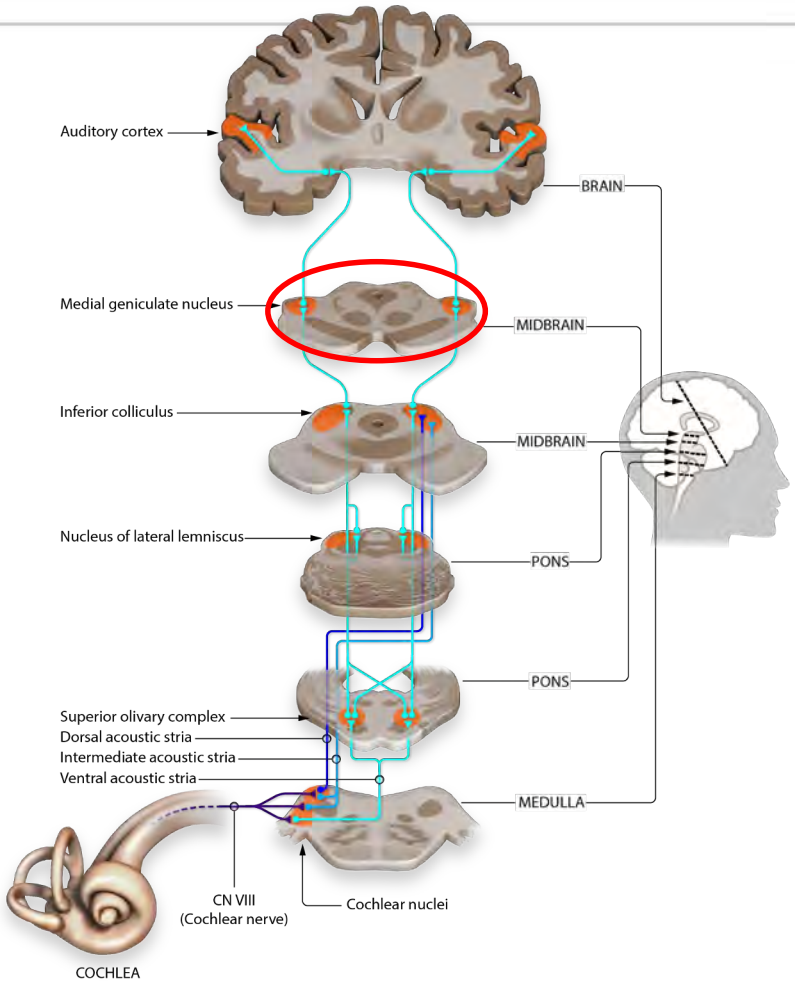
- Inputs:
  - Contra CN, SOC, DNLL
  - Ipsi LSO, MSO, DNLL, VNLL



CANS A&P

Medial Geniculate Body (MGB)





CANS A&P

Medial Geniculate Body (MGB)

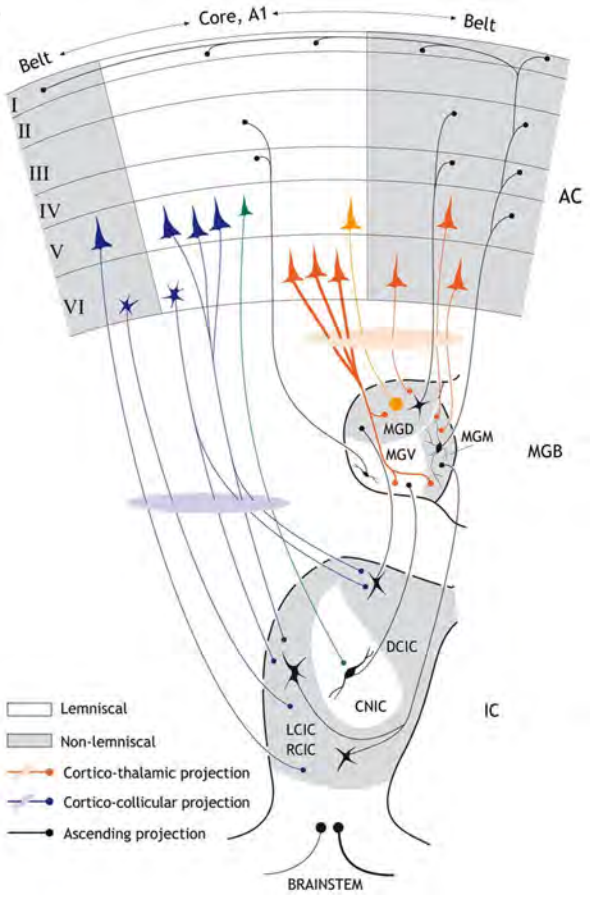
	INPUTS	OUTPUTS
vMGB (ventral) - tonotopic	Central nucleus of IC	mMGB Primary auditory cortex (A1, core)
mMGB (medial)	Central nucleus of IC *Pontine reticular formation* Lateral nucleus of IC	Insula *Amygdala*
dMGB (dorsal)	Dorsal nucleus of IC *Pontine reticular formation*	Secondary auditory cortex (A2, belt) Insula *Amygdala (via supra geniculate)*

Musiek & Baran (2020)

CANS A&P

CNIC □ MGV □ AC Projections

- "Classic" or "lemniscal" auditory pathway to primary auditory cortex (A1)
- Main input from CNIC is to MGV (both highly, auditory areas)
- Main input from MGV is to cortical layers III & IV in AI



CANS A&P

Heschl's Gyrus & Planum Temporale

Heschl's gyrus (Brodmann area 41)

- Includes primary auditory cortex (A1)
- Significant variability in anatomy across hemispheres & individuals

Planum temporale

- Proximity to Wernicke's area (Brodmann area 22)
- Also hemispheric & individual differences BUT is typically much larger in left than right hemisphere (up to 10 times in right-handed individuals)
- Language function tends to be lateralized to the left hemisphere; size difference reflects role in decoding auditory language (Geschwind & Galaburda, 1985)

CONTINU

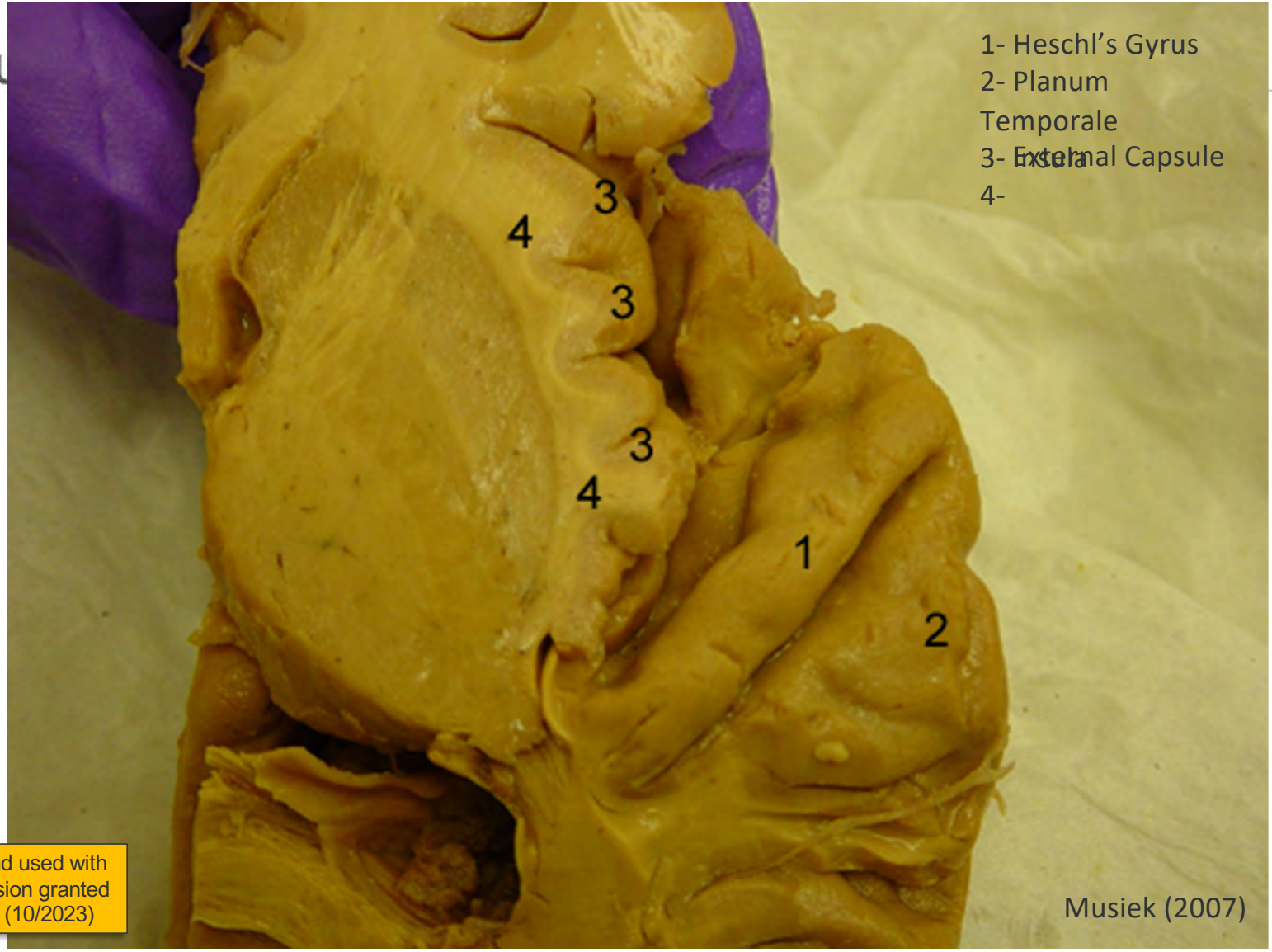


Photo taken by and used with expressed permission granted by Frank Musiek (10/2023)

CANS A&P

Right vs. Left Hemisphere

Left hemisphere (linguistic coding)

- Verbal
- Semantic-associative
- Time-dependent
- Isolated lesion: Pure word deafness

Right hemisphere (music; contour recognition)

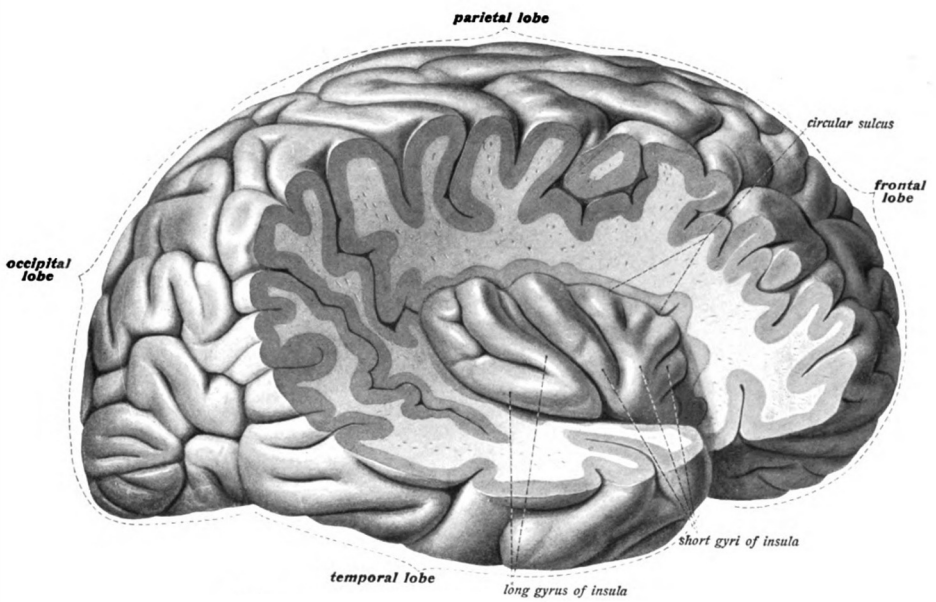
- Nonverbal
- Perceptive-discriminative
- Time independent
- Isolated lesion: Amusia

(Dorsaint-Pierre et al., 2006)

CANS A&P

Insula (Insular Cortex)

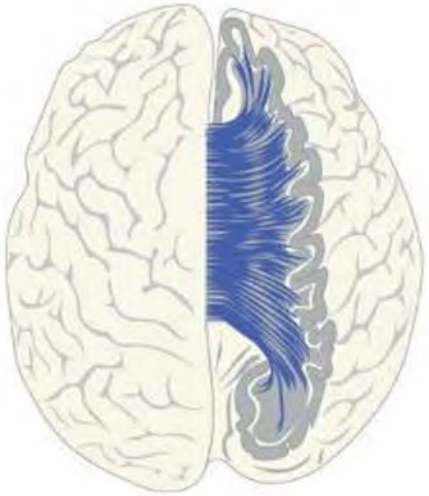
- Located deep in the Sylvian fissure, under parts of the temporal, frontal, parietal lobes
- Larger on the left side than the right side in humans
- Damage
  - One side: Dichotic listening, abnormal auditory evoked potentials
  - Both sides: Central deafness, severe auditory dysfunction, abnormal auditory evoked potentials (Habib et al., 1995)



CANS A&P

Corpus Callosum

A Dorsal



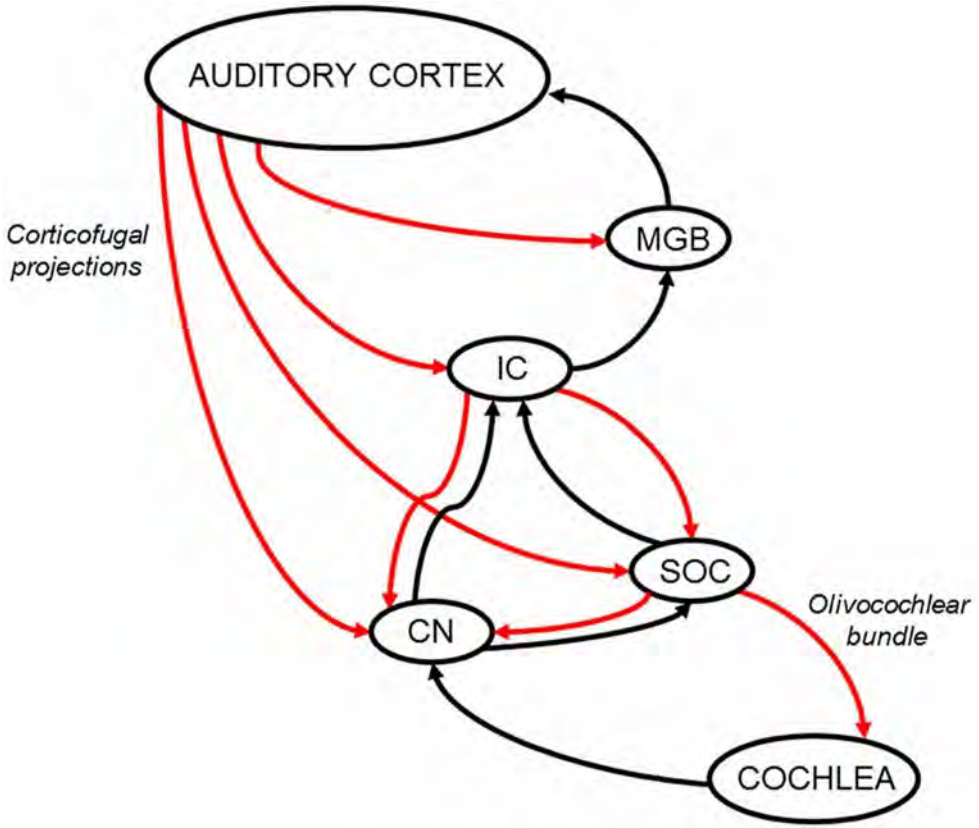
B Sagittal

C Coronal

CANS A&P

Descending Pathways

- Acoustic reflex arc
- Olivocochlear bundle
- Corticofugal pathways



Efferent Corticofugal Connection

Auditory Cortex to Cochlear Nucleus

Winer (2005)

- Auditory corticofugal projections to cochlear nucleus (CN) predominantly ipsilateral, with boutons targeting the granule cell domain (GCD) of the dorsal cochlear nucleus (DCN)
- Input to granule cells in CN arises from cortical layer V (i.e., large pyramidal cell layer – excitatory projection neurons)

Yaeger & Trussell (2015)

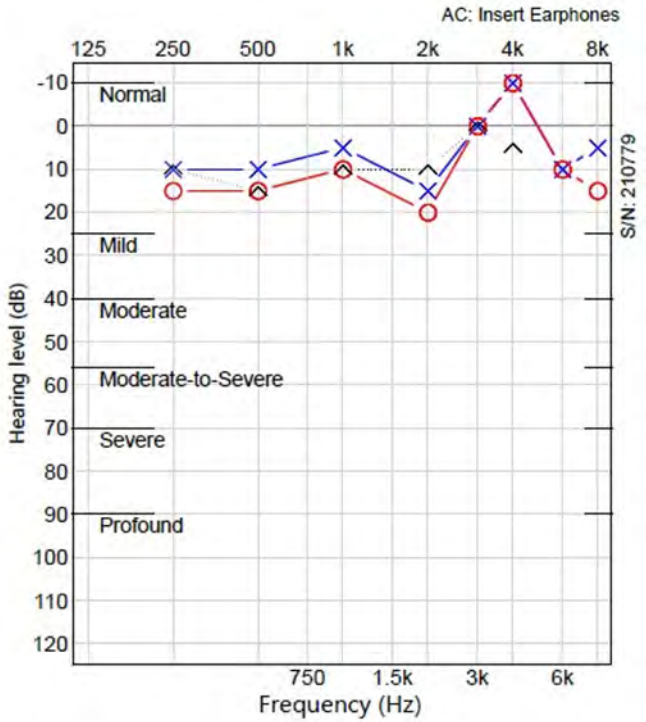
- Bursts of spikes in single granule cells in CN evoke Golgi cell (inhibitory) spiking
- Golgi cell spiking recruits inhibition onto granule cells of CN

Possible implications:

- Modulation of central auditory excitation vs. inhibition
- Integration of multisensory inputs with auditory processing

