Single-sided deafness (SSD): application of CROS, bone anchored implants, and cochlear implants

René Gifford, Ph.D., CCC-A

June 23, 2020

Department of Hearing and Speech Science
Vanderbilt University Medical Center

1

Learner Outcomes

After this course learners will be able to…

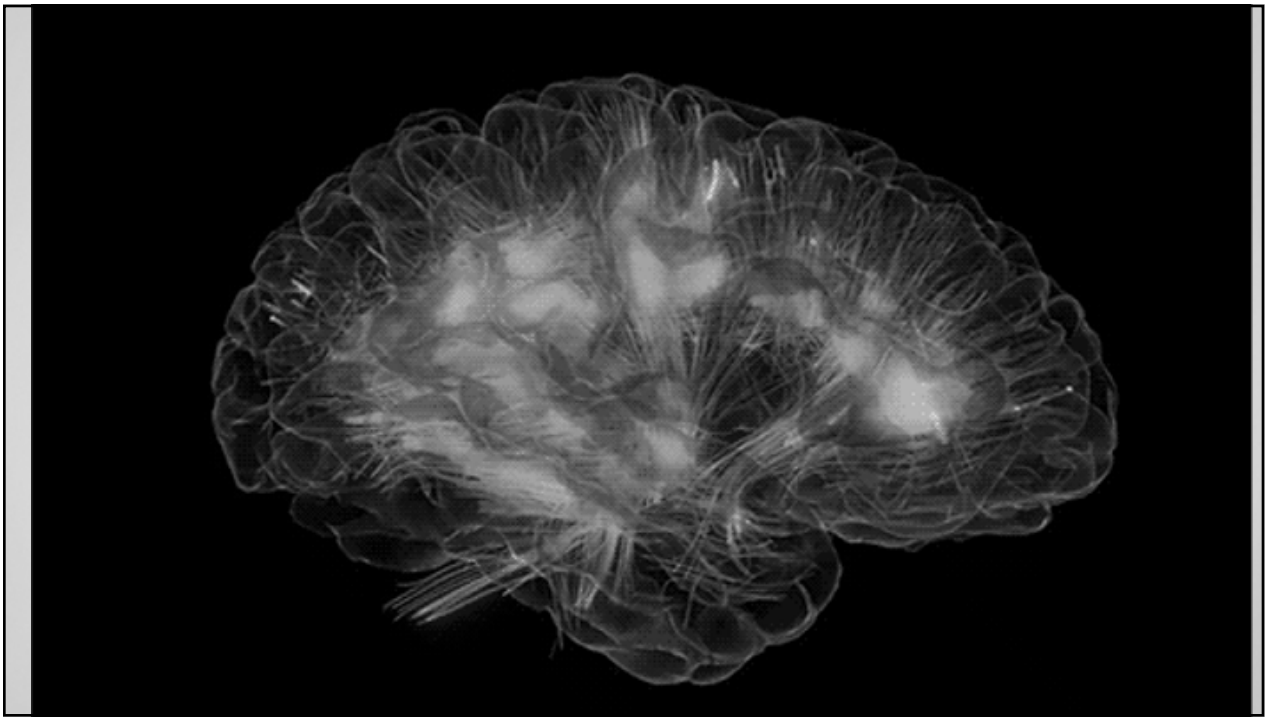
- Describe underlying hearing mechanisms driving spatial hearing abilities for individuals with single-sided deafness (SSD) using bone anchored implants and cochlear implants.
- Describe and contrast benefits of bone anchored implants and cochlear implants for the treatment of SSD.
- Describe results of preliminary studies demonstrating improvement in listening effort and reaction time for adults with SSD using bone anchored implants.

2

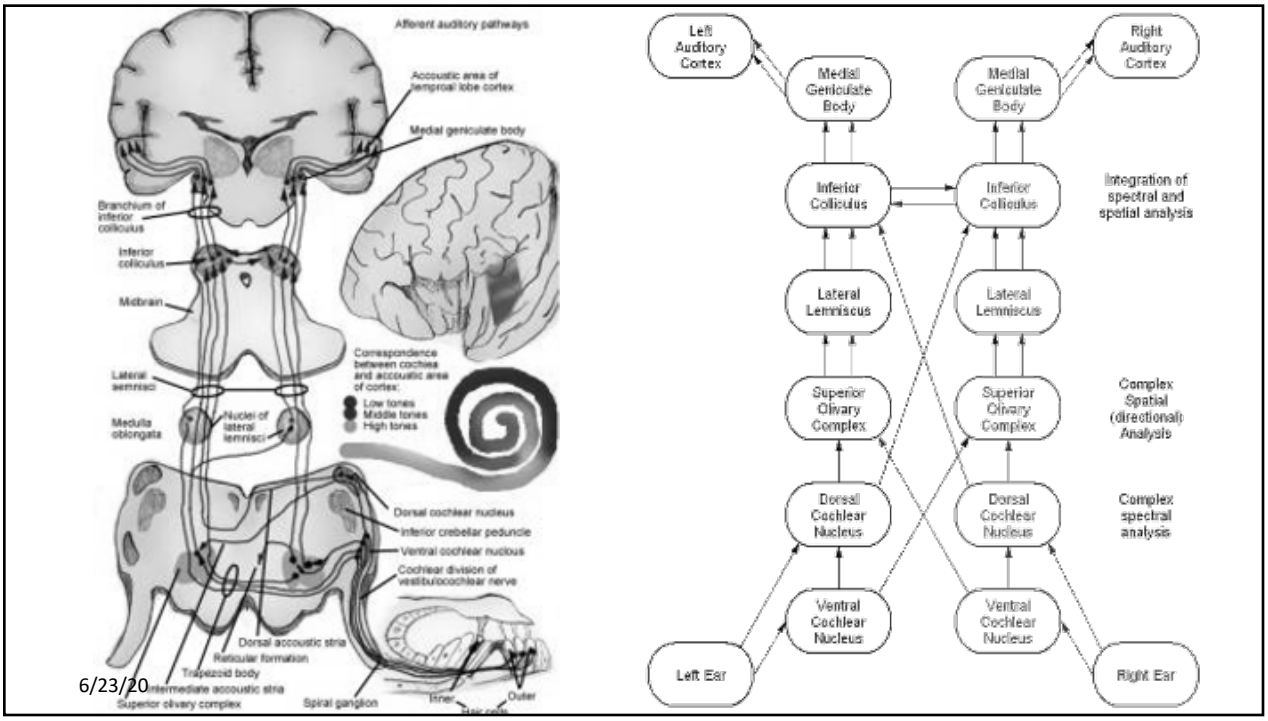
3

4

hip with



5


Afferent auditory pathways
Acoustic area of temporal lobe cortex
Medial geniculate body
Branchium of inferior colliculus
Inferior colliculus
Midbrain
Lateral lemnisci
Medulla oblongata
Nuclei of lateral lemnisci
Correspondence between cochlea and acoustic area of cortex:
Low tones
Middle tones
High tones
Dorsal cochlear nucleus
Inferior cerebellar peduncle
Ventral cochlear nucleus
Cochlear division of vestibulocochlear nerve
Dorsal acoustic stria
Reticular formation
Trapezoid body
Intermediate acoustic stria
Superior olivary complex
Spiral ganglion
Inner
Outer
Left Auditory Cortex
Right Auditory Cortex
Medial Geniculate Body
Medial Geniculate Body
Inferior Colliculus
Inferior Colliculus
Integration of spectral and spatial analysis
Lateral Lemniscus
Lateral Lemniscus
Superior Olivary Complex
Superior Olivary Complex
Complex Spatial (directional) Analysis
Dorsal Cochlear Nucleus
Dorsal Cochlear Nucleus
Complex spectral analysis
Ventral Cochlear Nucleus
Ventral Cochlear Nucleus
Left Ear
Right Ear

6

hip with

Causes of SSD

- Sudden SNHL (idiopathic)
- Autoimmune
- Temporal bone fracture
- Meniere's Disease
- Labyrinthitis
- Meningitis
- Cytomegalovirus (CMV)
- Enlarged Vestibular Aqueduct (EVA)

7

8

Intervention options for SSD

- Remote microphone system
- Contralateral routing of signal (CROS)
- Bone anchored implant (BAI)
- Cochlear implant
- "Do nothing"

6/23/20

9

Intervention options for SSD

- Remote microphone system
- Contralateral routing of signal (CROS)
- **Bone anchored implant (BAI)**
- **Cochlear implant**
- "Do nothing"

6/23/20

10

Binaural hearing: ITD & ILD cues

- Speech understanding in quiet and noise
  - Summation
  - Head shadow
    - Do not need 2 ears to benefit from head shadow
  - Squelch (or binaural unmasking of speech)
  - Spatial release from masking
- Spatial hearing
  - localization—static source
  - auditory motion perception—dynamic source
- Listening effort, sound quality

"Do nothing"

Untreated SSD:

- Poorer speech understanding in noise
- Poor spatial hearing abilities
- Increased listening effort
- Fatigue
- Stress
- Academic risk

Bess et al., 1998; Tharpe, 2008; Lieu et al., 2010, 2012; Lieu, 2013

Why consider a CI for a patient with SSD?

- Potential for binaural hearing
  - Better speech understanding in quiet and noise
    - Summation, head shadow, spatial release from masking
  - Spatial hearing
    - localization—static source
    - auditory motion perception—dynamic source
  - Less listening effort
  - Quality of life
- Tinnitus suppression

Offeciers et al. (2005). Acta Otolaryngol, 125, 918-919

Lit review:
CI vs. CROS vs. BAI for SSD

CI for adults with SSD

Arndt et al. (2011). Otol Neurotol, 32:39-47.

- 11 adults with SSD
  - Mean duration of deafness: 25 months
    - range: 4 to 110 months
- All had tried CROS or BAI unsuccessfully
  - BAI on softband
- localization & speech recognition in noise for unaided, CROS, BAI, and CI

CI for adults with SSD

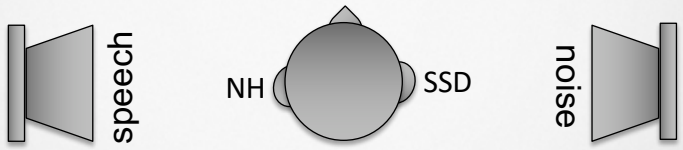
Arndt et al. (2011). Otol Neurotol, 32:39-47.

- 11 adults with SSD
  - Mean duration of deafness: 25 months
    - range: 4 to 110 months
- All had tried CROS or BAI unsuccessfully
  - BAI on headband
- localization & **speech recognition in noise** for unaided, CROS, BAI, and CI

VANDERBILT UNIVERSITY
6/23/20 CENTER

CI for adults with SSD

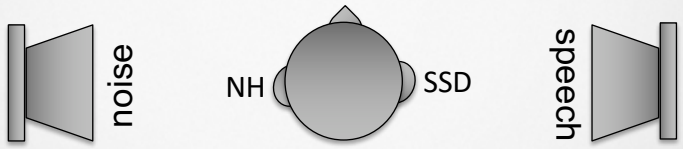
Arndt et al. (2011). Otol Neurotol, 32:39-47.



17

CI for adults with SSD

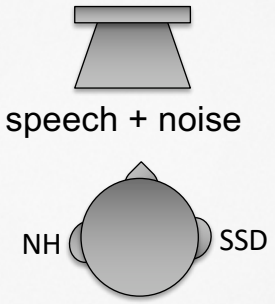
Arndt et al. (2011). Otol Neurotol, 32:39-47.



18

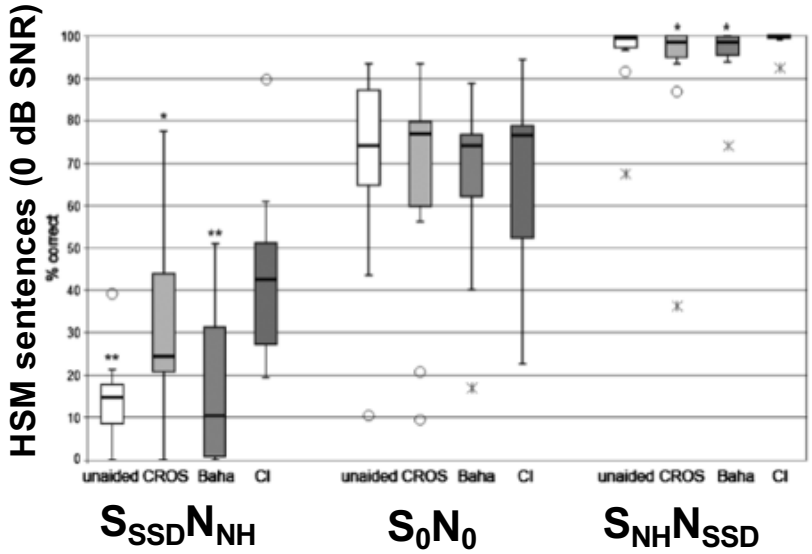
CI for adults with SSD

Arndt et al. (2011). Otol Neurotol, 32:39-47.



19

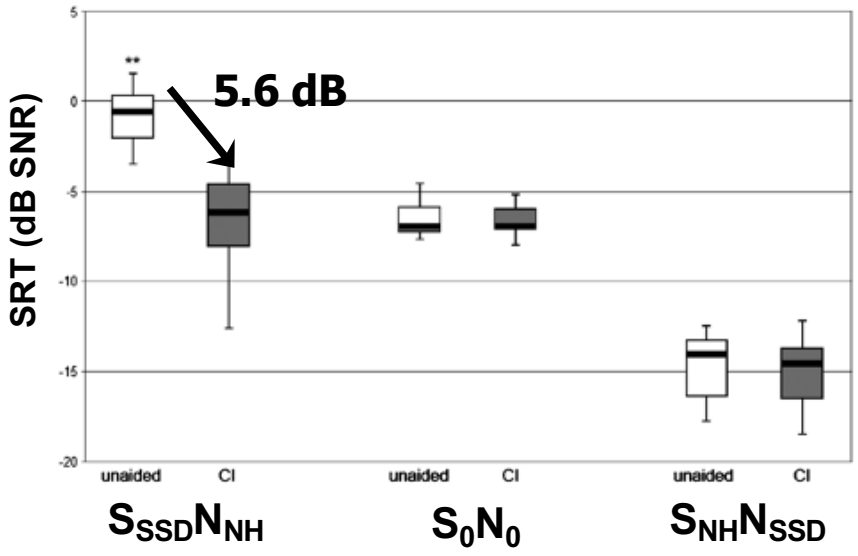
Arndt et al. (2011). Otol Neurotol, 32:39-47.



- *CI → equal or better speech rec* ($S_{SSD}N_{NH}$)
- No negative impact of CI on speech rec
- CROS & BAI were same as unaided for all conditions (except $S_{SSD}N_{NH}$ where CROS > unaided)

20

Arndt et al. (2011). Otol Neurotol, 32:39-47.