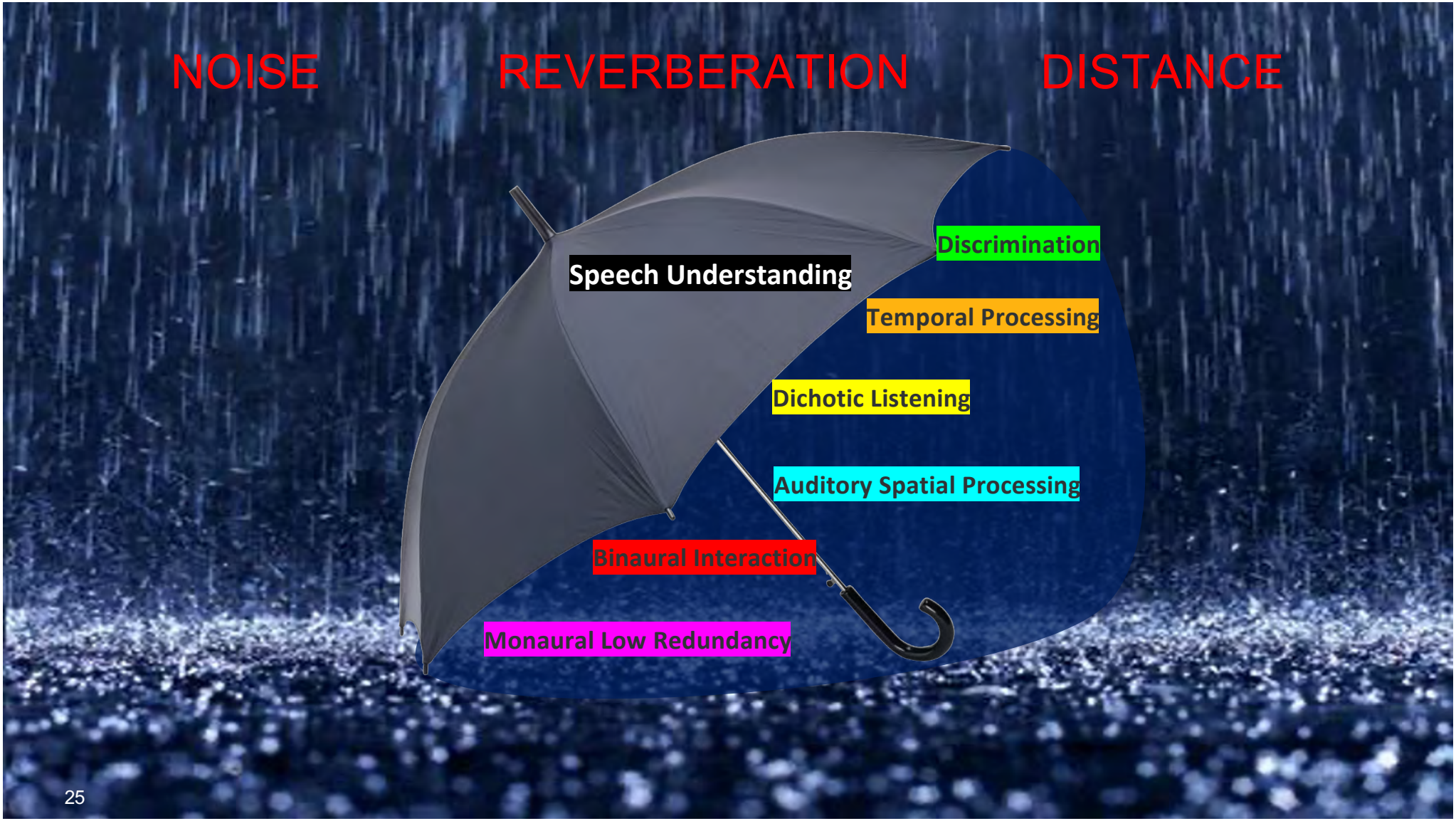
Central Auditory Processing Skills & Domains

Hearing Terminology



- How would you describe this audiogram?
- "Normal hearing"
- "Normal peripheral hearing sensitivity"
- "Normal pure-tone hearing sensitivity"
- The words we use to describe disorders of the auditory system matter

Main Central Auditory Processing Skill Areas	
Dichotic Listening	Binaural Integration Attending to and repeating back both left and right dichotic stimuli – *"free recall"*
	Binaural Separation Attending to one ear and repeating back what is heard while ignoring the other ear – *"forced attention"*
Temporal Processing	Temporal Resolution The shortest duration of time in which an individual can discriminate between 2 auditory signals
	Temporal Ordering/Sequencing The processing of 2 or more auditory stimuli in their order of occurrence
	Temporal Integration Results from summation or aggregation of neuronal activity as a function of additional duration of sound energy. May see signs during pure-tone audiometry. *"Time-intensity trade," "Time-intensity tradeoff"*
	Temporal Masking Masking occurring when a signal and a masker do not overlap in time (i.e., forward masking, backward masking)
Auditory Closure	The ability to hear and recognize speech in degraded listening environments (i.e., background noise, reverberation, at a distance) when context is low. Dependent upon effective interaction between factors of intrinsic redundancy (within CANS) and extrinsic redundancy (outside CANS)
Binaural Interaction	Brainstem-level process that contributes to sound localization/lateralization and signal detection/auditory performance in backgrounds of competing acoustic signals – *"binaural squelch," "binaural release from masking"*
Auditory Spatial Processing	The ability to selectively focus on sounds coming from one direction and suppress sounds coming from other directions. Measures spatial release from masking, though likely involves cortical CANS function.


NOISE
REVERBERATION
DISTANCE
Speech Understanding
Discrimination
Temporal Processing
Dichotic Listening
Auditory Spatial Processing
Binaural Interaction
Monaural Low Redundancy


Bottom-Up Factors
Nonmodularity of the CANS
Factors Affecting Central Auditory Processing
Top-Down Factors
Resource Allocation

CAPD

ASHA Definition

Central Auditory Processing Disorder (CAPD)

Terms used to describe a processing disorder may vary based on the perspective of the professional describing the problem. Terms include, but are not limited to, "auditory processing disorder," "(central) auditory processing disorder," "language processing disorder," and "auditory information processing disorder."

ASHA uses the term **Central Auditory Processing Disorder (CAPD)** to refer to deficits in the neural processing of auditory information in the CANS not due to higher order language or cognition, as demonstrated by poor performance in one or more of the skills listed above (ASHA, 2005). Although sometimes difficult, careful differential diagnosis is important to the process of treatment planning.

- CAPD may lead to or be associated with difficulties in higher order language, learning, and communication functions.
- CAPD may coexist with other disorders (e.g., attention-deficit/hyperactivity disorder [ADHD], language impairment, and learning disability).
- CAPD is not due to peripheral hearing loss, which includes conductive hearing loss (i.e., outer or middle ear), sensorineural hearing loss at the level of the cochlea or auditory nerve, including auditory neuropathy and synaptopathy (i.e., hidden hearing loss).

(ASHA Practice Portal, 2021)

CAPD Signs & Symptoms

ASHA

Signs and symptoms of CAPD may include one or more of the following behavioral characteristics:

- Difficulty localizing sound
- Difficulty understanding spoken language in competing messages, in noisy backgrounds, in reverberant environments, or when presented rapidly
- Taking longer to respond in oral communication situations
- Frequent requests for repetitions, saying "what" and "huh" frequently
- Inconsistent or inappropriate responding
- Difficulty comprehending and following rapid speech
- Difficulty following complex auditory directions or commands
- Difficulty learning songs or nursery rhymes
- Misunderstanding messages, such as detecting prosody changes that help to interpret sarcasm or jokes
- Poor musical and singing skills
- Difficulty paying attention
- Being easily distracted
- Poor performance on speech and language or psychoeducational tests in the areas of auditory-related skills
- Associated reading, spelling, and learning problems
- Difficulty learning a new language

This list is illustrative, not exhaustive, and these behavioral characteristics are not exclusive to CAPD. They may be present with other disorders (e.g., learning disability, language impairment, ADHD, and autism spectrum disorder). The variability in specific auditory processing skill deficits may contribute to the variability in observed behaviors.

(ASHA Practice Portal, 2021)

CAPD Prevalence

ASHA & AAA

Data to calculate the incidence and prevalence of CAPD are not available due to the lack of universal, standardized diagnostic criteria. Guidance from national organizations varies. CAPD diagnosis varies widely depending on the criteria and the assessment instruments used. Some studies have estimated prevalence (the number of cases at a given point in time) as the following:

- Children:
  - 2%–3% (Chermak & Musiek, 1997; Palfery & Duff, 2007).
  - 7.3%–96% (Wilson & Arnott, 2013).
- Male to female ratio of 2:1 (Chermak & Musiek, 1997; Palfery & Duff, 2007).
- Adults 55 and older: 23%–76% (Cooper & Gages, 1991; Golding, Carter, Mitchell, & Hood, 2004; Stach, Spretnjak, & Jerger, 1990).

With the transition to the *International Classification of Diseases, Tenth Revision, Clinical Modification* (ICD-10-CM; American Medical Association, 2017), audiologists and physicians are able to assign a diagnostic code for CAPD in the medical record and for health insurance claims. Although coding does not address confounding factors of diagnostic criteria or assessment instrument variations, use of the new code will provide data on patients receiving care for CAPD.

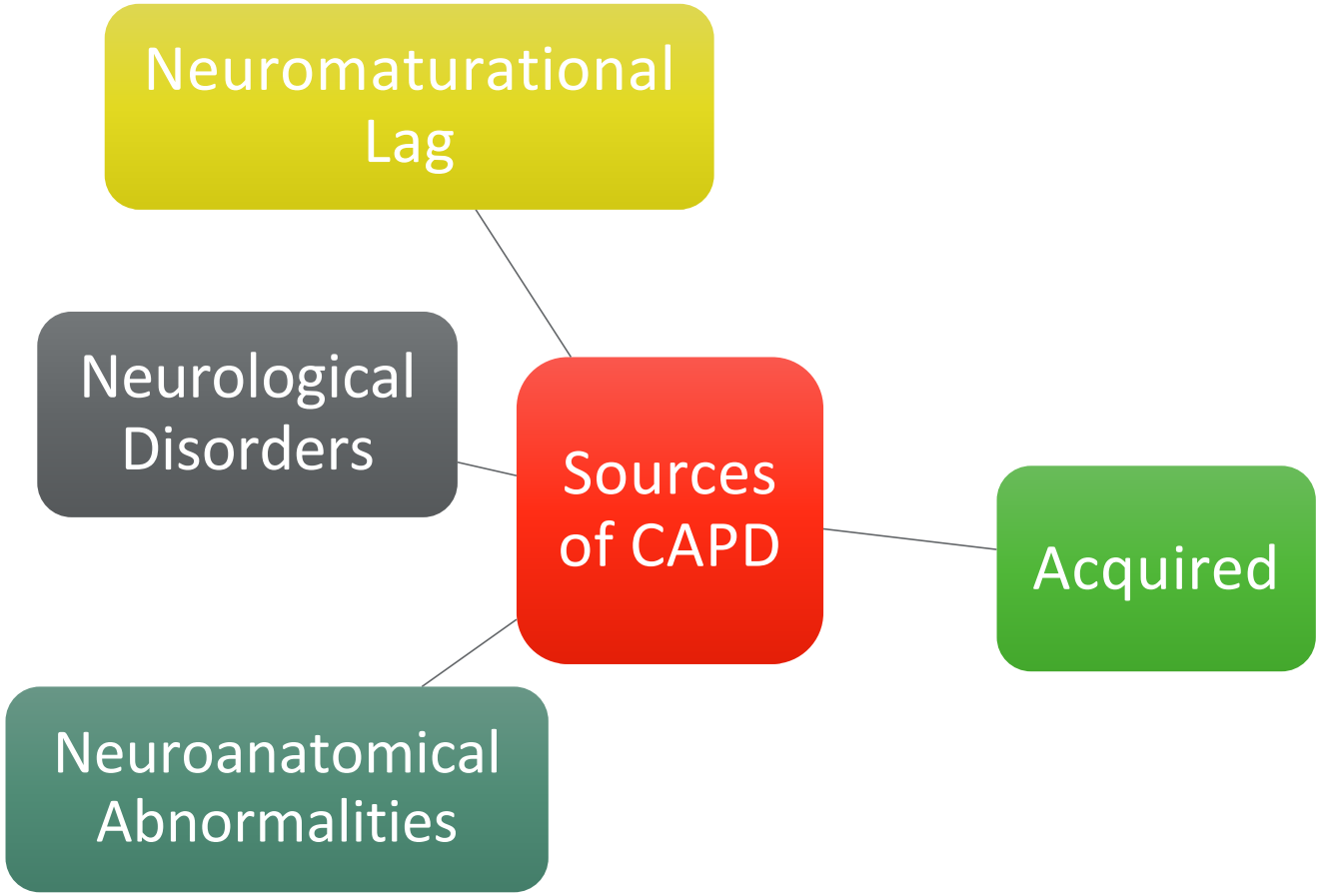
"It should be recognized that central auditory dysfunction and associated auditory behavioral difficulties may be of particularly high prevalence in the aging population and may be a predictor of success with ***binaural* hearing aids."**
(AAA CAPD Guidelines, 2010)

(AAA 2010; ASHA Practice Portal, 2021)

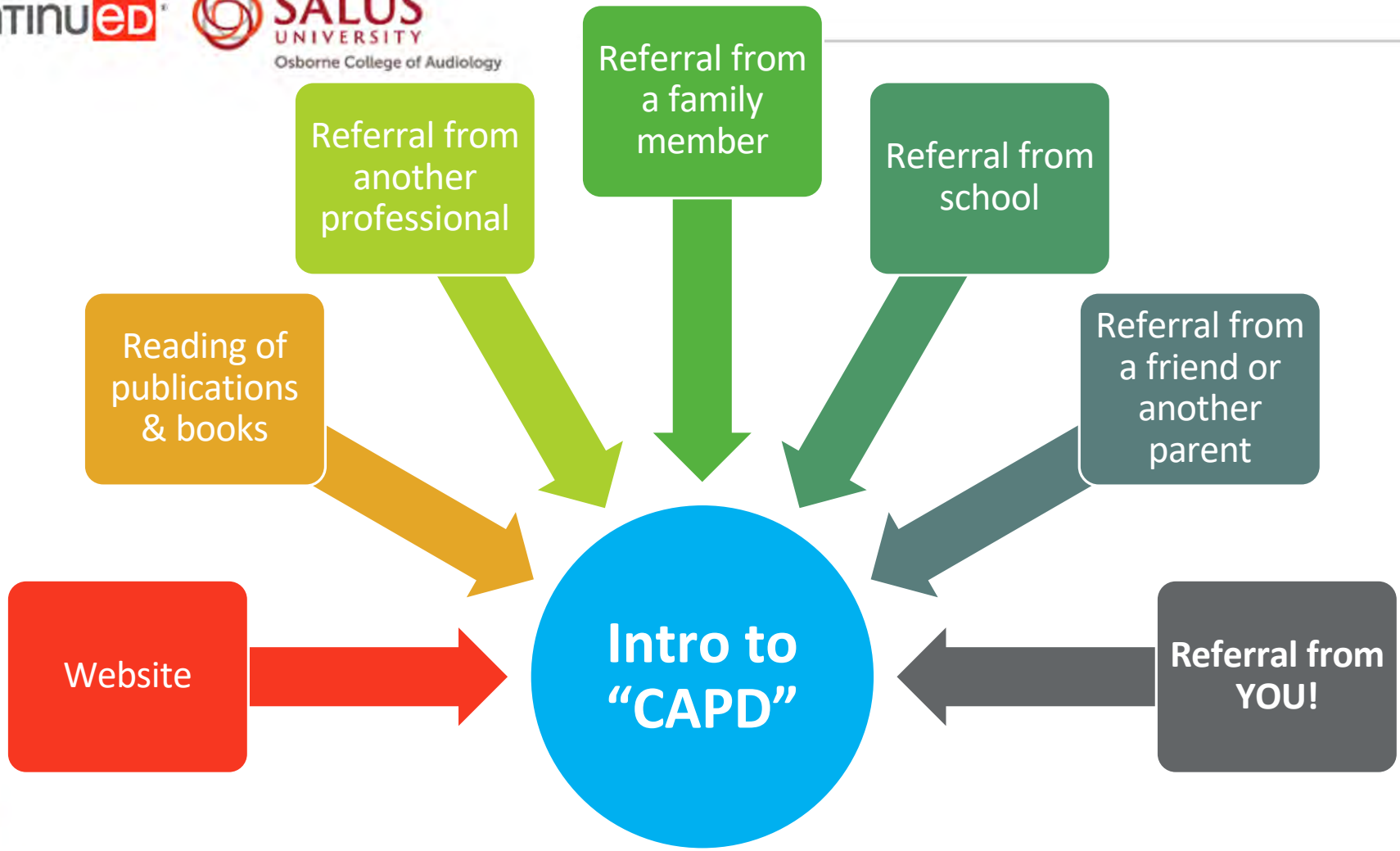
CAPD & Comorbidities

"Brain organization and function suggest that CAPD may be best characterized not as a disorder in which deficits are auditory alone, but where difficulties in the auditory modality are *most pronounced*."

(Bellis, Billiet, & Ross, 2011; Musiek & Chermak, 2014)


Neuromaturational Lag
Neurological Disorders
Sources of CAPD
Acquired
Neuroanatomical Abnormalities

Behavioral CAPD Testing: Candidacy & Evaluation


Referral from another professional
Referral from a family member
Referral from school
Reading of publications & books
Referral from a friend or another parent
Website
Intro to "CAPD"
Referral from YOU!

CAPD Evaluation Candidacy

Pre-Assessment Stage

How the pre-assessment stage of a potential CAPD evaluation is handled will drive the examining audiologist's ability to design individualized test batteries, monitor the testing environment, judge responses and response patterns, interpret evaluation data, and *ultimately diagnose or appropriately withhold a diagnosis of CAPD*.

CAPD Evaluation Candidacy

Pre-Assessment Stage

Completing a *targeted* chart review and thoughtful preparation prior to performing a CAPD evaluation – especially for pediatrics – will increase the audiologist's clinical effectiveness, the quality of recommendations for treatment and management, and the patient's (and patient's family member's/guardian's) confidence in the audiologist's clinical abilities and expertise.