21

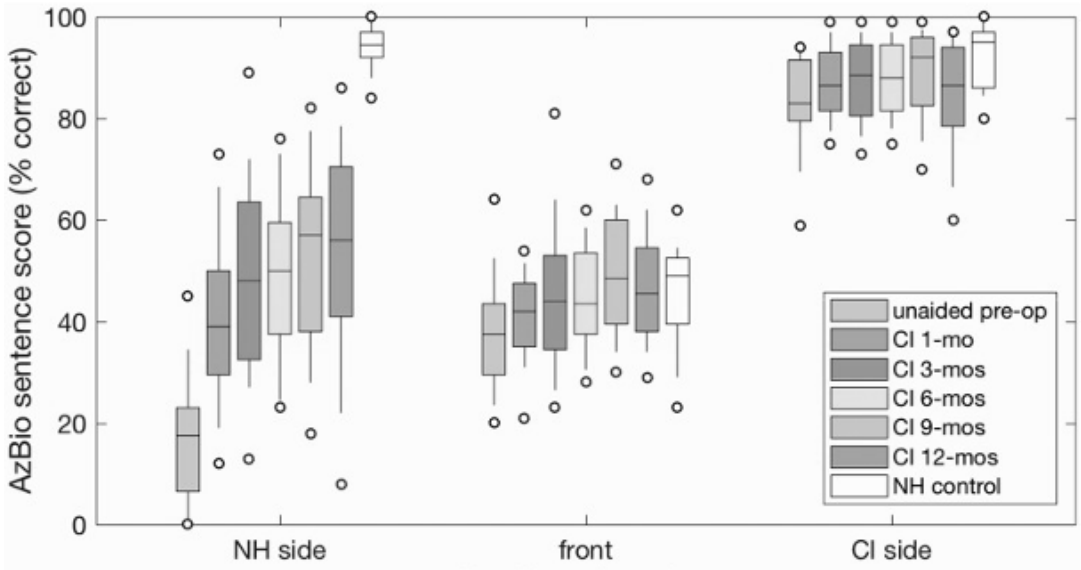
CI for adults with SSD

Buss et al. (2018). Trends Hear, 22: 1–15

- 20 adults with SSD (or near SSD)
- 23-74 yrs
- Duration of deafness:
  - 0.6-6.6 yrs
- Tested with BAI prior to CI
  - 2 had tried BAI, others tested acutely

22

Buss et al. (2018). Trends Hear, 22: 1–15



6/23/20

S_0N_{NH} S_0N_0 S_0N_{SSD}

23

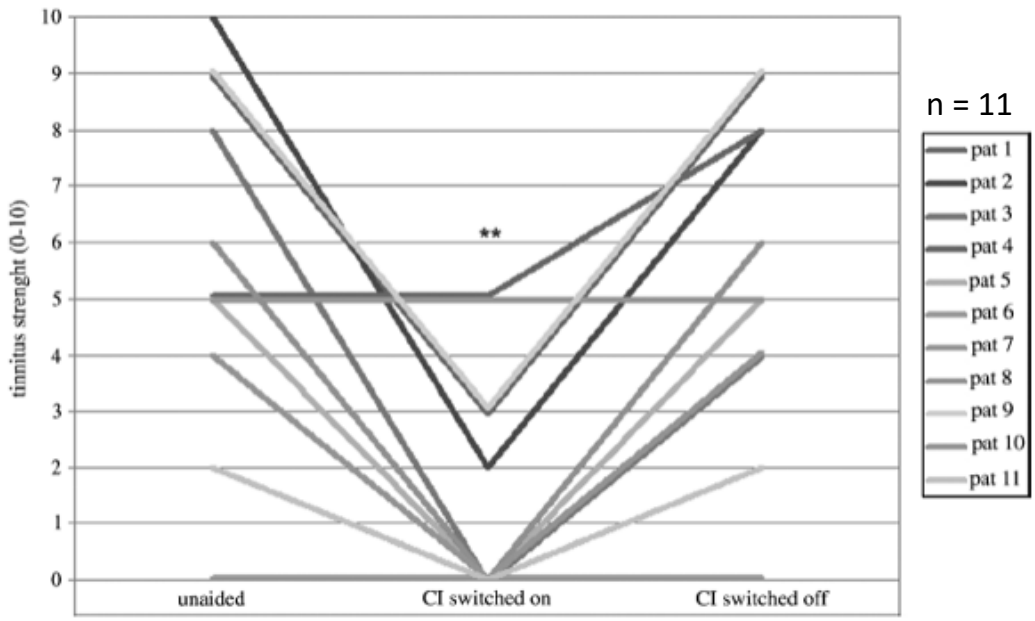
Tinnitus

- Tinnitus affects 10-15% of adult population
- Many forms of tinnitus are thought to be caused by auditory deprivation
- Different theories on why CIs improve tinnitus:
  - Deafferentation → reduction in inhibition from thalamocortical feedback loops → increase in synaptic gain in central auditory neurons → increase in spontaneous firing interpreted as sound
    - Chambers et al. (2016). Neuron, 89, 1-13.
    - Kaltenbach & Afman (2000). Hear Res, 140: 165-172.
  - Effects of deafferentation can be reversed by cochlear implantation, which leads to a reduction in tinnitus
    - Electrical stimulation helps *regulate neural activity*

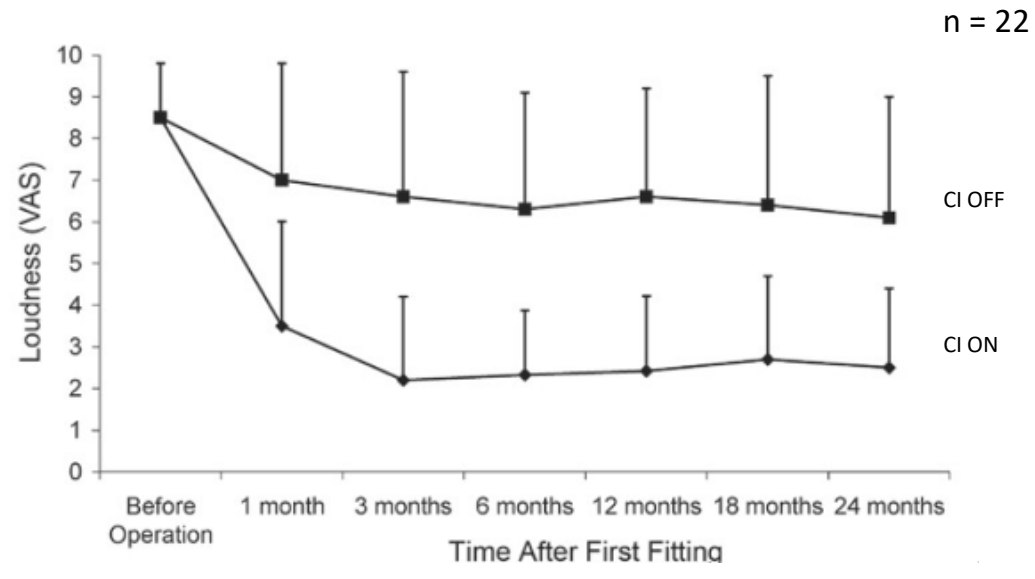
VANDERBILT UNIVERSITY CENTER

6/23/20

24

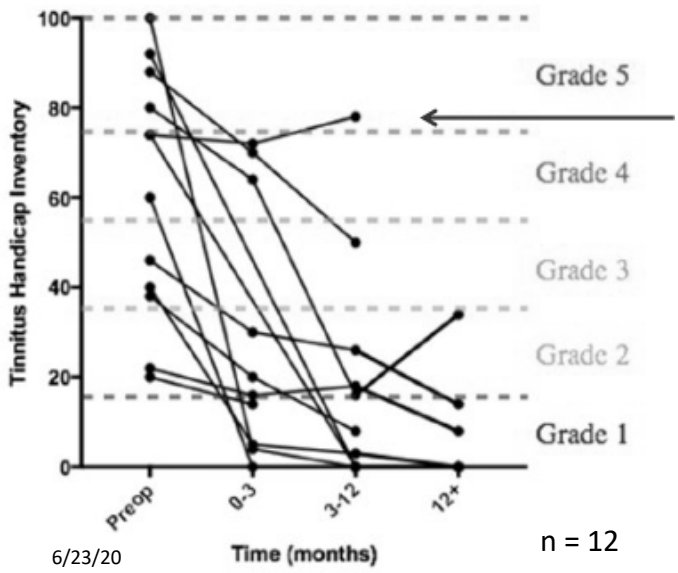


Arndt et al. (2011). Otol Neurotol, 32:39-47



Van de Heyning et al. (2008). Ann Otol Rhinol Laryngol. 117:645-52.