Multidisciplinary evaluations & interventions are the goal

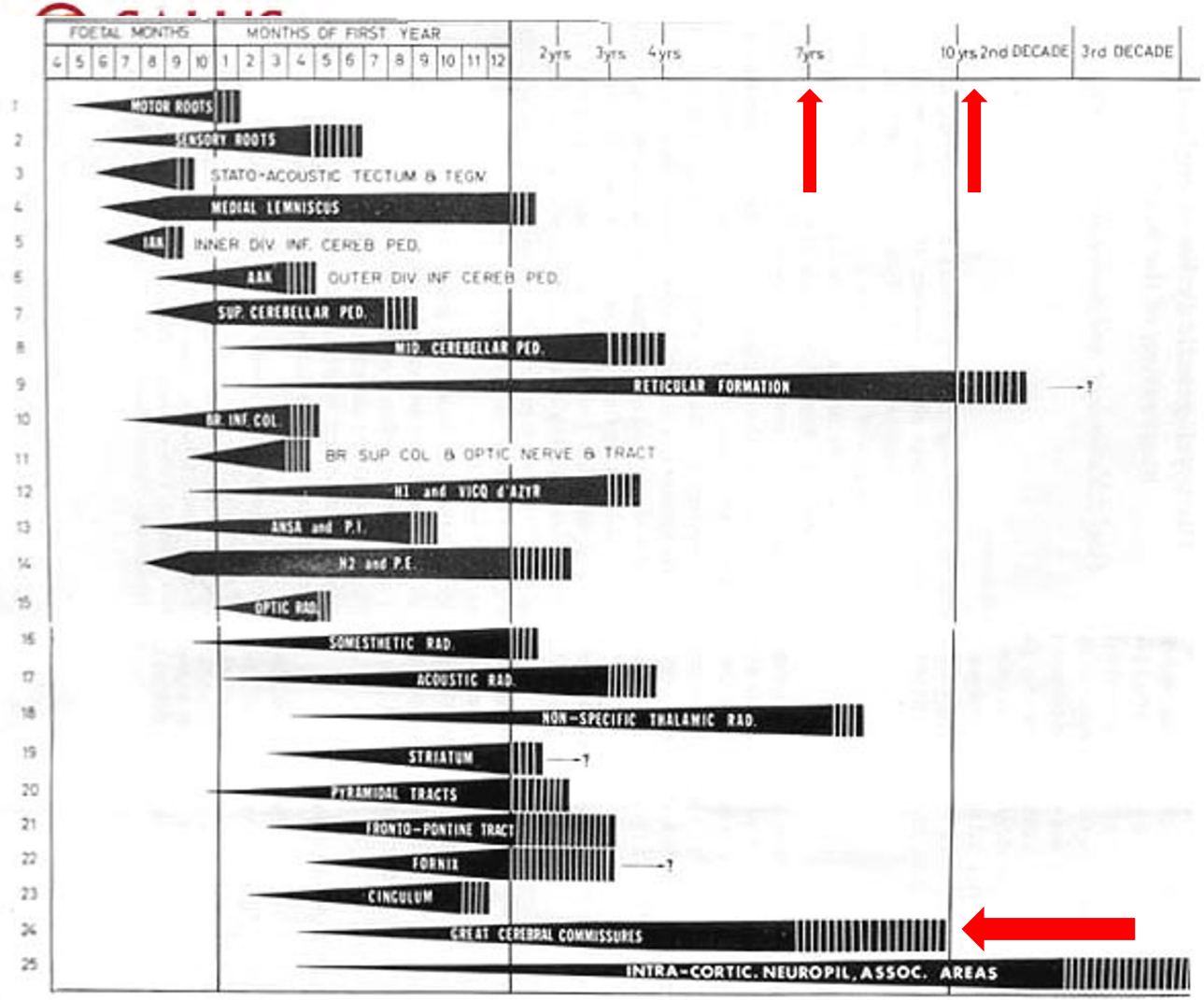
Interdisciplinary evaluations & interventions are often the reality

Maturation of the CANS

Structural, Electrophysiological, & Behavioral Correlates in Maturation			
AGE	**STRUCTURAL**	**ELECTROPHYSIOLOGICAL**	**BEHAVIORAL**
< 6 months	• Layer I cortical axons mature • Acoustic radiation myelination starts	• ABR wave I latency mature • ABR waves III-V, MLR, P2, MMR present but latencies immature	• Discrimination of (speech) sounds, detection of change
6 months – 5 years	• Brainstem axons are mature • Acoustic radiation myelination mature • Axonal neurofilaments in cortical layers IV, V, & VI mature • Cortical synaptic density peaks	• ABR, MLR, P2, N2, MMN, T-complex mature • P1 present but latency immature	• Onset and development of perceptual language & general auditory perception
5-12 years	• Axonal neurofilaments in cortical layers II & III mature • Decrease in cortical synaptic density	• P1 matures, N1 emerges but amplitude remains immature	• Processing of masked & degraded speech improves
>12 years	• Cortical axons are all mature • Temporofrontal language-related nerve tracts mature	• Asymptotic maturation of N1	• Speech understanding in reverberation & background noise matures

Critical age for CAPD diagnostic testing: **7 years**

(Musiek & Chermak, 2014)



(Yakovlev et al., 1967)

Pre-Assessment

Information for Patients & Referring Providers

- A diagnosis of CAPD (H93.25) can only be made by a licensed audiologist trained in the processes of the central auditory nervous system (CANS)
- Ages for testing (diagnostic vs. “at risk”)
- Definition of CAPD & how this guides determination of candidacy for testing and formal diagnosis of the disorder
- Submission of pertinent records (mainly pediatrics), including neuropsychology & SLP evaluation reports
- Submission of records does not guarantee that a CAPD evaluation will be recommended and/or that a diagnosis of CAPD will ultimately be rendered

CAPD Evaluation Candidacy

ICD-10: H93.25 (Central Auditory Processing Disorder)

▶ **H93.25** Central auditory processing disorder
Congenital auditory imperception
Word deafness

Excludes1: mixed receptive-expressive language disorder (F80.2)

H93.29 Other abnormal auditory perceptions

- ▶ **H93.291** Other abnormal auditory perceptions, right ear
- ▶ **H93.292** Other abnormal auditory perceptions, left ear
- ▶ **H93.293** Other abnormal auditory perceptions, bilateral
- ▶ **H93.299** Other abnormal auditory perceptions, unspecified ear

ASHA 2021 ICD-10-CM Diagnostic Codes Related to Hearing and Vestibular Disorders
https://www.asha.org/siteassets/uploadedfiles/icd-10-codes-audiology.pdf

CAPD Evaluation Candidacy

ICD-10: F80.2 (Mixed Receptive-Expressive Language Disorder)

▶ **F80.2** Mixed receptive-expressive language disorder
Developmental dysphasia or aphasia, receptive type
Developmental Wernicke's aphasia

Excludes1: central auditory processing disorder (H93.25)
dysphasia or aphasia NOS (R47.-)
expressive language disorder (F80.1)
expressive type dysphasia or aphasia (F80.1)
word deafness (H93.25)

Excludes2: acquired aphasia with epilepsy [Landau-Kleffner] (G40.80-)
pervasive developmental disorders (F84.-)
selective mutism (F94.0)
intellectual disabilities (F70-F79)

ASHA 2021 ICD-10-CM Diagnostic Codes Related to Speech, Language, and Swallowing Disorders
https://www.asha.org/siteassets/uploadedfiles/icd-10-codes-slp.pdf

CAPD Evaluation Candidacy

ICD-10: H93.293 (Abnormal Auditory Perceptions, Bilateral)

▶ **H93.25** Central auditory processing disorder
Congenital auditory imperception
Word deafness

Excludes1: mixed receptive-expressive language disorder (F80.2)

H93.29 Other abnormal auditory perceptions

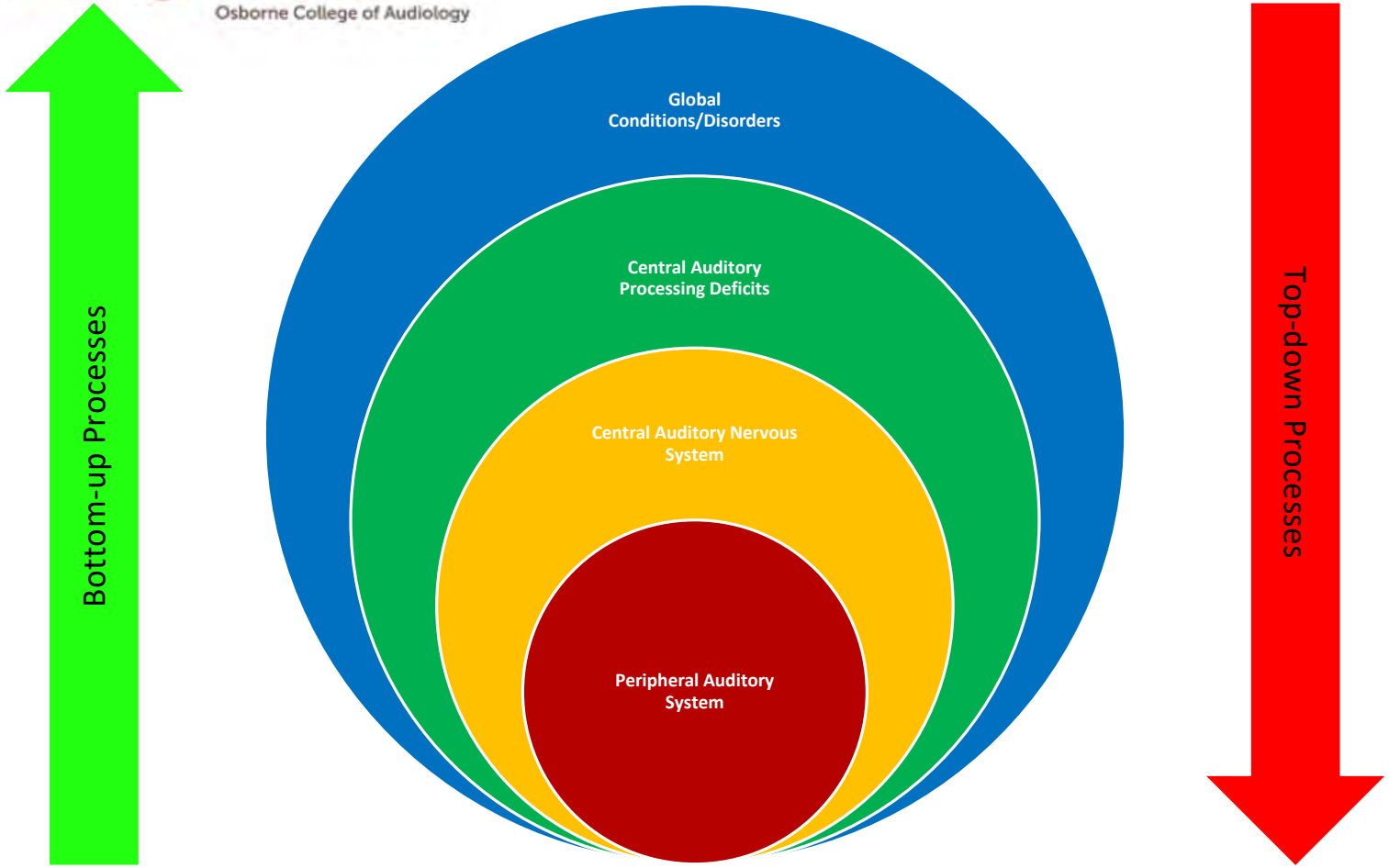
- ▶ **H93.291** Other abnormal auditory perceptions, right ear
- ▶ **H93.292** Other abnormal auditory perceptions, left ear
- ▶ **H93.293** Other abnormal auditory perceptions, bilateral
- ▶ **H93.299** Other abnormal auditory perceptions, unspecified ear

ASHA 2021 ICD-10-CM Diagnostic Codes Related to Hearing and Vestibular Disorders
https://www.asha.org/siteassets/uploadedfiles/icd-10-codes-audiology.pdf

Minimizing Language & Cognitive Confounds

Chermak et al. (2017)

"To distinguish between two or more conditions presenting with similar symptoms or attributes requires multidisciplinary, comprehensive assessment. To ensure that the most appropriate interventions are employed, the audiologist is a member of the multidisciplinary team responsible for *determining whether there is an auditory component to other presenting deficits or whether one condition is responsible for the symptoms seen in another*."


Bottom-up Processes
Global Conditions/Disorders
Central Auditory Processing Deficits
Central Auditory Nervous System
Peripheral Auditory System
Top-down Processes

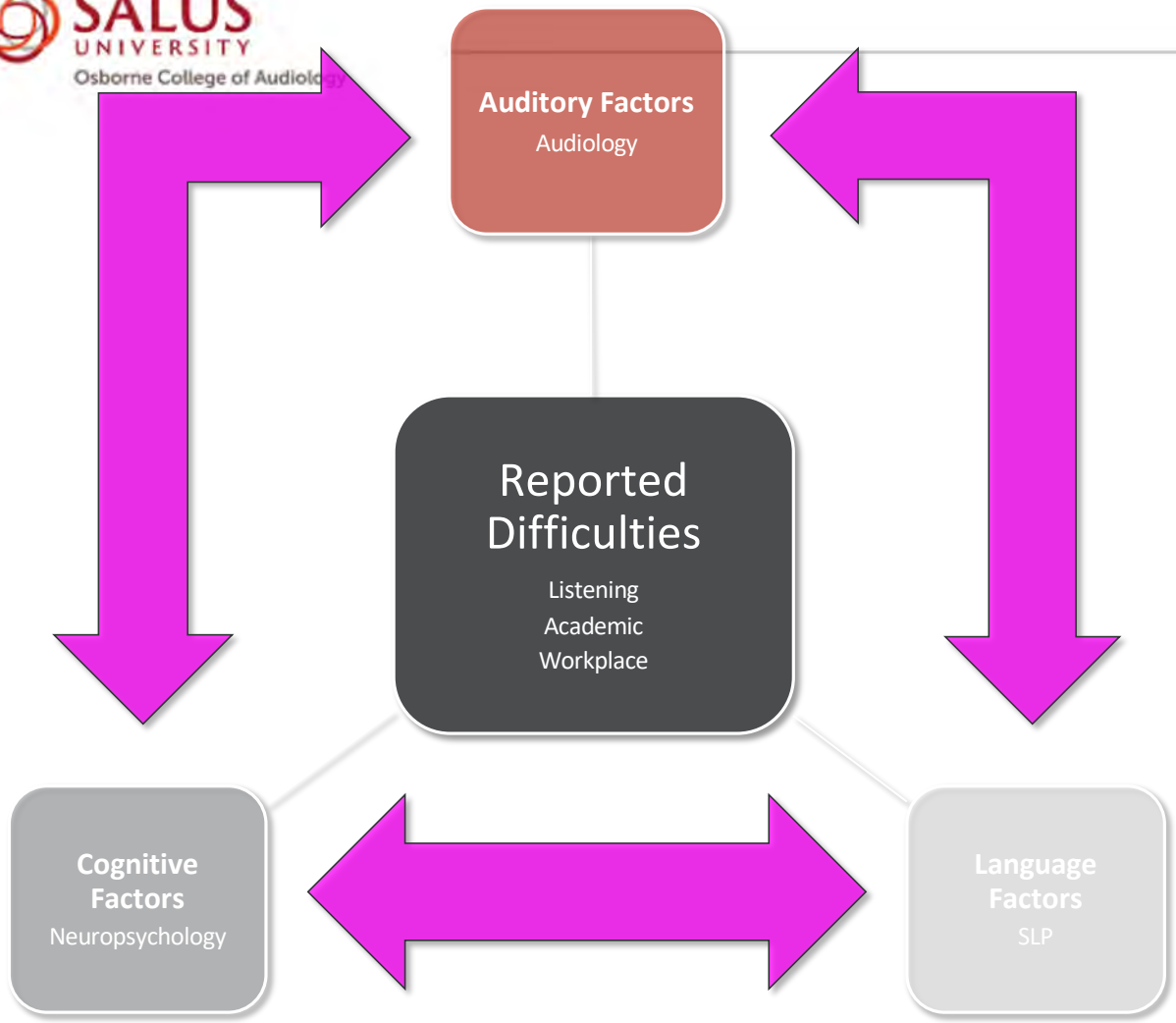
Minimizing Language & Cognitive Confounds

Chermak et al. (2017)

- There are potential interactions between auditory, linguistic, and cognitive factors

- Listening difficulties in CAPD result *primarily* from auditory perceptual deficiencies rather than global attention deficits or behavioral deficits

Neurology work-up & imaging records can also be very helpful



Neuropsychology Report

- ***Cognitive/intellectual ability – standard score of 85 or above, especially on measures of nonverbal intelligence***
- Attention factors (i.e., ADD/ADHD)
- Learning disorders/disabilities (e.g., dyslexia, etc.)
- Working memory
- Any mention of autism spectrum disorder (ASD) diagnosis?
- Any mention of neurological disorder or neuroanatomical abnormality?
- Review of recommendations

Speech-Language Pathology (SLP) Report

- Does the child have a documented speech and/or language disorder, including decreased vocabulary skills?
- ***If so, is the language disorder considered mixed receptive-expressive?***
- Are there consistent articulation errors to be aware of re: word scoring?
- Any mention of ASD (impacts pragmatic language and social interaction skills)
- Review of recommendations

Audiologic Evaluation

- Normal peripheral hearing sensitivity, bilaterally, without significant asymmetries and air-bone gaps
- No more than a mild to moderate high-frequency sensorineural hearing loss that is symmetrical and without significant air-bone gaps
- Are you able to obtain the pure-tone audiogram reliably using a response button?
- Does the patient have symmetrical peripheral hearing sensitivity but asymmetrical word recognition scores?
- Normal, type A tympanograms
- Ipsilateral and contralateral acoustic reflex threshold results, taken independently but also in conjunction with OAEs, if ARTs elevated/absent
- If there were tests administered to screen for CAPD, what were the measures used as well as the results?
- Review of recommendations

Questionnaires

- Do results indicate the patient is “at-risk” for academic, workplace, and/or social problems?
- If so, in which area(s) is the patient considered “at-risk” – do these agree with the neuropsychology and/or SLP report(s)?
- Do the results of the questionnaire(s) support reported case history, including listening/hearing complaints and/or academic/workplace difficulties?

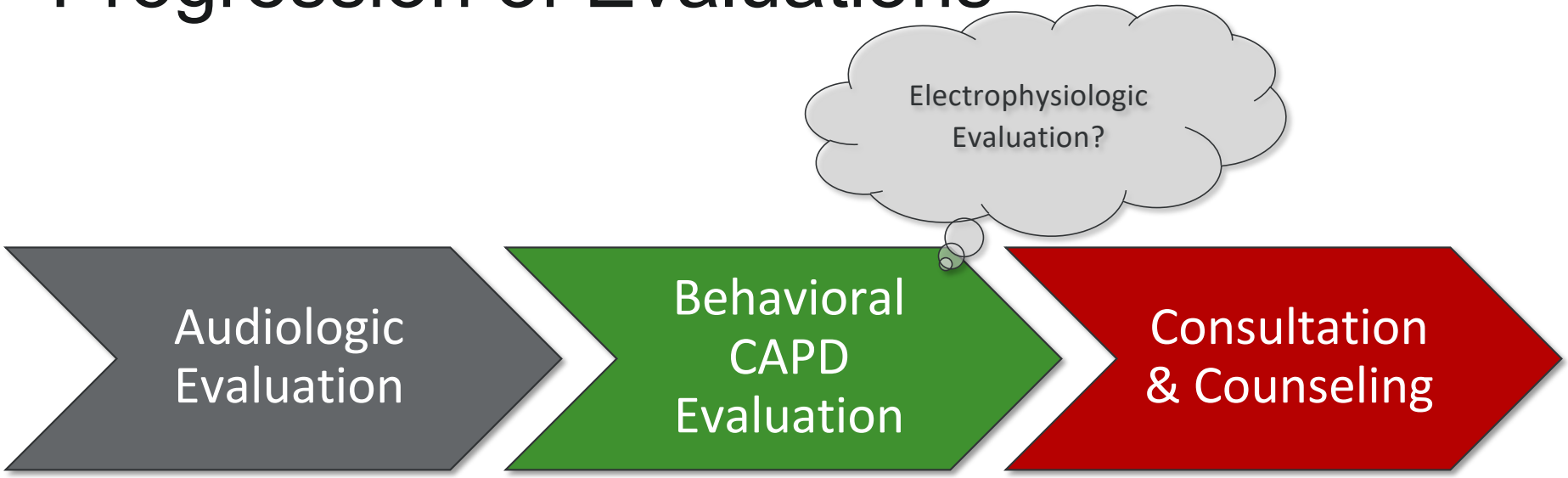
Case History Red Flags

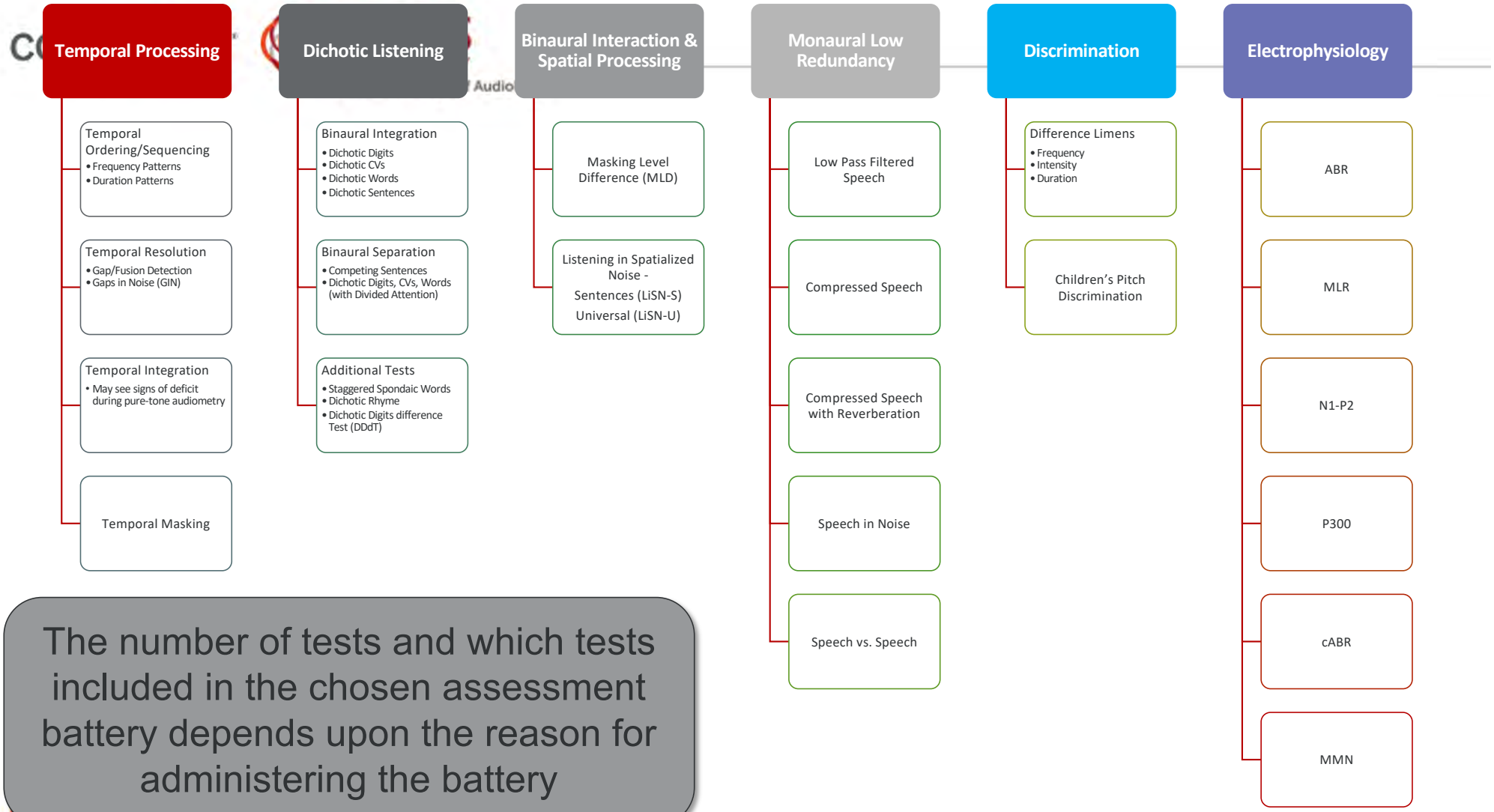
- Head injury, with or without loss of consciousness
- Chronic otitis media in childhood
- Family history of ADD/ADHD, learning disorders (e.g., dyslexia), CAPD, other neurological disorders
- Listening complaints in the presence of normal and symmetrical peripheral hearing sensitivity
- Decline in academic/workplace performance, or a pattern of performance consistent with learning/workplace environment – especially in reading

Considerations

- What if a behavioral CAPD evaluation is not recommended?
  - Intellectual disability
  - Significant peripheral hearing loss that is not a maximum of symmetrical moderate high-frequency SNHL
  - Younger than 7 years of age
- Choosing between diagnostic (H93.25) vs. documenting functional deficits (H93.293)
- Consideration of electrophysiological measures
- Recommendations
  - strengthen underlying neural representations for speech
  - decrease problematic effects of background noise/reverberation/distance/low-context

Progression of Evaluations





The number of tests and which tests included in the chosen assessment battery depends upon the reason for administering the battery

Temporal Processing

What is Temporal Processing?

- The perception of sound or the alteration of sound within a restricted or defined time domain
- Considered by many to be the most fundamental component of most auditory processing capabilities
- “Many, if not all, characteristics encompassing auditory information are in some way influenced by time” (Musiek & Chermak, 2014)

Temporal Processing

Temporal Resolution

The shortest duration of time in which an individual can discriminate between 2 auditory signals

- 2-3 msec (for brief sounds)
- Threshold known as “temporal auditory acuity” or “minimum integration time”
- Temporal modulation transfer function (TMTF) – Tests the ability to detect amplitude modulation
- Gap detection threshold (GDT) – Tests ability to detect and indicate whenever a silent interval is heard when embedded in an ongoing noise burst or sound

Temporal Processing

Temporal Resolution

- Gaps-in-Noise (GIN) Test (Musiek) – Ages 7:0+ years
- Random Gap Detection Test (RGDT; Keith) – Ages 5:0-11:11 years

Temporal Processing

Temporal Resolution (GIN Test)

- Presented at 35-50 dB SL re: SRT, monaurally

- 6 tracks
  - 1000 Hz calibration tone
  - Practice list
  - 4 test lists (2 and 3 take less time from start to finish)
- 6-second-long bursts of white noise, with 0, 1, 2, or 3 gaps embedded
- Gap durations (in msec): 2, 3, 4, 5, 6, 8, 10, 12, 15, 20
- Each gap duration presented 6 times in each list

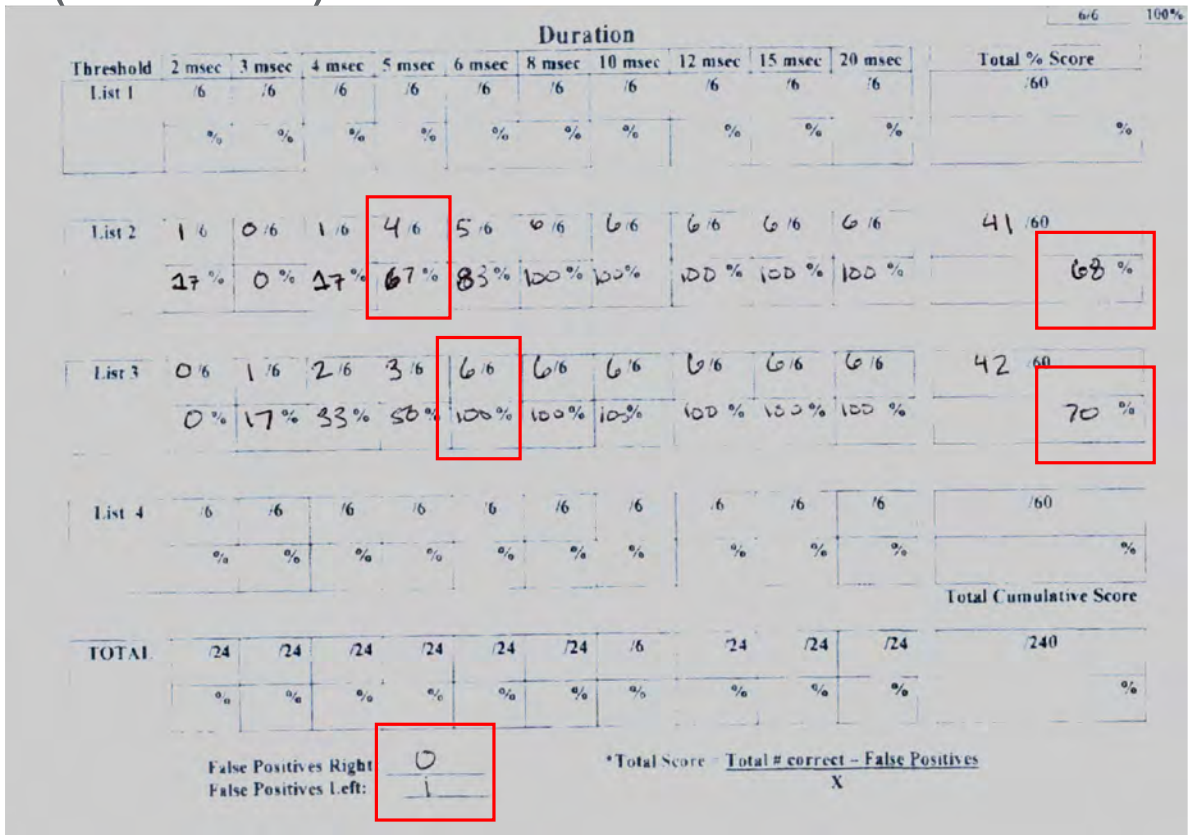
Temporal Processing

Temporal Resolution (GIN Test)

A.Th

Total % Score

False Positives



Threshold	2 msec	3 msec	4 msec	5 msec	6 msec	8 msec	10 msec	12 msec	15 msec	20 msec	Total % Score
	Duration										
List 1	/6	/6	/6	/6	/6	/6	/6	/6	/6	/6	/60
	%	%	%	%	%	%	%	%	%	%	%
List 2	1/6	0/6	1/6	4/6	5/6	6/6	6/6	6/6	6/6	6/6	41/60
	17%	0%	17%	67%	83%	100%	100%	100%	100%	100%	68%
List 3	0/6	1/6	2/6	3/6	6/6	6/6	6/6	6/6	6/6	6/6	42/60
	0%	17%	33%	50%	100%	100%	100%	100%	100%	100%	70%
List 4	/6	/6	/6	/6	/6	/6	/6	/6	/6	/6	/60
	%	%	%	%	%	%	%	%	%	%	%
										Total Cumulative Score	
TOTAL	/24	/24	/24	/24	/24	/24	/6	/24	/24	/24	/240
	%	%	%	%	%	%	%	%	%	%	%

False Positives Right: 0
False Positives Left: 1

*Total Score = Total # correct − False Positives / X

Temporal Processing

Temporal Ordering/Sequencing

The processing of 2 or more auditory stimuli in their order of occurrence

- Accuracy depends on both the left and right hemispheres to be anatomically and physiology intact
- Neither hemisphere alone can adequately process temporal patterns
- Sensitive to hemispheric lesions as well as interhemispheric dysfunction

Temporal Processing

Temporal Ordering/Sequencing

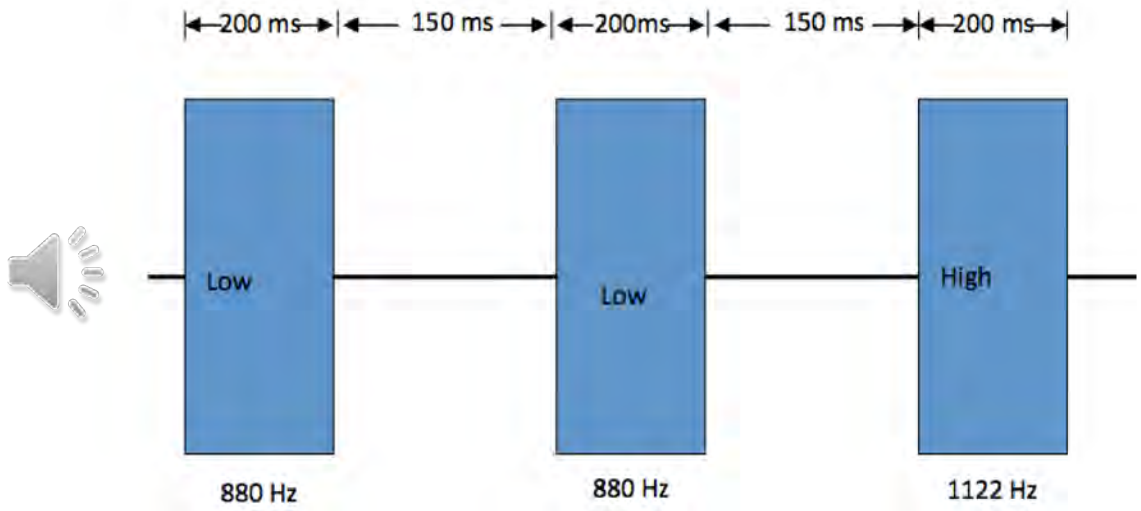
- Frequency Pattern Test – Ages 8:0+ years
- Duration Pattern Test – Ages 11:0+ years

Temporal Processing

Temporal Ordering/Sequencing (Frequency Patterns)

- 2 frequencies: 880 Hz (“low”) & 1122 Hz (“high”)

- Each trial contains a sequence of 3 tones composed of a mix of the high and low frequencies
  - H-L-L
  - L-H-H
  - L-H-L
  - H-L-H
  - L-L-H
  - H-H-L

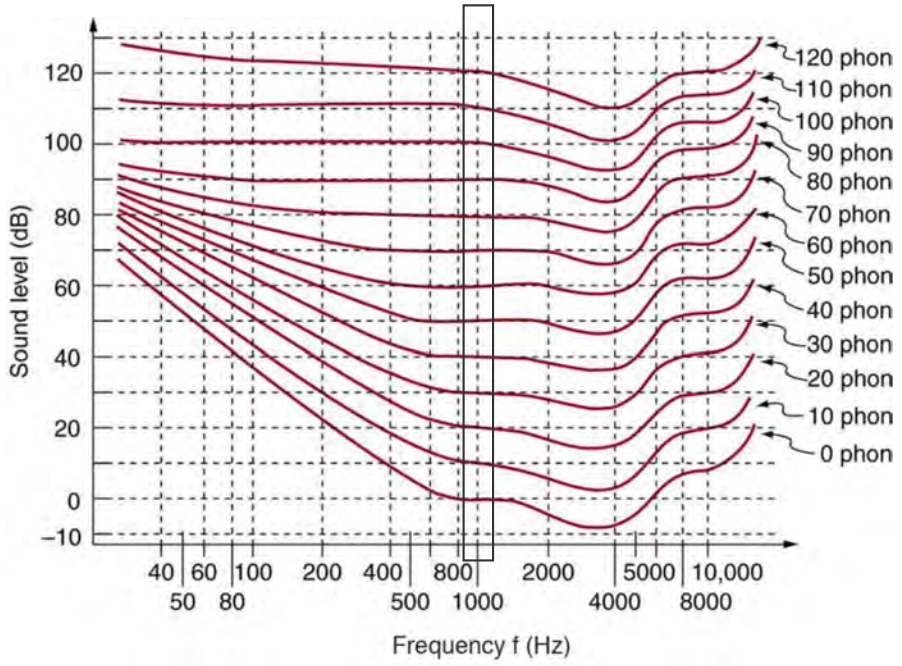


Temporal Processing

Temporal Ordering/Sequencing (Frequency Patterns)

If a patient has mild-to-moderate high-frequency sensorineural hearing loss and is still considered a candidate for a CAPD evaluation:

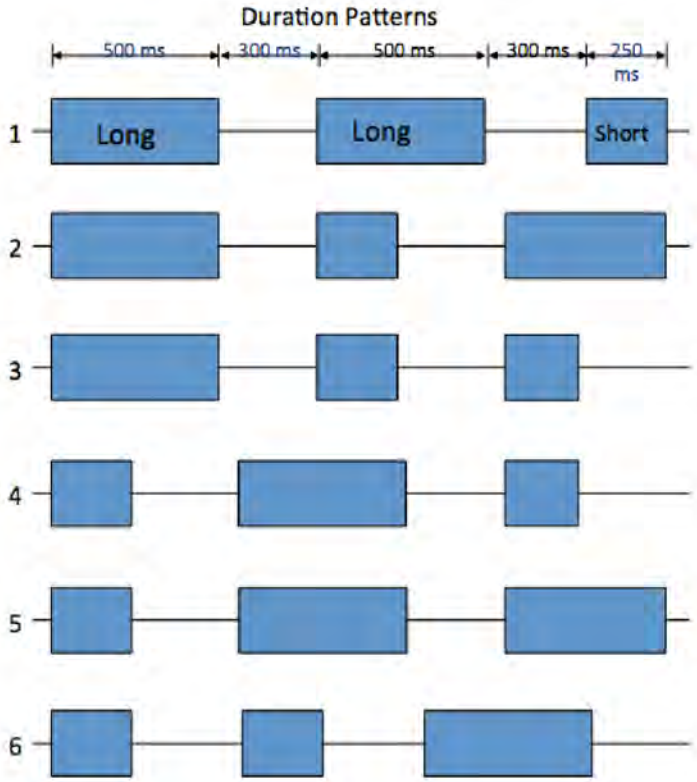
- Do not administer the Frequency Pattern Test
- Do administer the Duration Pattern Test



Temporal Processing

Temporal Ordering/Sequencing (Dura

- 2 stimulus durations: 300 msec ("short") & 550 msec ("long")
- 1 frequency: 1000 Hz
- Each trial is 1850 msec
- Each duration separated by 300 msec of silence



Temporal Processing

Temporal Ordering/Sequencing

- Monaural presentation preferred; binaural/soundfield?
- Each trial scored as a whole pattern
- Reversals are always incorrect
- Keep track of responses that are total pattern reversals

Dichotic Listening

What is Dichotic Listening?