Holder et al. (2017). Am J Otolaryngol, 38: 226-229.

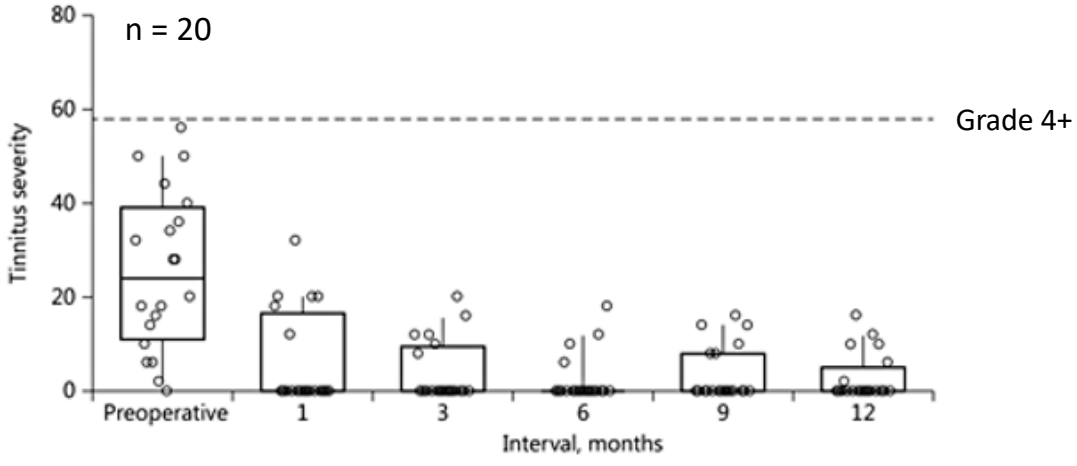


n = 12

THI grades

1) <u>Slight</u>: heard in quiet, easily masked. No interference.
2) <u>Mild</u>: easily masked, easily forgotten May occasionally interfere
3) <u>Moderate</u>: noticed, even in noise, daily activities may still be performed.
4) <u>Severe</u>: almost always heard, rarely masked, disturbed sleep, interferes with daily activities
5) <u>Catastrophic</u>: always heard, disturbed sleep patterns, difficulty with any activity.

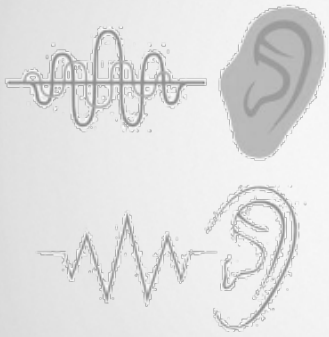
27



Dillon et al. (2017). Audiol Neurotol, 22:259-271.

28

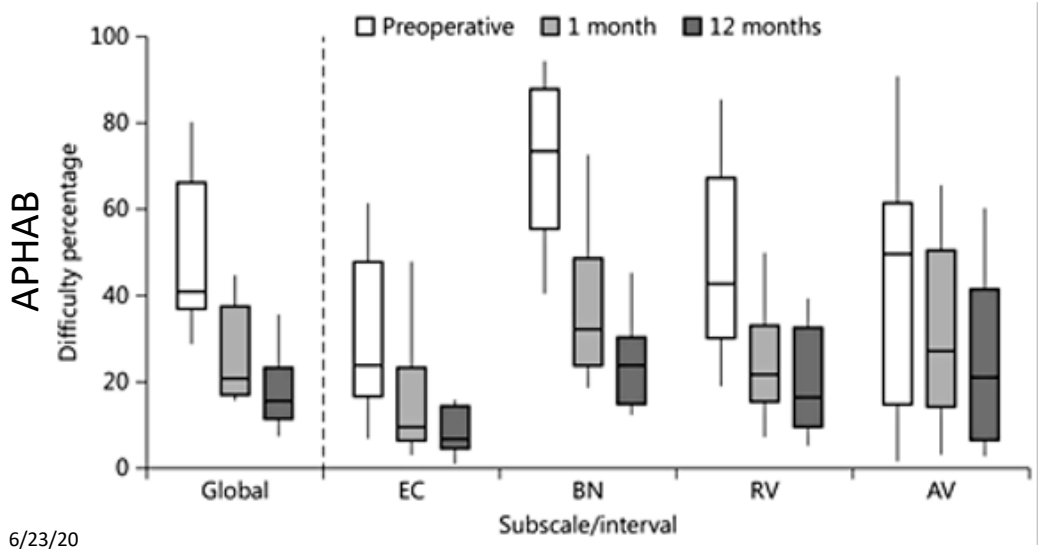
Quality of Life



VANDERBILT UNIVERSITY
6/23/20 CENTER

29

Dillon et al. (2017). Audiol Neurotol, 22:259-271.

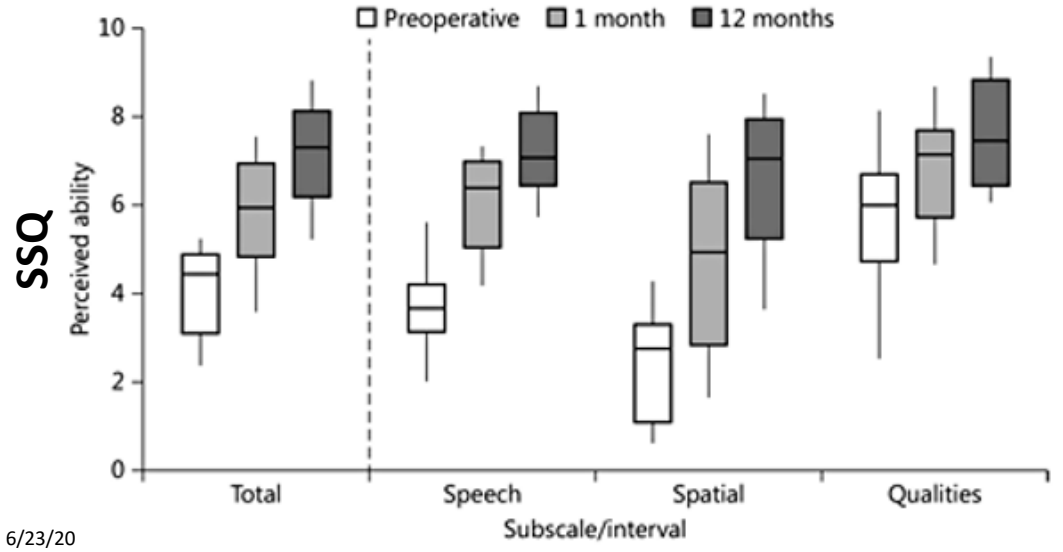


n = 20

6/23/20

30

Dillon et al. (2017). Audiol Neurotol, 22:259-271.