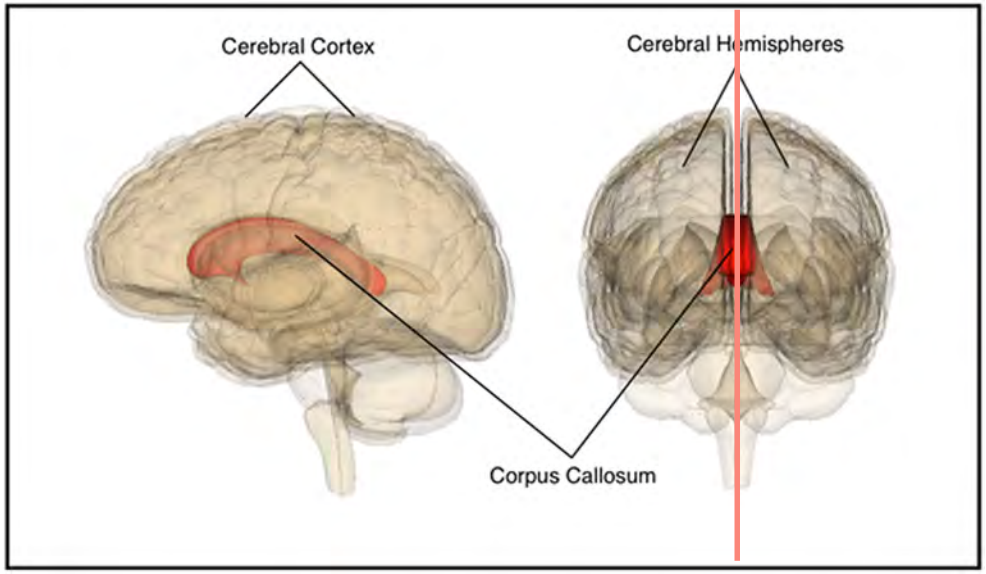
The simultaneous stimulation of both ears, but with a different stimulus in each ear (Stevens & Davis, 1938)

- Stimuli recommended to be presented at 50 dB SL re: SRT or PTA for each ear
- Stimulus onsets should be *carefully aligned* between sources when created

An investigation of ear dominance effects – the tendency of one ear to have an advantage and outperform the other when engaged in dichotic listening

Split Brain Studies

Sperry & Gazzaniga

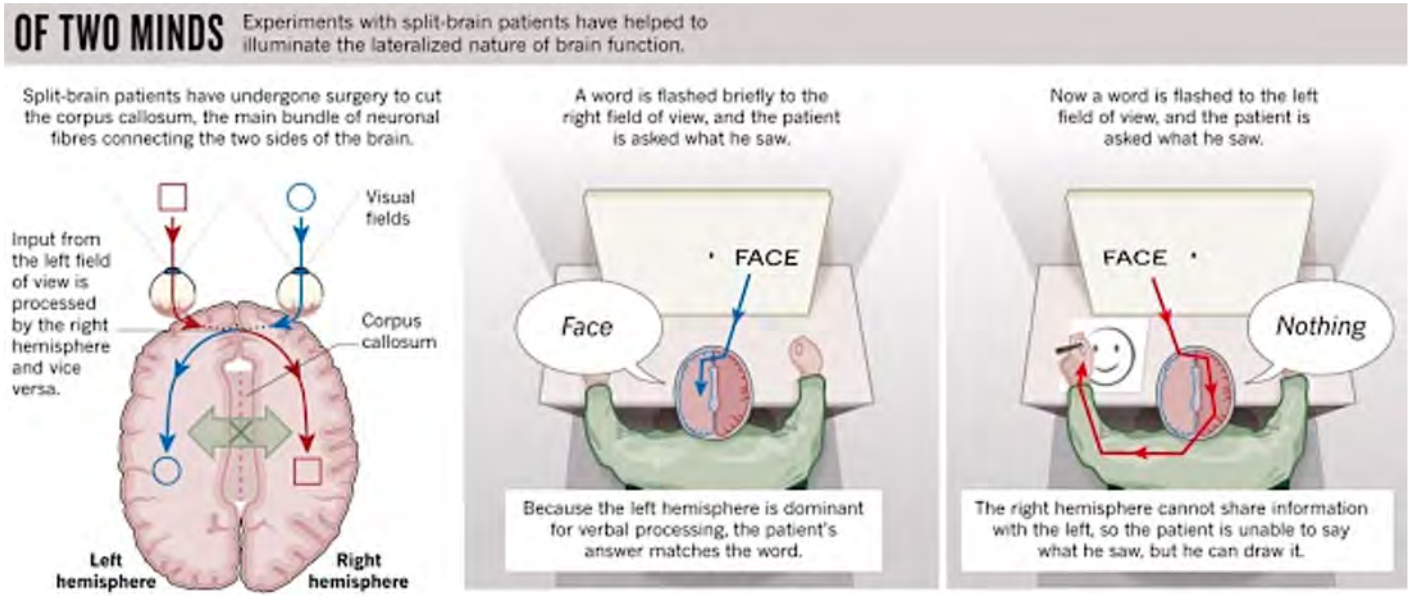


Corpus Callosotomy surgery

- Severing of corpus callosum as treatment for severe epilepsy
- Attempt to limit the “electrical storm” of the seizures from one hemisphere to the other

Split-Brain Studies

Sperry & Gazzaniga



 (Wolman, 2012)

Split-Brain Studies

Musiek & Weihing (2011)

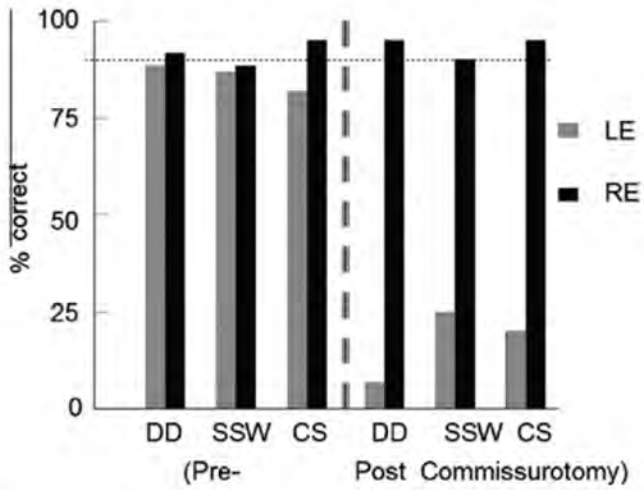


Fig. 4. Effect of commissurotomy on dichotic performance. Note decrease in left ear scores post commissurotomy.

Dichotic Listening Tests

- Dichotic Digits Test (Musiek) – Binaural integration
- Competing Sentences (Willeford) – Binaural separation
- Staggered Spondaic Words (Katz; SSW) – Binaural integration/separation/fusion

Dichotic Listening

Response Tasks

- Free-recall
- Directed attention – right
- Directed attention – left

Dichotic Listening

Dichotic Digits Test

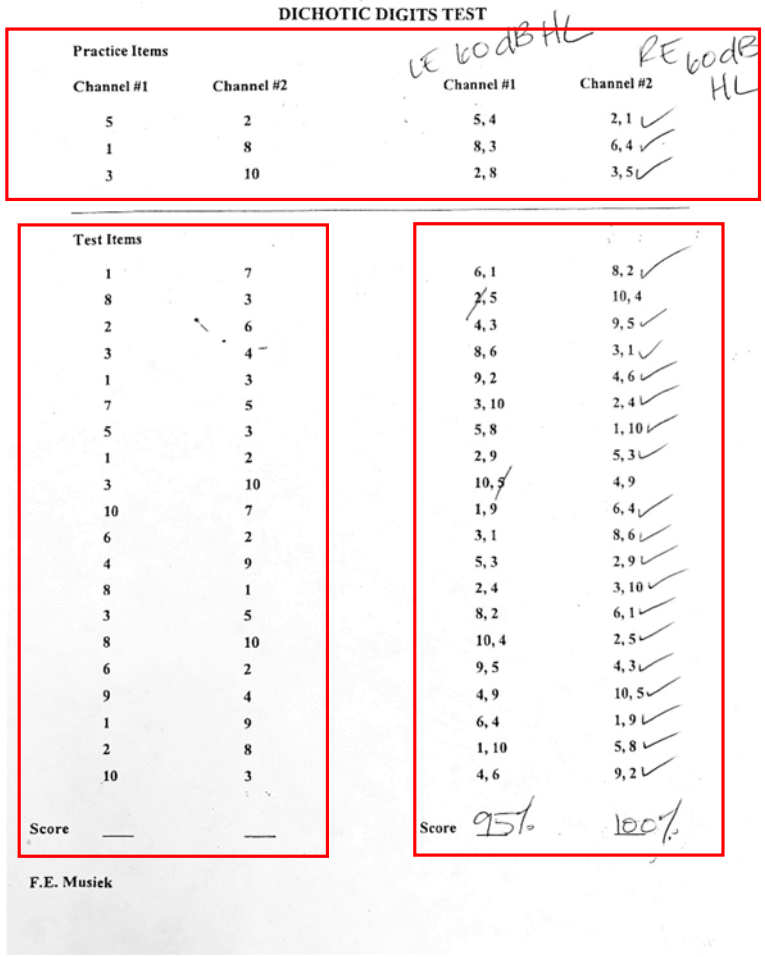
Test of binaural integration

Double digit scoring

- Each number worth 2.5%
- Can miss 4 numbers in each ear and score 90%, bilaterally

Single digit scoring…

Time between test items



DICHOTIC DIGITS TEST

LE 60dB HL

RE 60dB HL

Practice Items			
Channel #1	Channel #2	Channel #1	Channel #2
5	2	5, 4	2, 1 ✓
1	8	8, 3	6, 4 ✓
3	10	2, 8	3, 5 ✓

Test Items			
1	7	6, 1	8, 2 ✓
8	3	~~2, 5~~	10, 4
2	6	4, 3	9, 5 ✓
3	4	8, 6	3, 1 ✓
1	3	9, 2	4, 6 ✓
7	5	3, 10	2, 4 ✓
5	3	5, 8	1, 10 ✓
1	2	2, 9	5, 3 ✓
3	10	10, ~~5~~	4, 9
10	7	1, 9	6, 4 ✓
6	2	3, 1	8, 6 ✓
4	9	5, 3	2, 9 ✓
8	1	2, 4	3, 10 ✓
3	5	8, 2	6, 1 ✓
8	10	10, 4	2, 5 ✓
6	2	9, 5	4, 3 ✓
9	4	4, 9	10, 5 ✓
1	9	6, 4	1, 9 ✓
2	8	1, 10	5, 8 ✓
10	3	4, 6	9, 2 ✓
Score ___	___	Score 95%	100%

F.E. Musiek

Dichotic Listening

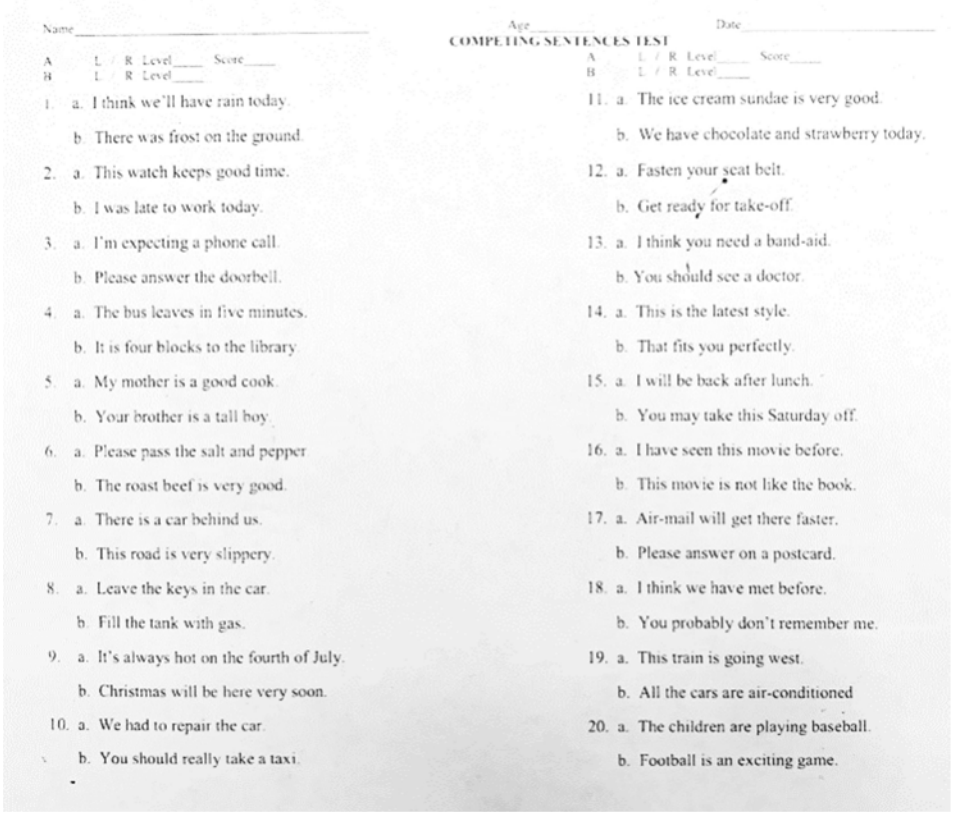
Competing Sentences

Test of binaural separation

Scoring relies on how much meaning is included in the response

10 sentences per ear, with 4 units of meaning for each sentence

- 100% meaning = 10 points
- 75% meaning = 7.5 points
- 50% meaning = 5 points
- 25% meaning = 2.5 points
- 0% meaning = 0 points



Name_____ Age_____ Date_____

COMPETING SENTENCES TEST

A ___ L / R Level____ Score____
B ___ L / R Level____

1. a. I think we'll have rain today.
   b. There was frost on the ground.
2. a. This watch keeps good time.
   b. I was late to work today.
3. a. I'm expecting a phone call.
   b. Please answer the doorbell.
4. a. The bus leaves in five minutes.
   b. It is four blocks to the library.
5. a. My mother is a good cook.
   b. Your brother is a tall boy.
6. a. Please pass the salt and pepper.
   b. The roast beef is very good.
7. a. There is a car behind us.
   b. This road is very slippery.
8. a. Leave the keys in the car.
   b. Fill the tank with gas.
9. a. It's always hot on the fourth of July.
   b. Christmas will be here very soon.
10. a. We had to repair the car.
    b. You should really take a taxi.

A ___ L / R Level____ Score____
B ___ L / R Level____

11. a. The ice cream sundae is very good.
    b. We have chocolate and strawberry today.
12. a. Fasten your seat belt.
    b. Get ready for take-off.
13. a. I think you need a band-aid.
    b. You should see a doctor.
14. a. This is the latest style.
    b. That fits you perfectly.
15. a. I will be back after lunch.
    b. You may take this Saturday off.
16. a. I have seen this movie before.
    b. This movie is not like the book.
17. a. Air-mail will get there faster.
    b. Please answer on a postcard.
18. a. I think we have met before.
    b. You probably don't remember me.
19. a. This train is going west.
    b. All the cars are air-conditioned
20. a. The children are playing baseball.
    b. Football is an exciting game.

Binaural Interaction & Auditory Spatial Processing

What is Binaural Interaction?

- Brainstem-level process that contributes to sound localization/lateralization and signal detection/auditory performance in backgrounds of competing acoustic signals – *"binaural squelch," "binaural release from masking"*

- Masking Level Difference (MLD) assesses an individual's use of interaural phase difference cues (MSO "time pathway") that gives rise to binaural release from masking

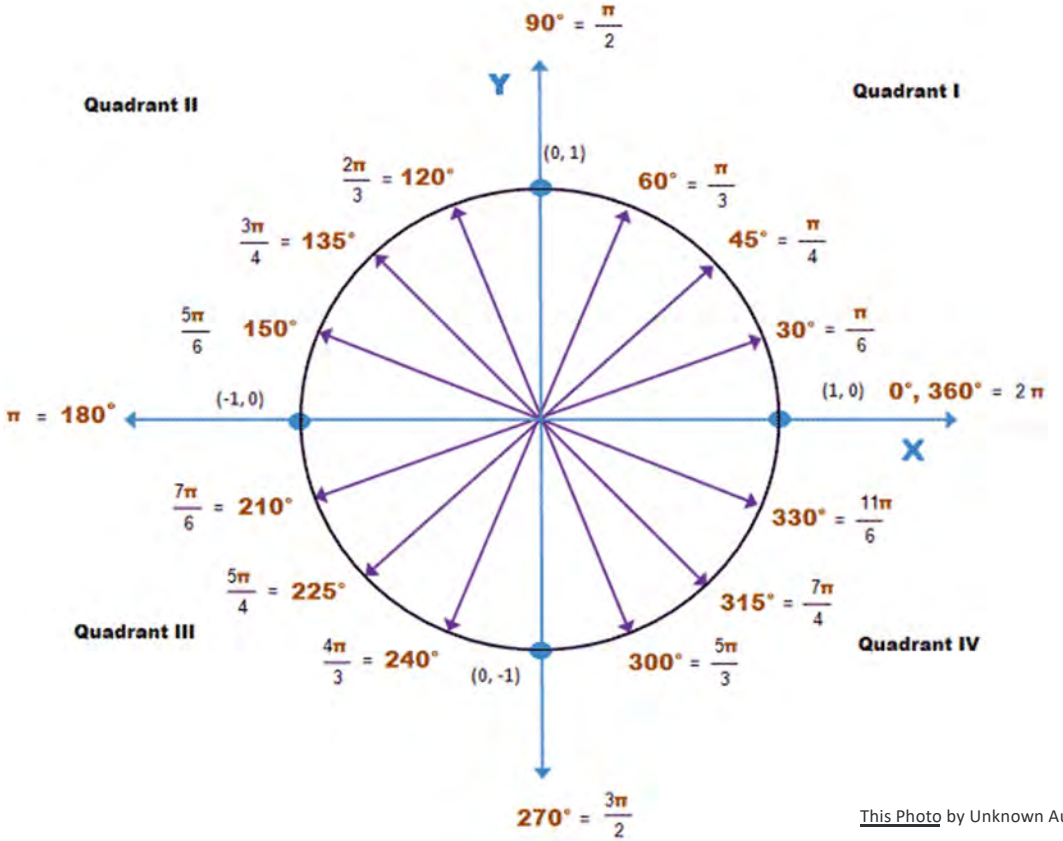
Binaural Interaction

Masking Level Difference (MLD)

- Clinically obtained using tones (S) and narrowband noise centered around test frequency (N)
- MLD at 500 Hz can be as great as 15 dB
- MLD progressively decreases – 3 dB for frequencies higher than 1500 Hz up to at least 4000 Hz
- 3 testing conditions (S0N0, SπN0, S0Nπ)

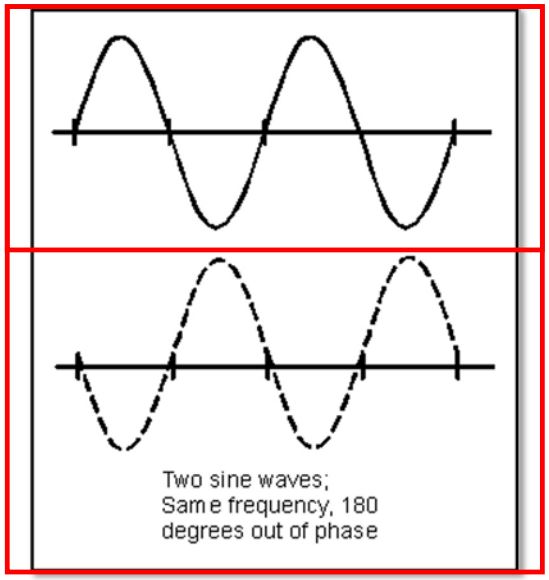
Binaural Interaction

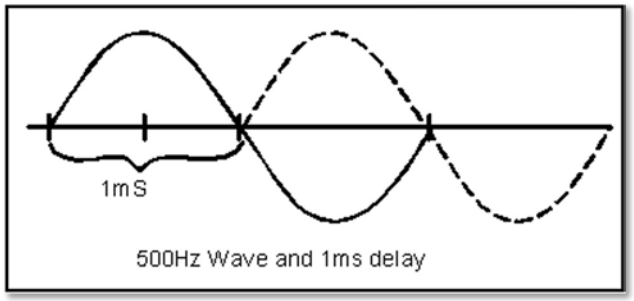
MLD



MLD

In-Phase & Out-of-Phase Waveforms





π means that a signal or noise has an interaural phase difference of π radians, or 180 degrees

Masking Level Difference (MLD)

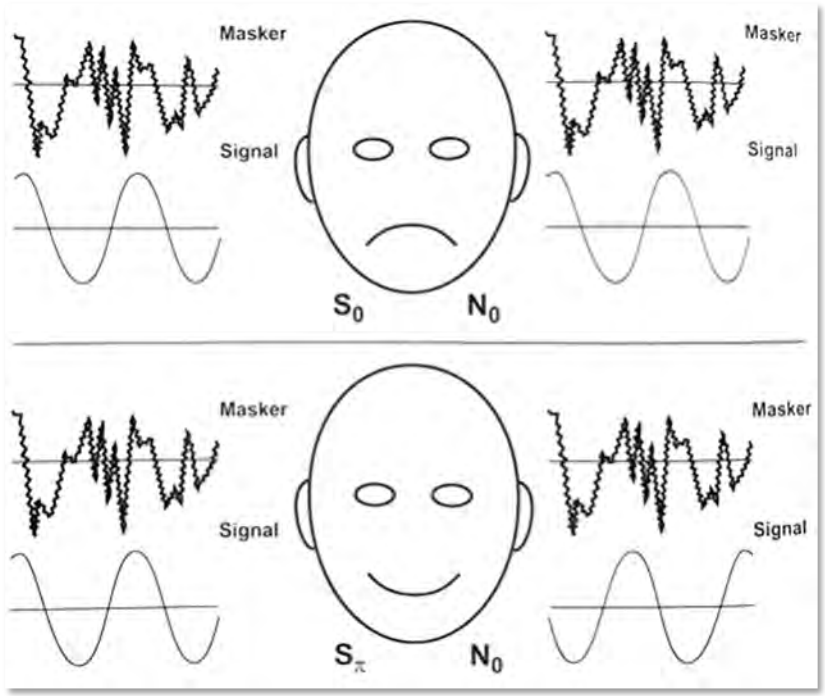
Homophasic paradigm – S_0N_0

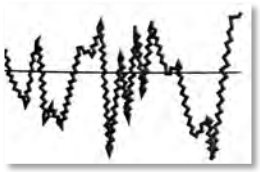
- Signals in the two channels are in-phase with one another
- Noise maskers in the two channels are in-phase with one another
- "0" indicates that there is no interaural phase difference

Antiphasic paradigm – $S_\pi N_0$ & S_0N_π

- $S_\pi N_0$ = Signal is 180 degrees out-of-phase (typically leads to best signal threshold)
- S_0N_π = Noise is 180 degrees out-of-phase
- "π" indicates that there is an interaural phase difference of 180 degrees

Masking Level Difference



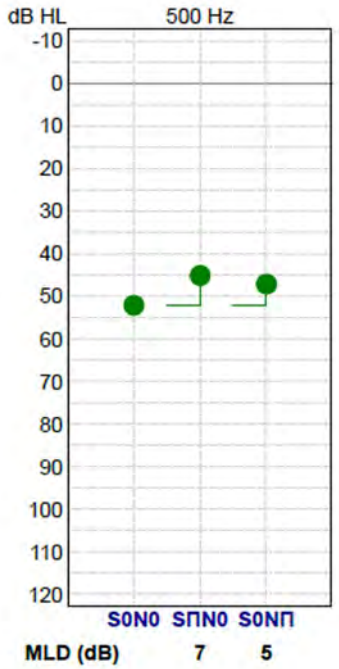


N_π

$MLD = S_0N_0 - S_\pi N_0$

MLD

Graph & Results



- Average MLD in normal CANS is 12 dB
- An MLD below 7 dB (i.e., 6 dB or less) is considered abnormal

Table 1.—Mean Masking-Level Difference (MLD), Range, and SD Under $S\pi No$ and $SoN\pi$ Antiphasic Conditions*

		$S\pi No$			$SoN\pi$		
	N	MLD	SD	Range	MLD	SD	Range
Normal†	10	12.2	1.1	10-14	10.2	1.1	8-12
Cerebral lesion	12	10.4	2.4	8-14	9.9	2.0	8-15
Upper pons, midbrain or thalamic lesion	5	10.6	1.9	8-13	8.4	2.2	6-12
Pontomedullary lesion	9	2.4	1.7	0-5	2.3	1.5	0-5

*$S\pi No$ indicates signal reversed; $SoN\pi$, noise reversed.
†From Michaud.[3]

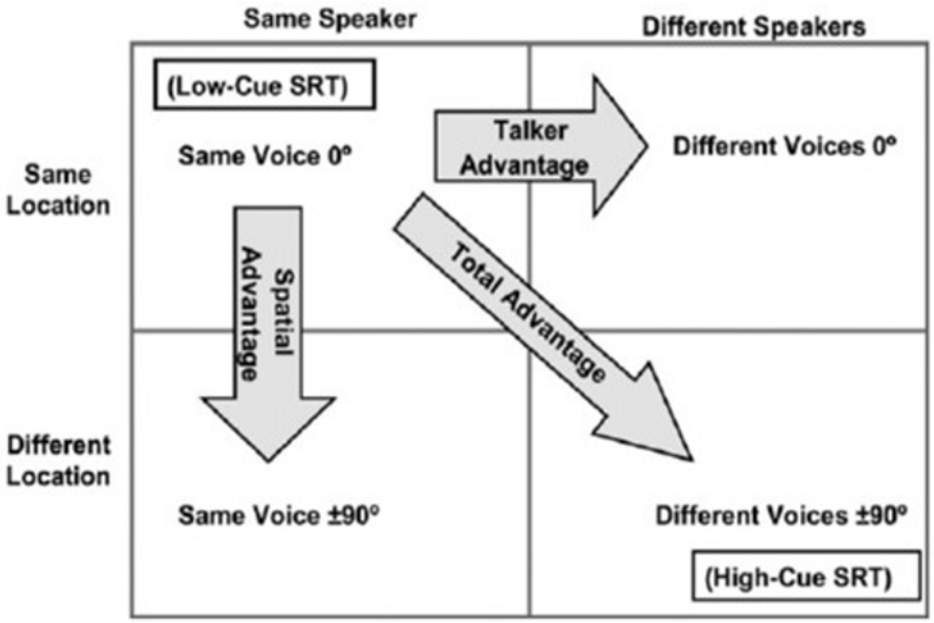
(Lynn et al., 1981)

What is Auditory Spatial Processing?

- The ability to selectively focus on sounds coming from one direction and suppress sounds coming from other directions
- Measures spatial release from masking, though likely involves cortical CANS function
- Listening in Spatialized Noise-Sentences (LiSN-S) Test
  - Talker variations (voice of target speech vs. background babble; same/different)
  - Location variations (location of target speech vs. background babble; same/different)
  - 4 conditions
  - 5 measures

LiSN-S

NAL; Cameron & Dillon, 2007



"LiSN-S is an adaptive, virtual reality speech test…"
(National Acoustic Laboratories)

- **Low-Cue SRT:** Threshold for speech when no talker or spatial cues available
- **High-Cue SRT:** Threshold for speech when both talker and spatial cues available

- **Talker Advantage:** Compares SRTs for conditions with different voices to conditions with same voice. Represents a person's ability to make use of voice differences to improve speech understanding in noise
- **Spatial Advantage:** Compares SRTs for conditions with different locations to conditions with same location. Represents a person's ability to make use of spatial differences to improve speech understanding in noise
- **Total Advantage:** Compares Low-Cue SRT to High-Cue SRT to determine a person's ability to make use of both voice and spatial differences to improve speech understanding in noise

Monaural Low-Redundancy Speech Tests

Redundancy Defined

redundancy noun

Save Word

re·dun·dan·cy | \ ri-ˈdən-dən(t)-sē \

plural **redundancies**

Definition of *redundancy*

1 **a** : the quality or state of being redundant : SUPERFLUITY

b : the use of redundant components

also : such components

c *chiefly British* : dismissal from a job especially by layoff

2 : PROFUSION, ABUNDANCE

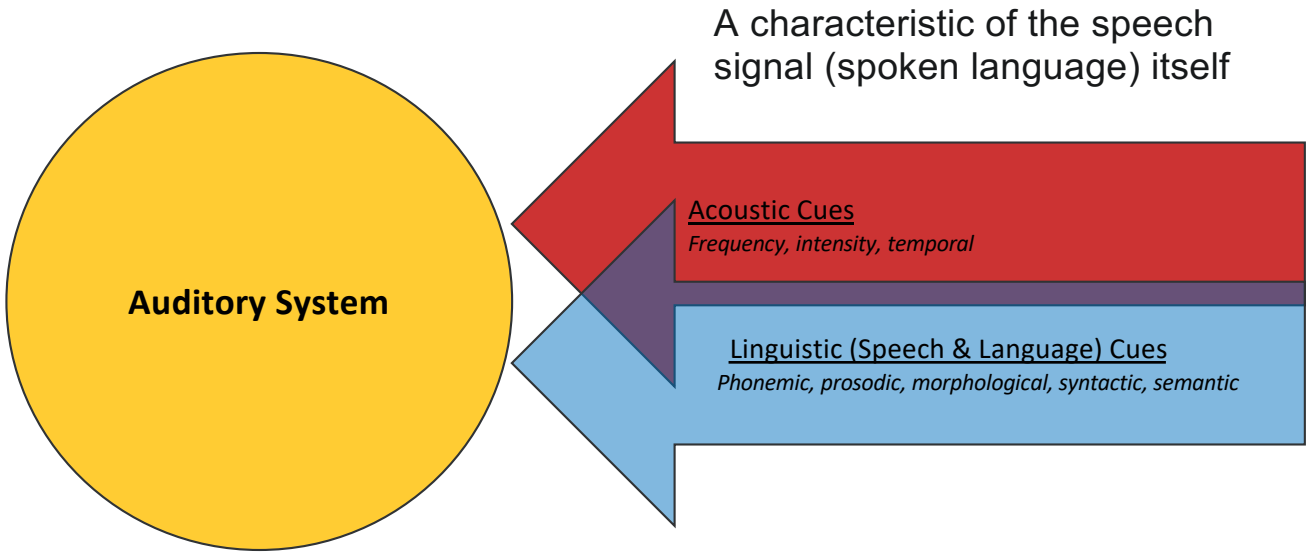
3 **a** : superfluous repetition : PROLIXITY

b : an act or instance of needless repetition

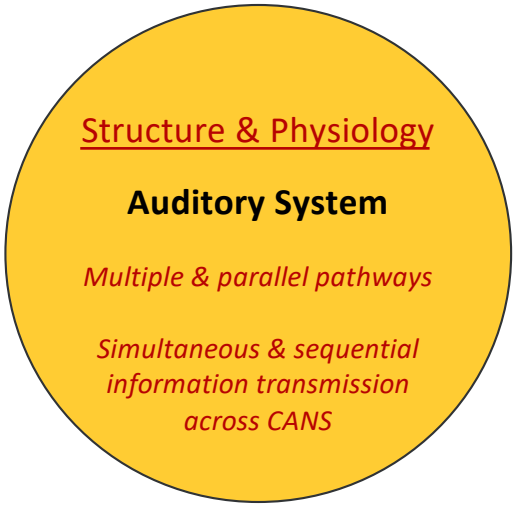
4 : the part of a message that can be eliminated without loss of essential information

Merriam-Webster Dictionary (online)

Extrinsic Redundancy



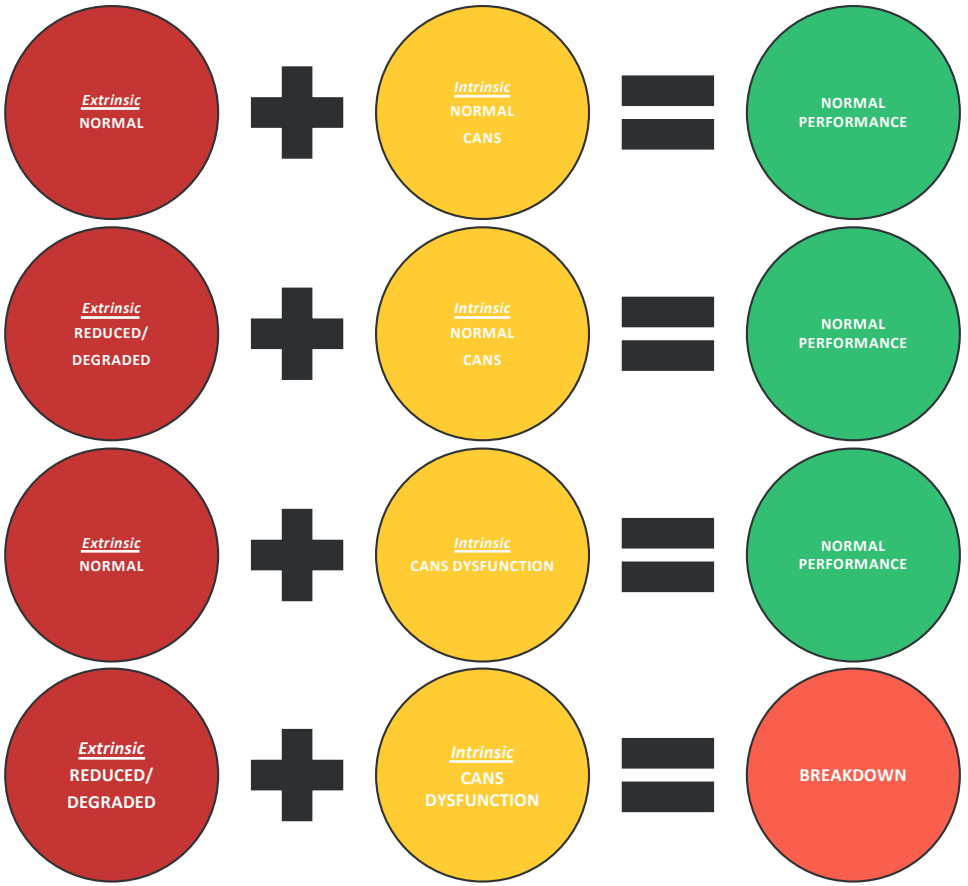
Intrinsic Redundancy

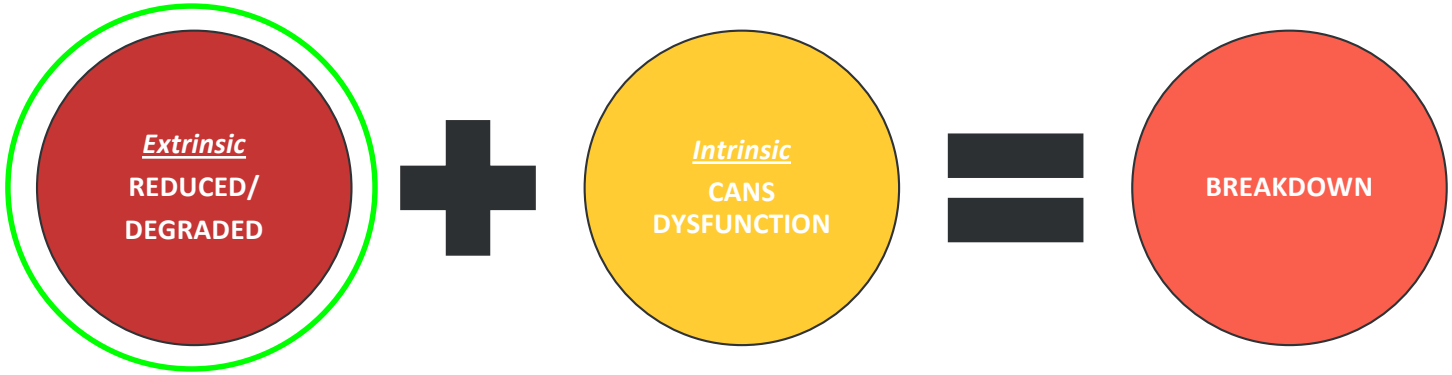


- Auditory system integrity itself
- Peripheral, central, or both?