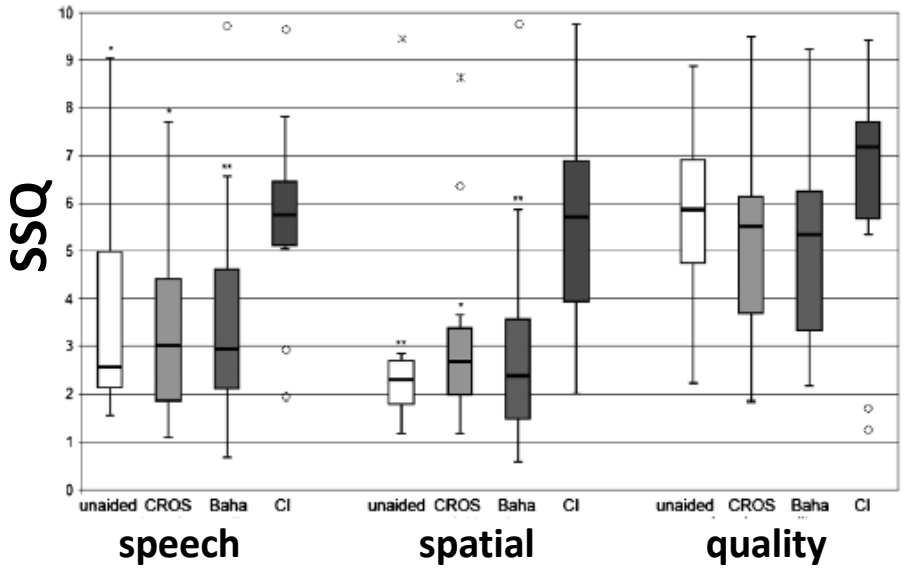


n = 20

6/23/20

31

Arndt et al. (2011). Otol Neurotol, 32:39-47.



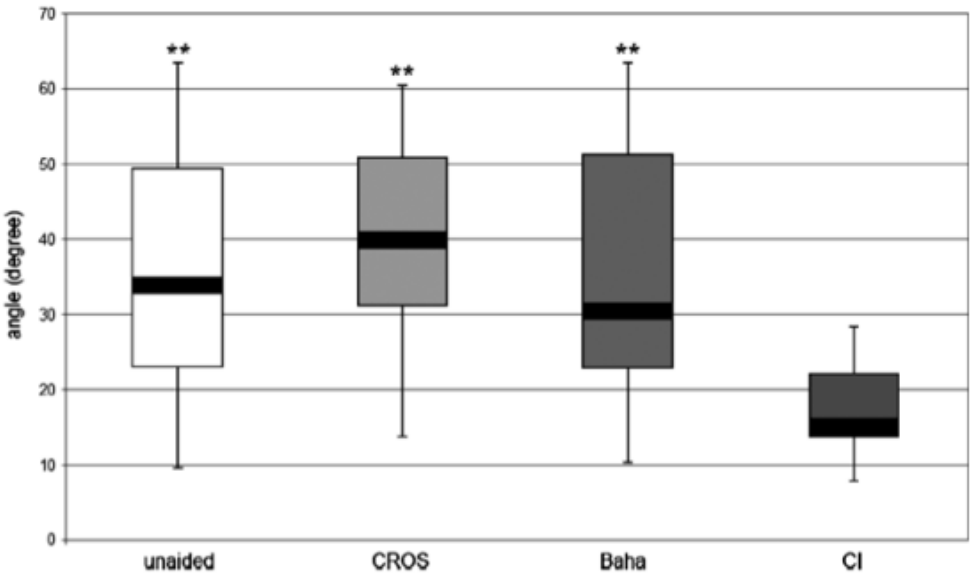
6/23/20

32

Localization

VANDERBILT UNIVERSITY
6/23/20 CENTER

33



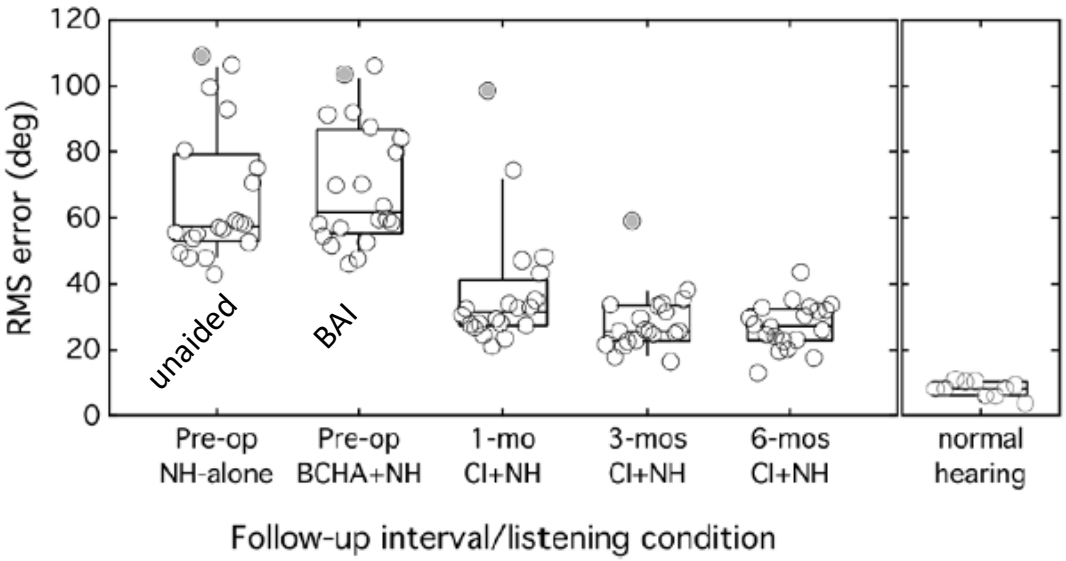
n = 11

Arndt et al. (2011). Otol Neurotol, 32:39-47

6/23/20

34

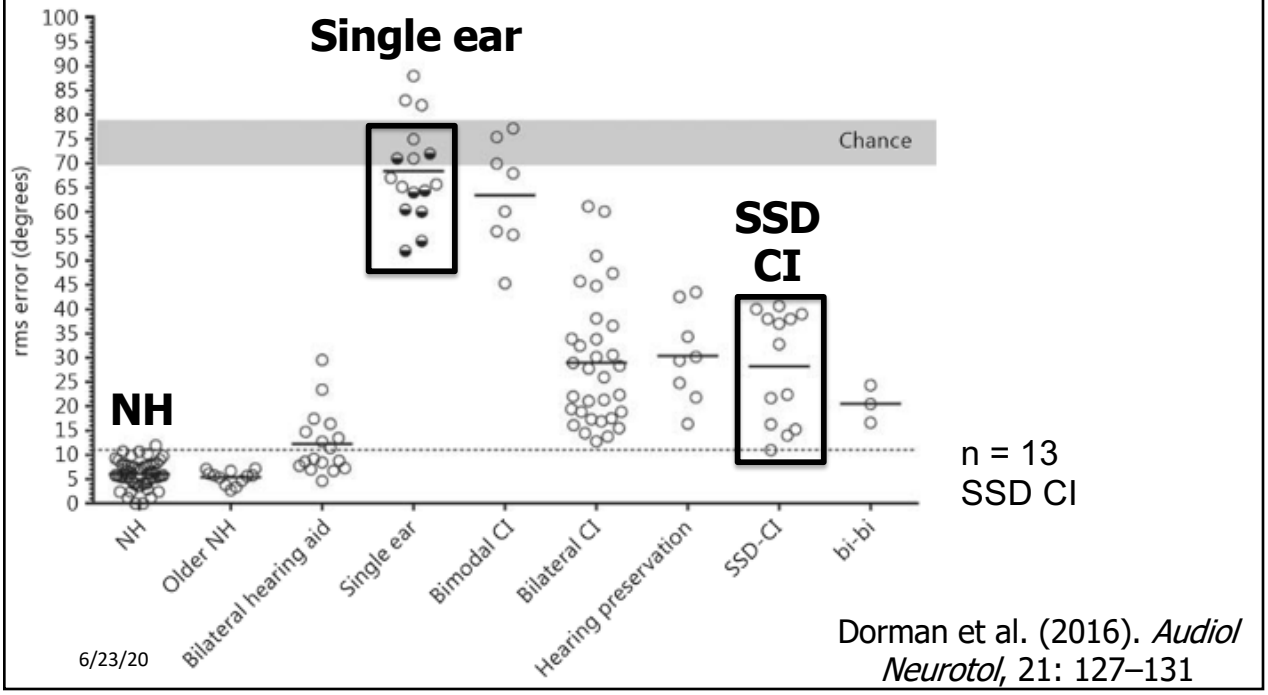
hip with



n = 20

Dillon et al. (2017). Ear Hear, 38:611–620.