Redundancy

Extrinsic + Intrinsic = Performance





Manipulating stimuli ***is*** clinically controllable

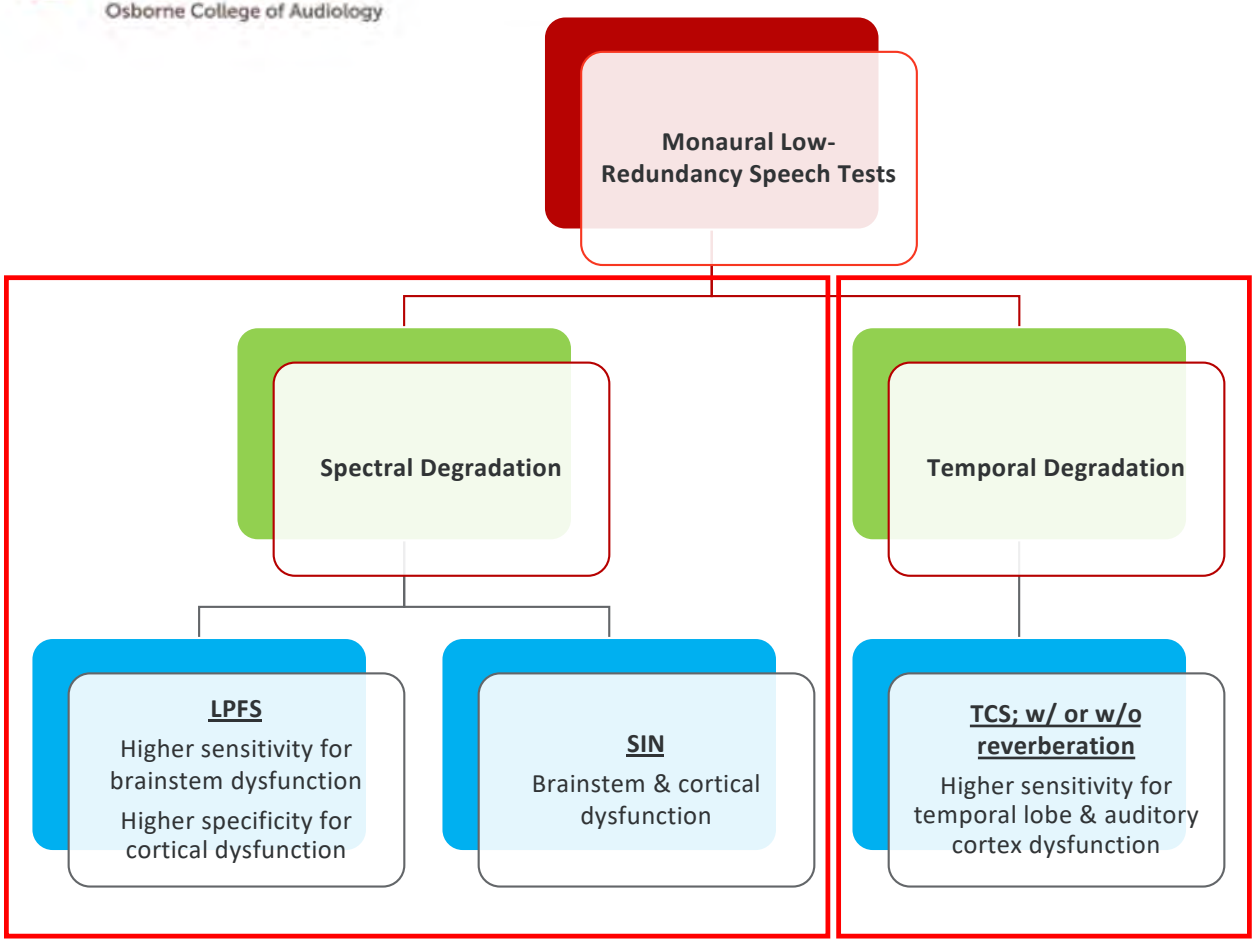
Existence of CANS dysfunction ***is not*** clinically controllable (diagnostically)

Existence of speech and/or language disorder ***is not*** clinically controllable

Consequences of Low-Redundancy

- Low-redundancy is driven by 4 main factors
  - Degraded listening environments
  - Speech and language disorders
  - Auditory system (including CANS) dysfunction
  - Cognitive disorders/decline

- Difficulty understanding speech in listening environments with
  - Background noise
  - Echo/reverberation
  - Talkers at a distance, or speech at softer levels
  - Low contextual cues


Monaural Low-Redundancy Speech Tests
Spectral Degradation
Temporal Degradation
LPFS
Higher sensitivity for brainstem dysfunction
Higher specificity for cortical dysfunction
SIN
Brainstem & cortical dysfunction
TCS; w/ or w/o reverberation
Higher sensitivity for temporal lobe & auditory cortex dysfunction

Results: Clinical & Patient-Centered Interpretation

CAPD Behavioral Test Norms by Age

Compiled by Jennifer Gonzalez, Au.D., Ph.D., CCC-A

	CAPD Test Measure								
Age	**DDT**	**GIN**	**FP/PPST**	**DP**	**FW**	**Comp. Speech**	**SSW**	**Comp. Sent.**	**DR**
7:0 – 7:11	LE: 55% RE: 70%	A.th ≥ 8 ms; % correct ≤ 52%	N/A	N/A	60% AU	N/A	LE: 55% RE: 75%	N/A	30-60% AU
8:0 – 8:11	LE: 65% RE: 75%	A.th ≥ 8 ms; % correct ≤ 52%	40% AU	N/A	70% AU	N/A	LE: 75% RE: 80%	LE: 40% RE: 82%	30-60% AU
9:0 – 9:11	LE: 75% RE: 80%	A.th ≥ 8 ms; % correct ≤ 52%	65% AU	N/A	70% AU	N/A	LE: 75% RE: 80%	LE: 75% RE: 90%	30-60% AU
10:0 – 10:11	LE: 75% RE: 85%	A.th ≥ 8 ms; % correct ≤ 52%	72% AU	N/A	70% AU	N/A	LE: 80% RE: 85%	90% AU	30-60% AU
11:0 - Adult	90%, AU	A.th ≥ 8 ms; **11 y.o.** % correct ≤ 52% **12 y.o. – Adult** % correct ≤ 54%	75% AU	70% AU	70% AU	80% AU	LE: 90% RE: 88%	90% AU	LE: 30-60% RE: 32-68%

MLD result should be **7 dB or greater.** A normal result is usually around **12 dB.**

Abbreviations Key	
DDT	Dichotic Digit Test
GIN	Gaps-in-Noise Test
FP/PPST	Frequency Pattern/Pitch Pattern Sequence Test
DP	Duration Pattern
FW	Filtered CNC Words (not VA version)
Comp. Speech	Compressed Speech, (NU-6; 45% compressed, no reverb)
SSW	Staggered Spondaic Words
Comp. Sent.	Competing Sentences Test
DR	Dichotic Rhyme
MLD	Masking Level Difference

When Scores are Significant

Performance deficits noted in one or both ears of at least 2 standard deviations below the mean on 2 or more tests in the battery

IF poor performance noted on only 1 test

- Diagnosis may be withheld unless performance falls at least **3 standard deviations below the mean** or the finding is accompanied by significant functional difficulty in auditory behaviors that rely on the process being assessed

- The failed test – and other tests that assess the same process – should be re-administered to confirm initial findings

(ASHA, 2021; Chermak & Musiek, 1997; Musiek & Chermak, 2014)

Sensitivity & Specificity of Common Behavioral CAPD Tests		
Test	**Sensitivity**	**Specificity**
GIN	Overall CANS: **67%** (Musiek et al., 2005)	Overall CANS: **94%** (Musiek et al., 2005)
Frequency Patterns	Cerebral Lesions: **83-86%** Weaker for Brainstem Lesions (Emanuel, 2002; Musiek et al., 1987, 1990; 2011)	Cerebral Lesions: **92-100%** Weaker for Brainstem Lesions (Emanuel, 2002; Musiek et al., 1987, 1990; 2011)
Duration Patterns	Cerebral Lesions: **86%** Weaker for Brainstem Lesions (Emanuel, 2002; Musiek et al., 1987, 1990)	Cerebral Lesions: **92%** Weaker for Brainstem Lesions (Emanuel, 2002; Musiek et al., 1987, 1990)
Dichotic Digits	CANS w/o SNHL (90% criterion): **75-80%** CANS w/ SNHL (80% criterion): **72.2%** Overall CANS: **70-90%** (Hurley & Musiek, 1997; Musiek et al., 1983; Musiek et al., 1991; Musiek et al., 2011)	CANS w/o SNHL (90% criterion): **83-89%** CANS w/ SNHL (80% criterion): **90%** Overall CANS: **80-90%** (Hurley & Musiek, 1997; Musiek et al., 1983; Musiek et al., 1991; Musiek et al., 2011)
Competing Sentences	Cerebral Lesions: **68-75%** Overall CANS: **56%** (Musiek et al., 1983, 2011)	Cerebral Lesions: **91%** (Musiek et al., 2011)
MLD	≤ 6 dB Criterion (SπN0) Pontomedullary Lesions: **100%** Upper Pons, Midbrain, Thalamic Lesions: **0%** Cerebral Lesions: **0%** Multiple Sclerosis: **50%** (Lynn et al., 1981; Noffsinger et al., 1972)	≥ 7 dB Criterion (SπN0) All subjects with pontomedullary, upper pons, midbrain, thalamic, cerebral lesions had same MLD as normal controls. (Lynn et al., 1981)
LiSN-S	"17% of children referred for assessment for CAPD across various studies have been diagnosed with SPD." (Dillon et al., 2012; Musiek & Chermak, 2014)	
Filtered Words (LPFS)	Brainstem: **62-64%** Temporal Lobe: **65-67%** Cerebral Lesions: **25-50%** (Karlsson & Rosenhall, 1995; Musiek et al., 2011)	Cerebral Lesions: **91%** (Musiek et al., 2011)
Compressed Speech	Brainstem: **62-64%** Auditory Cortex & Temporal Lobe Lesions: **80%** (Karlsson & Rosenhall, 1995)	Limited Data

Site of Involvement

Clues Based on Behavioral Test Performance

Brainstem		Cortex	
Cochlear nuclei and/or mid to lower pons	**Upper pons and more rostral areas**	**Without corpus callosum involvement**	**With corpus callosum involvement**
Performance deficit generally will be ipsilateral to the site or bilateral	Performance deficit in the ear contralateral to the lesion	Contralateral effect on behavioral tests	Dichotic listening tests generally reveal deficit (or greater deficit) in ear ipsilateral to cortical hemisphere dominant for linguistic coding

(Jerger & Jerger, 1974; Musiek & Chermak, 2014; Musiek, Kibbe, & Baran, 1984)

cont

Contributions to Differential Information					
Test	Cochlear	Eighth Nerve	Brain Stem	Cortex	Corpus Callosum
Pure Tones	■	■	□	□[1]	□
Standard Speech Recognition in Quiet	▭	▭	□	□	□
Otoacoustic Emissions	▭	□	□	□	□
Acoustic Reflex	▭	■	▭	□	□
Dichotics		▭	▭	■	■
Masking Level Difference		▭	■	□	□
Localization & Lateralization	■	■	■	■	
Frequency & Duration Patterns			□	■	■
Gap Detection			■	■	
Low Redundancy Speech[2]			▭	▭	□
ABR	▭	■	■	□	□
MLR	▭		■	■	□
P1, P2, P3	▭	▭		■	□

The authors' view of the value of selected audiologic tests for lesions at various levels of the auditory system.

LEGEND

Relative Contribution to Differential Diagnosis:

□ Minimal ▭ Moderate ■ Considerable

1 In cases of Central Deafness, pure tones may be grossly abnormal

2 Speech recognition in noise, filtered speech and compressed speech

(Musiek, Chermak, Bamiou, & Shinn, 2018)

Differential Diagnosis

Musiek & Chermak (2014)

"As there is considerable overlap in the behavioral manifestations of several other cognitive and learning disorders, it is important that the audiologist carefully observe the individual's performance throughout the test battery. Inconsistent behaviors or responding patterns are likely to signal a non-auditory problem rather than (or in addition to) a CAPD."

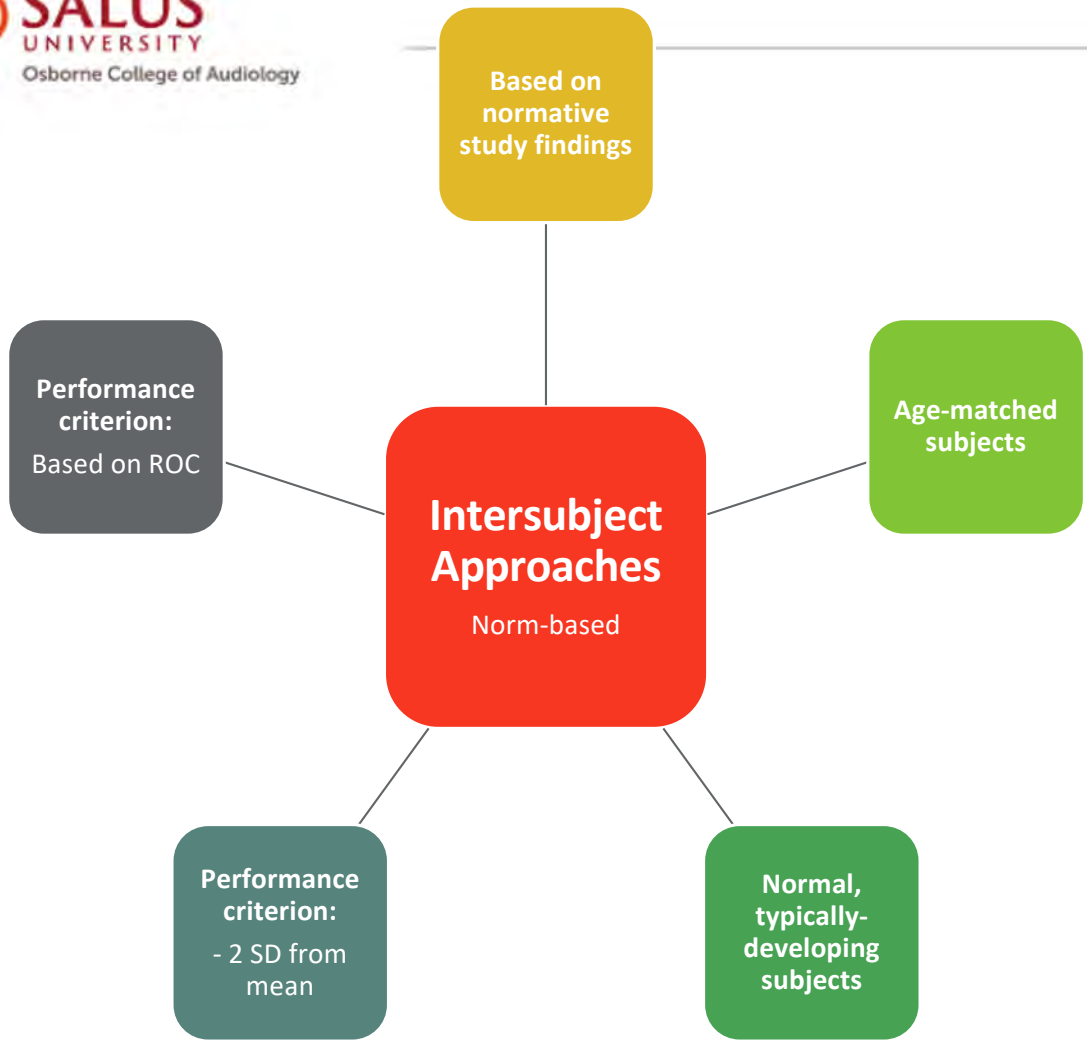
Differential Diagnosis

Musiek & Chermak (2014)

"Likewise, pervasive deficits noted on all tests within a central test battery may well signal a cognitive or supramodal deficit, such as an attention or memory deficit, or some other non-auditory influence on test performance, such as motivation, fatigue, boredom with the testing process, and so forth, rather than a CAPD."

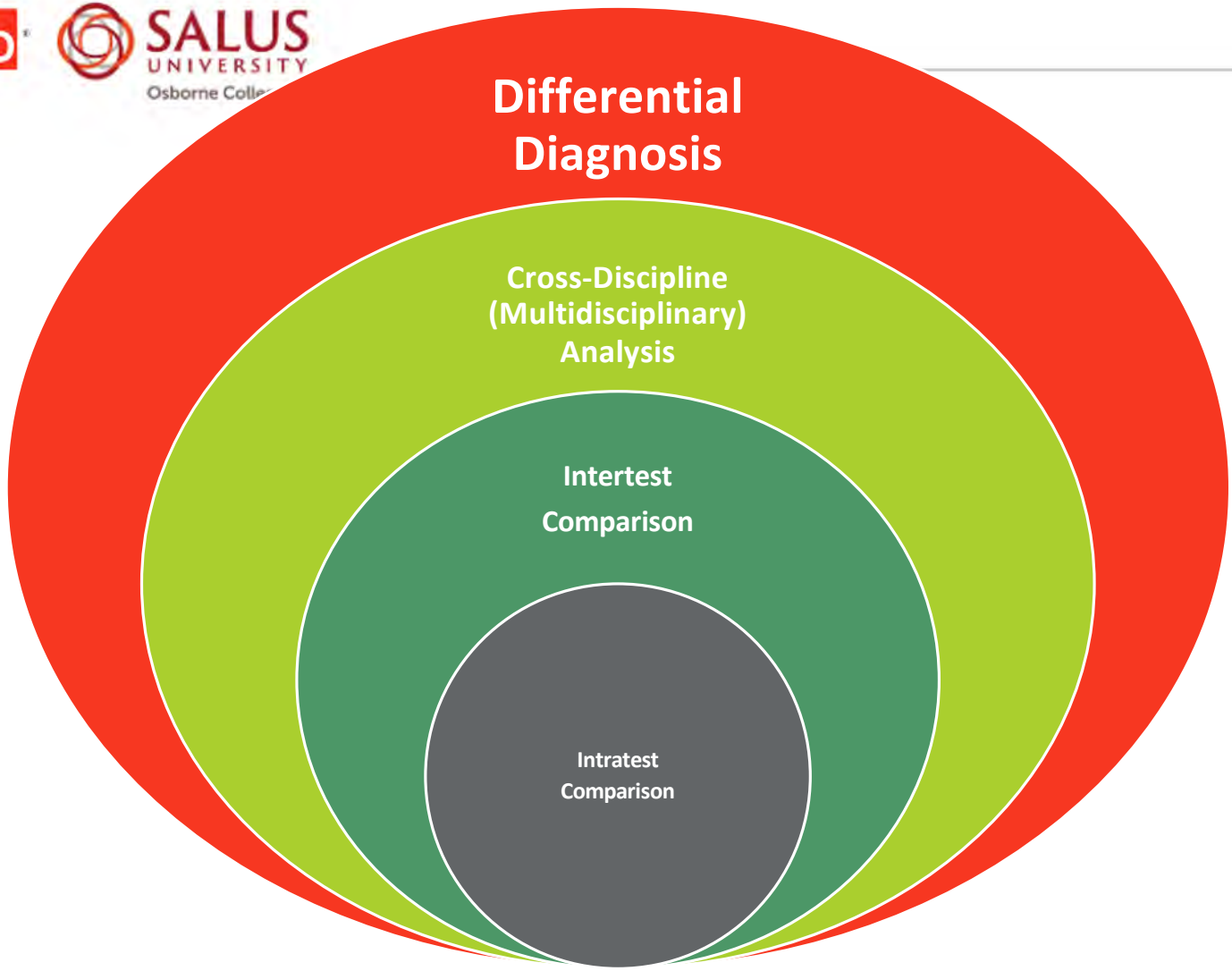
Intersubject Analysis

Between-Subject Comparisons


Based on normative study findings
Performance criterion:
Based on ROC
Age-matched subjects
Intersubject Approaches
Norm-based
Performance criterion:
- 2 SD from mean
Normal, typically-developing subjects