35



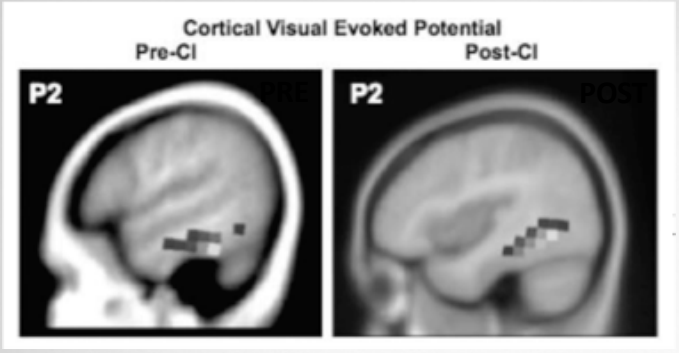
n = 13
SSD CI

Dorman et al. (2016). *Audiol Neurotol*, 21: 127–131

36

Sharma et al. (2016). Otol Neurotol, 37:e26–e34

- Case study
- Progressive hearing loss in right ear beginning at 5 years of age
  - Unknown etiology
  - Little benefit from CROS and FM systems
- Ultimately pursued BAI—insurance denial
- At 9.9 years of age → RIGHT CI



Sharma et al. (2016). Otol Neurotol, 37:e26–e34

Visual stimulation

39

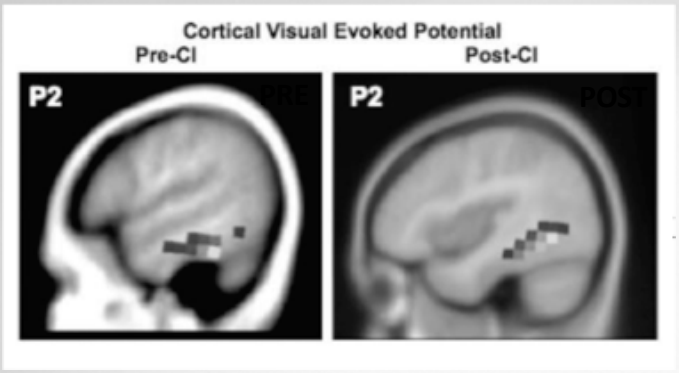
40

hip with

41

42

hip with

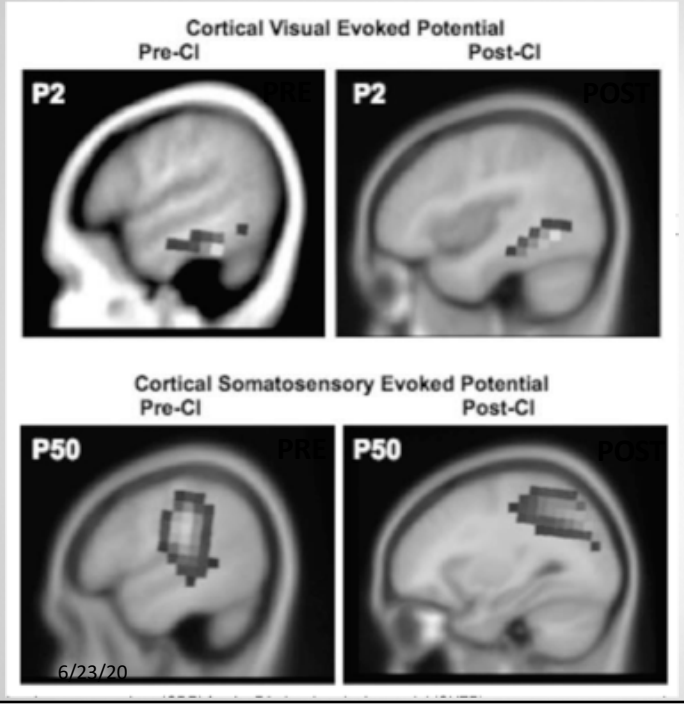


Sharma et al. (2016). Otol Neurotol, 37:e26–e34

Visual stimulation

Post CI: Visual activation is retreating away from auditory cortex

43



Sharma et al. (2016). Otol Neurotol, 37:e26–e34

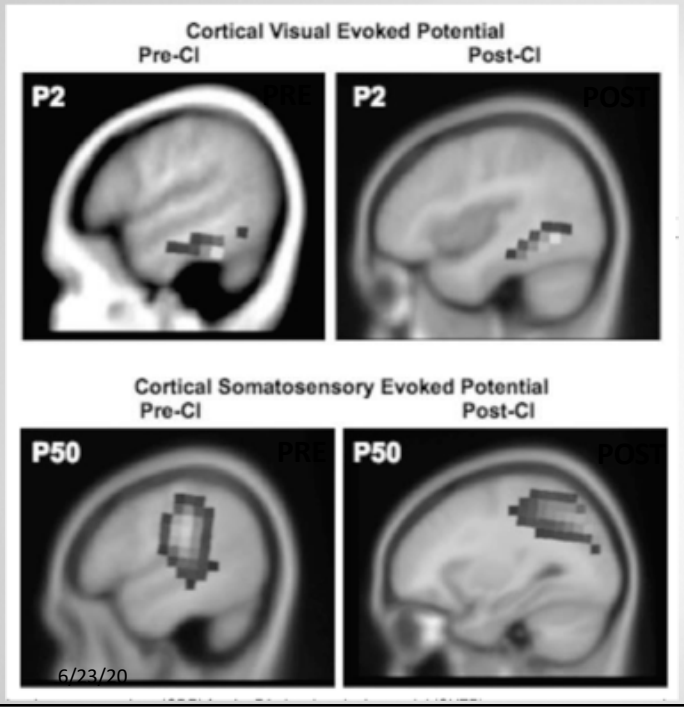
Visual stimulation

Post CI: Visual activation is retreating away from auditory cortex

Somatosensory stimulation

Post CI: Somatosensory stimulation is retreating away from auditory cortex

44



Sharma et al. (2016). Otol Neurotol, 37:e26–e34

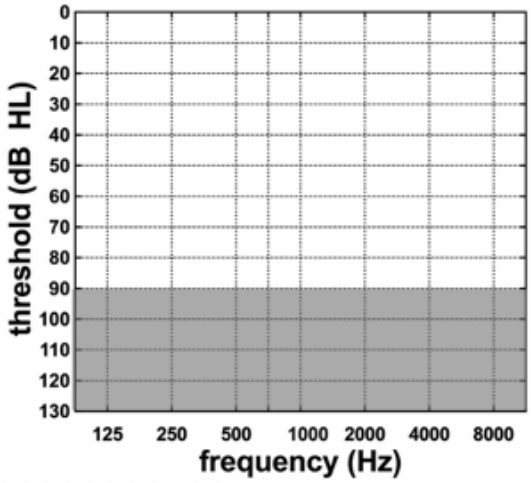
Evidence of neural plasticity following CI for SSD.

Limitations: SSD CI literature

- BAI on headband
- Recruitment bias
- Experimental bias
  - Laboratory conditions (noise to NH_{ear})
- Not all "true SSD"
- Short durations of deafness
  - …the very best CI candidates

Limited literature on success with congenital losses.

Labeled indications for SSD CI in U.S.



5+ years of age

≤ 5% CNC in poor ear

Not currently covered by CMS

47

CI is not appropriate for everyone

- Long durations of deafness
- Motivation
- Nerve resection
- Health concerns (surgery, general anesthesia)
- Insurance restrictions

48

BAI: viable option for SSD

- significant improvement:
  - speech in noise
    - Speech to poor ear ($S_{SSD}N_{NH}$)
    - Speech to front (S_0N_0 & S_0N_{NH})
  - listening effort & quality of life

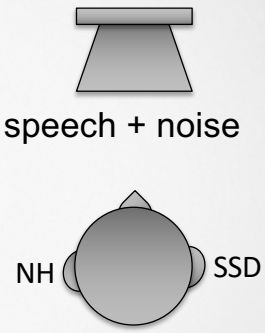
6/23/20

49

BAI for adults with SSD

René Gifford, PhD & Devin McCaslin, PhD

- Previous studies



VANDERBILT UNIVERSITY MEDICAL CENTER

MAYO CLINIC

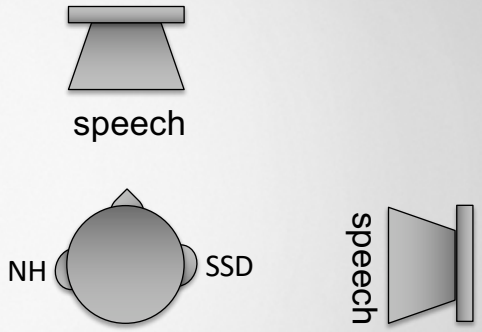
6/23/20

50

BAI for adults with SSD

René Gifford, PhD & Devin McCaslin, PhD

- Previous studies



VANDERBILT UNIVERSITY
6/23/20 CENTER

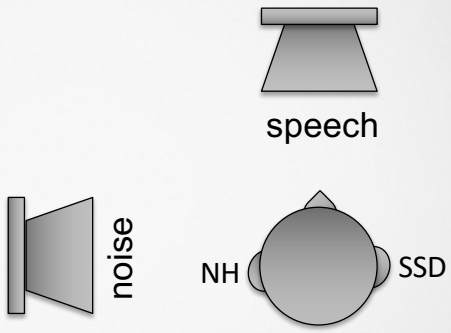
MAYO CLINIC

51

BAI for adults with SSD

René Gifford, PhD & Devin McCaslin, PhD

- Previous studies



VANDERBILT UNIVERSITY
6/23/20 CENTER

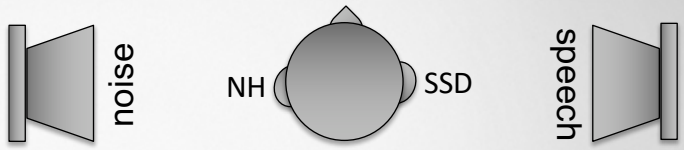
MAYO CLINIC

52

BAI for adults with SSD

René Gifford, PhD & Devin McCaslin, PhD

- Previous studies



VANDERBILT UNIVERSITY
6/23/20 CENTER

MAYO CLINIC

53

6/23/20

54

55

BAI for adults with SSD

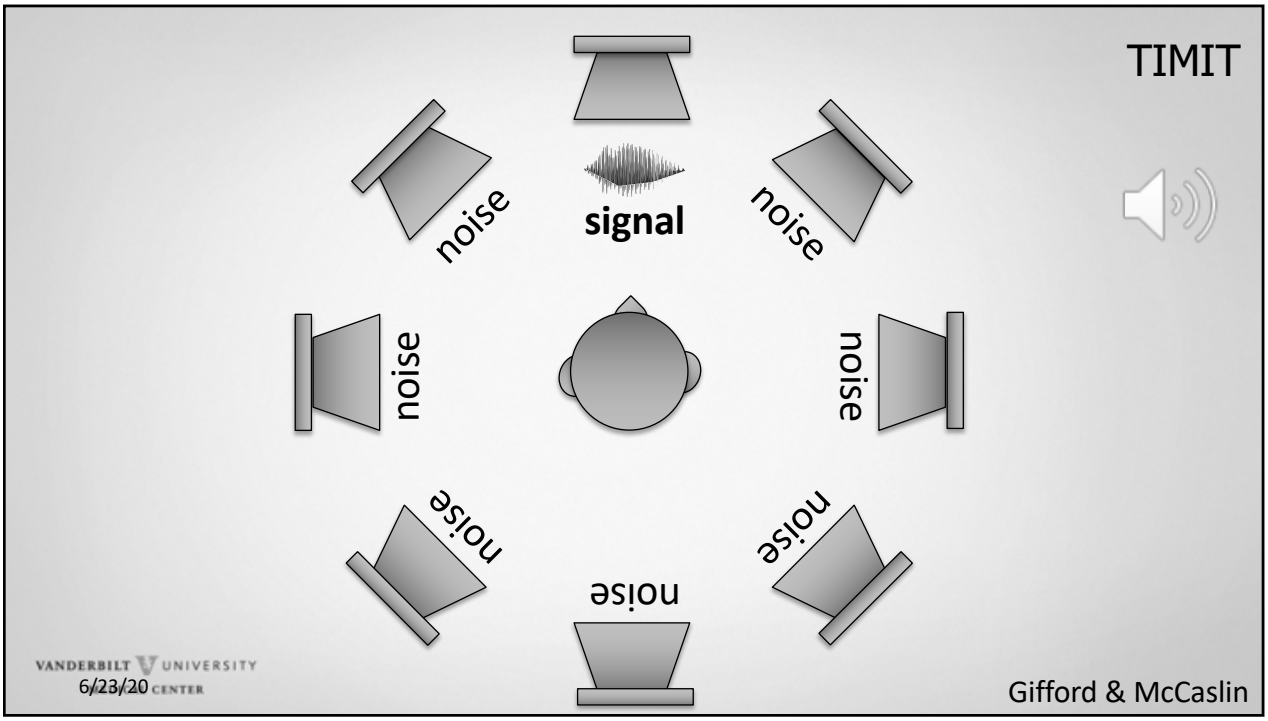
René Gifford, PhD & Devin McCaslin, PhD

- Previous studies: specific noise location
- What about more typical listening environments?
  - Small groups, diffuse noises, roving talker(s)
- n = 3
- 25, 32, & 44 years*
- Ponto Power Pro