Intrasubject ANalysis

Within-Subject Comparisons

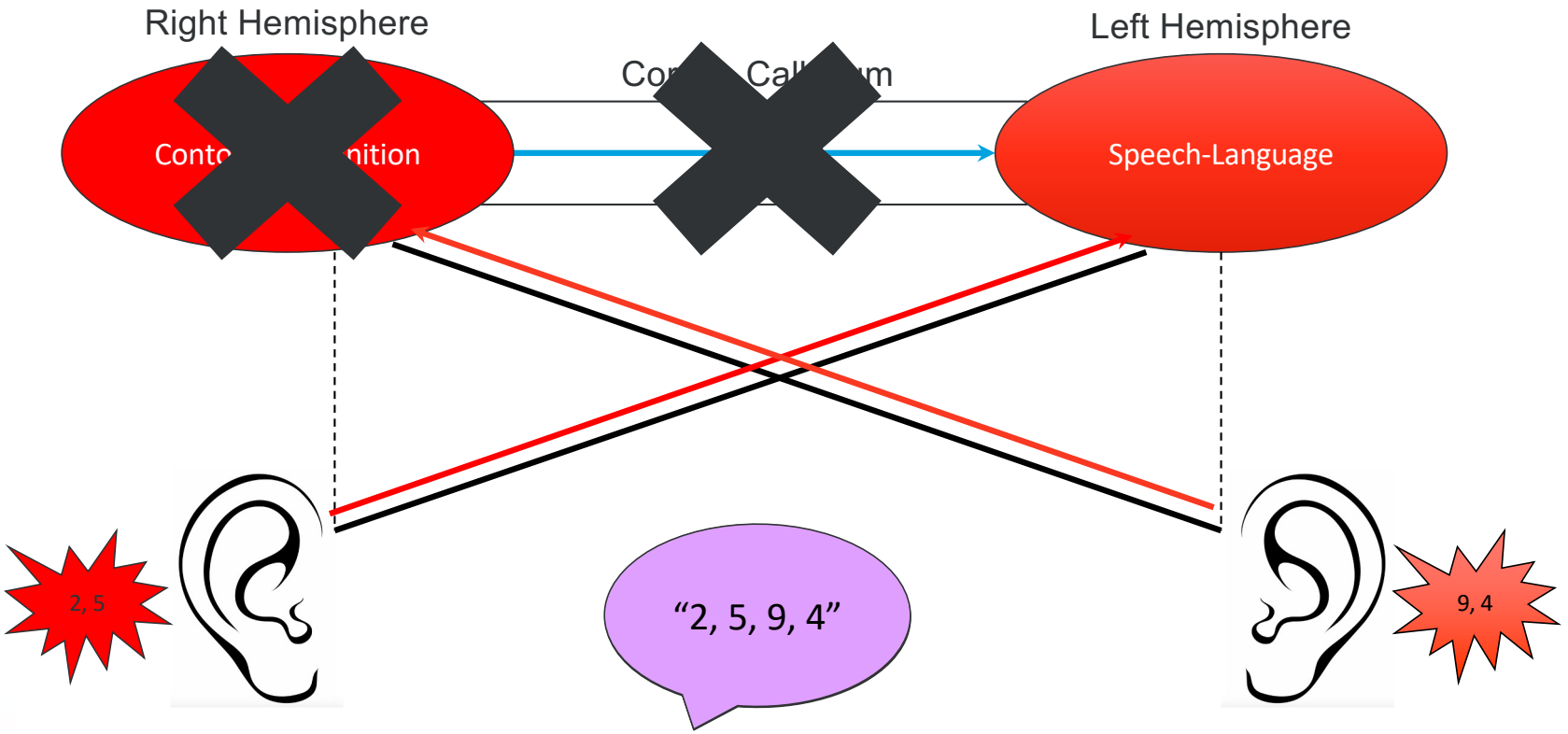

Differential Diagnosis
Cross-Discipline (Multidisciplinary) Analysis
Intertest Comparison
Intratest Comparison

Intertest Interpretation

Questions to Answer

- Is there a consistent pattern between test results?
- What tests are more diagnostically sound?
- Does the pattern of results suggest influences from non-auditory factors?
- Can I trust these results?
- What is the diagnostic criteria for CAPD?
- Can I make a formal CAPD diagnosis?

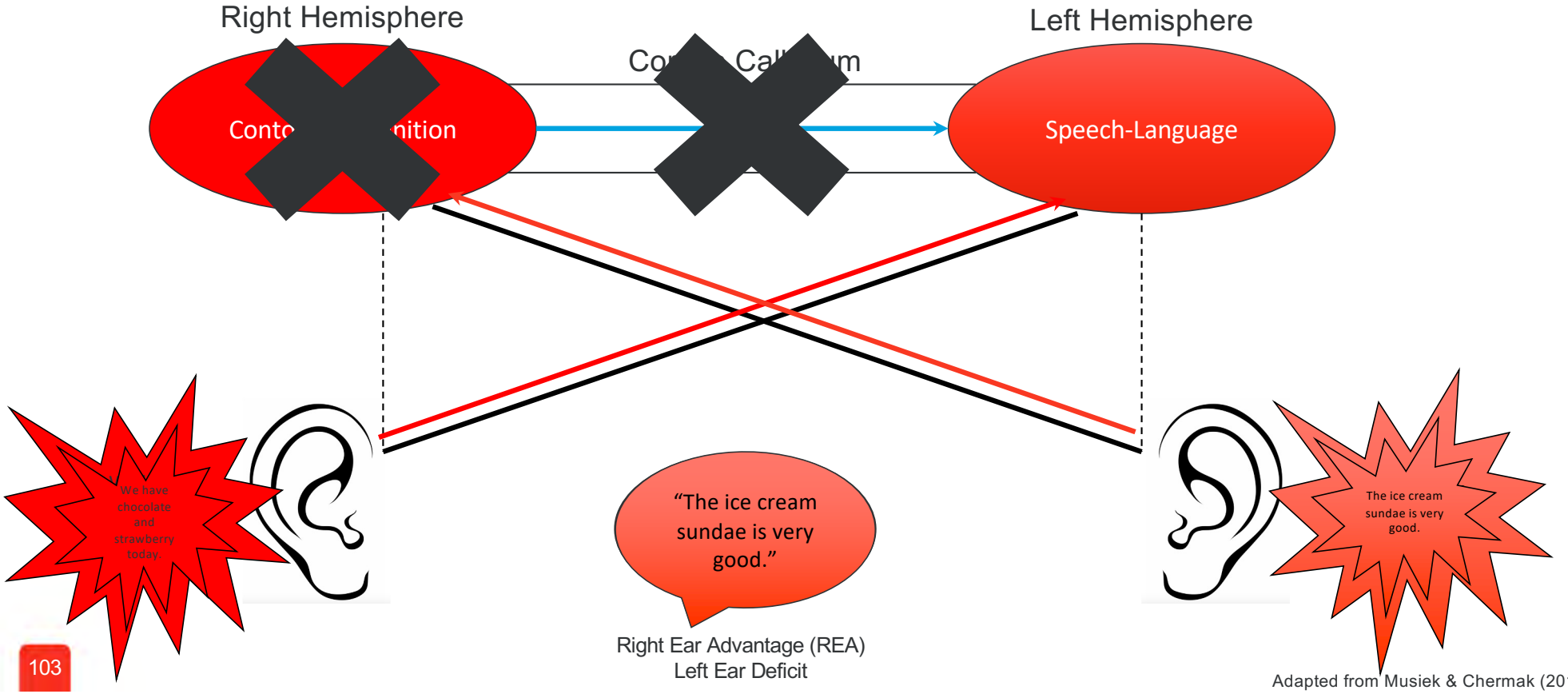
Binaural Integration Dichotic Digits Test



Right Ear Advantage (REA)
Left Ear Deficit

Adapted from Musiek & Chermak (2014)

Binaural Separation Competing Sentences Test

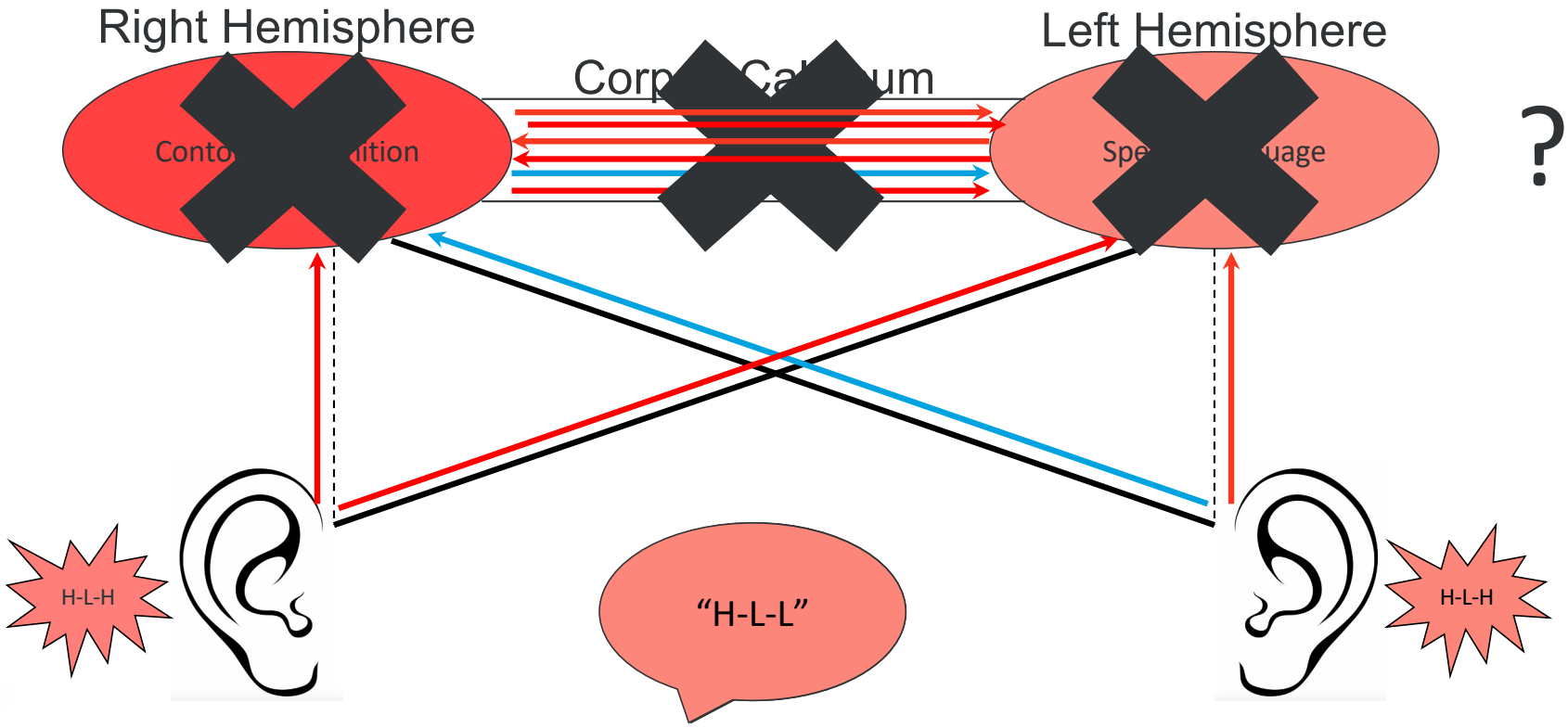


Right Ear Advantage (REA)
Left Ear Deficit

Adapted from Musiek & Chermak (2014)

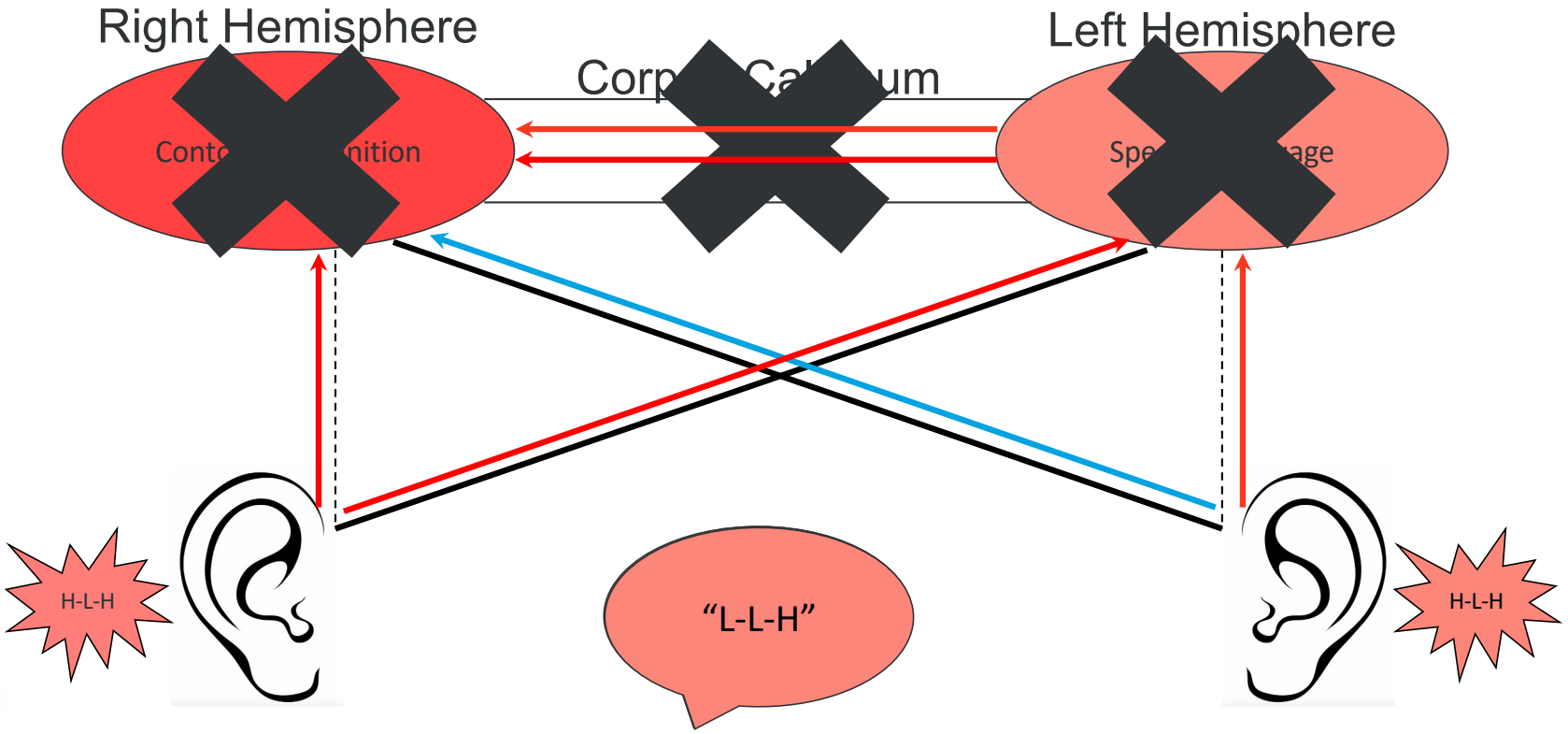
Temporal Ordering/Sequencing

Labeling Response Task



Adapted from Musiek & Chermak (2014)

Temporal Patterning/Sequencing Humming Response Task



Adapted from Musiek & Chermak (2014)

Test Interpretation

Dichotic Listening vs. Temporal Ordering/Sequencing

Right Hemisphere Damage		
Test	Right Ear	Left Ear
DDT	WNL	ABN
CS	WNL	ABN
FPT/DPT (Labeled)	ABN	ABN
FPT/DPT (Hummed)	ABN	ABN

Corpus Callosum Damage		
Test	Right Ear	Left Ear
DDT	WNL	ABN
CS	WNL	ABN
FPT/DPT (Labeled)	ABN	ABN
FPT/DPT (Hummed)	WNL	WNL

Left Hemisphere Damage		
Test	Right Ear	Left Ear
DDT	ABN	ABN
CS	ABN	ABN
FPT/DPT (Labeled)	ABN	ABN
FPT/DPT (Hummed)	WNL	WNL

Patient-Centered Interpretation

Binaural Interaction

- Difficulty telling where sound is coming from
- Difficulty detecting sound in spatial environments
- Patient feels “bombarded” by noise due to reduced binaural squelch
- Lower than expected benefit from binaural amplification due to binaural interference
- Patient may have challenges acclimatizing to hearing aids for managing binaural peripheral hearing loss

Binaural Integration

- Difficulty hearing and understanding multiple verbal messages at once (e.g., in classroom, during meetings/lectures, etc.)
- Patient may express that they favor one ear over the other despite having symmetrical hearing sensitivity
- Patient may report “muffled” hearing in one ear compared to the other ear despite having symmetrical hearing sensitivity

Binaural Separation

- Difficulty directing/focusing attention to one ear and suppressing/inhibiting extraneous messages/sound/noise in the other ear
- Patient may only be able to use one ear on the phone or have difficulty using the phone monaurally in noisy environments
- Patient may express that they favor one ear over the other despite having symmetrical hearing sensitivity
- Patient may report “muffled” hearing in one ear compared to the other ear despite having symmetrical hearing sensitivity

Patient-Centered Interpretation

Temporal Resolution

- Patient reports that people talk too fast
- Speech in the patient's native language sounds like a different language, "jumbled," or "like Charlie Brown's teacher"
- Misunderstandings and increased requests for repetition
- Difficulty hearing breaks between words/phrases/sentences
- Difficulty following the rhythm of speech and music
- Difficulty learning a foreign language
- Taking longer to process speech; delayed responses, taking longer to answer questions

Temporal Ordering/Sequencing

- Difficulties may vary depending on site of involvement
- Right hemisphere: Challenges hearing the difference between 2+ sounds that are similar but different; difficulty "reading between the lines" for interpretation of sarcasm or jokes; lack of interest/enjoyment of music; challenges learning how to play an instrument; "flat" or monotone speech; difficulty perceiving emotion conveyed by voice/rhythm/intonation, suprasegmentals of speech
- Left hemisphere, interhemispheric transfer: Transposition or reversals of phonemes in words; misinterpretations of questions vs. statements; replacement of one phoneme for another that is similar in formant structure

Auditory Spatial Processing

- Difficulty understanding speech in environments with different sound source locations and noise qualities
- Unease in large, complex spatial sound environments
- Spatial disorientation, agitation, and even dizziness in spatial sound environments – does patient have history of head injury?

Auditory Closure

- Difficulty learning new topics/lessons/skills in a classroom, meeting, or large group setting without accommodations
- May also occur in patients with peripheral hearing loss and/or higher-order cognitive and/or language disorder

References:

Thank you!

Email: gonzalez.jennifer@mayo.edu