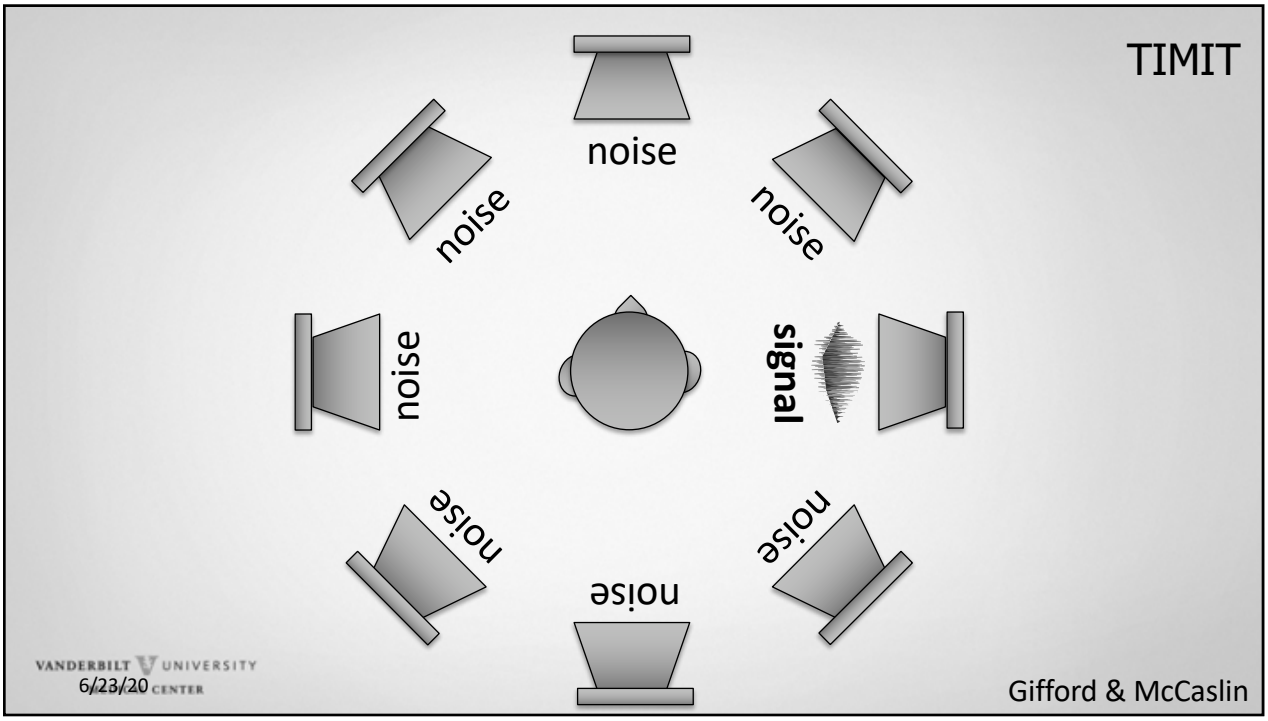
VANDERBILT UNIVERSITY CENTER

MAYO CLINIC

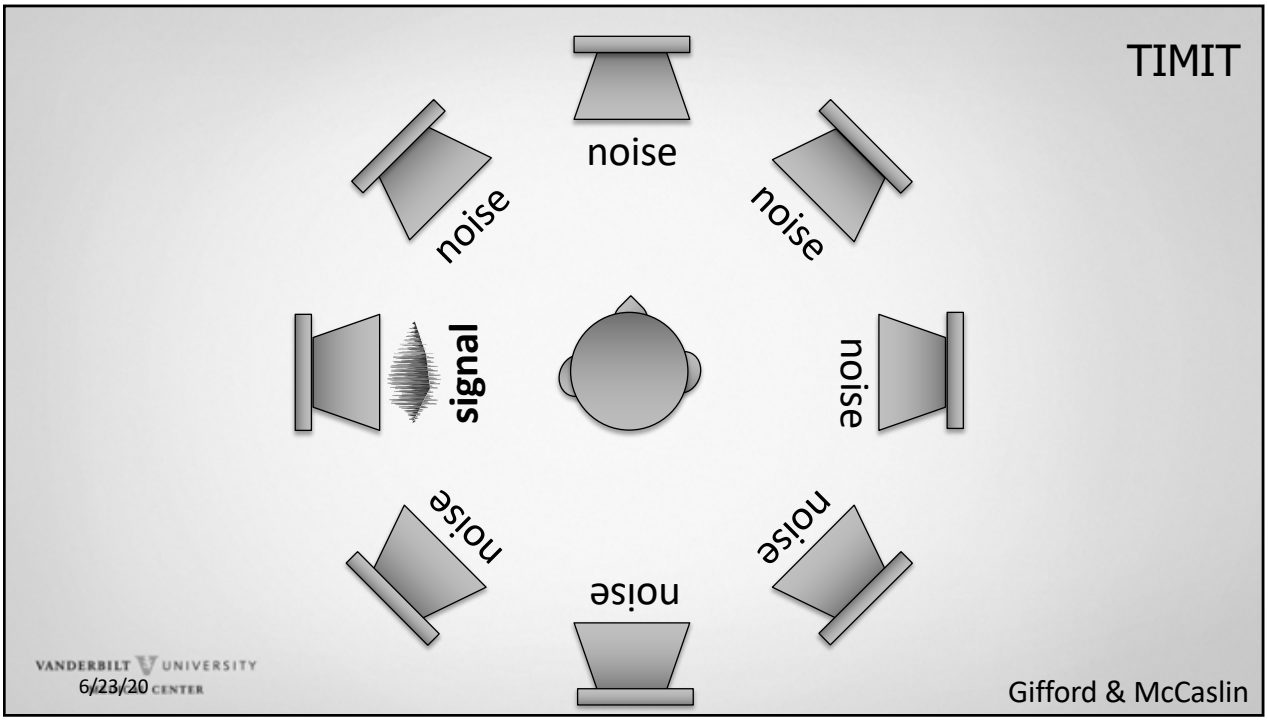
56


TIMIT
noise
signal
noise
noise
noise
noise
noise
noise
VANDERBILT UNIVERSITY
6/23/20 CENTER
Gifford & McCaslin

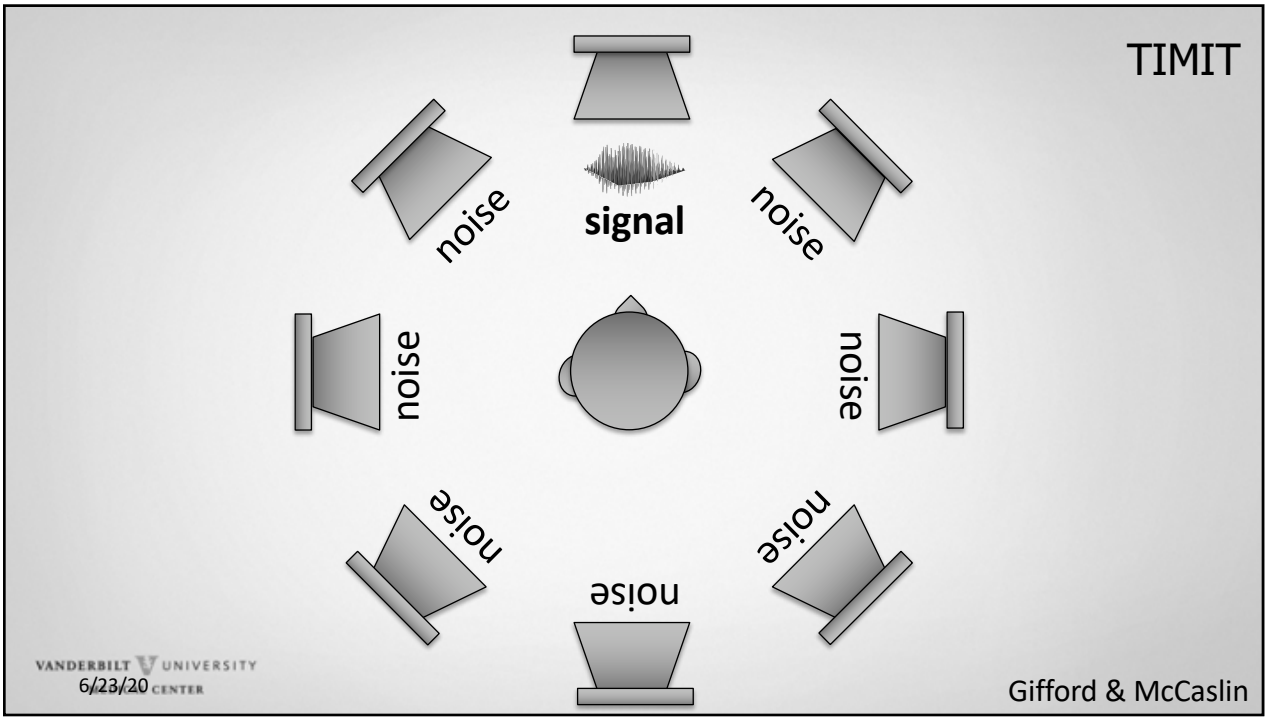
57


TIMIT
noise
noise
noise
noise
signal
noise
noise
noise
VANDERBILT UNIVERSITY
6/23/20 CENTER
Gifford & McCaslin

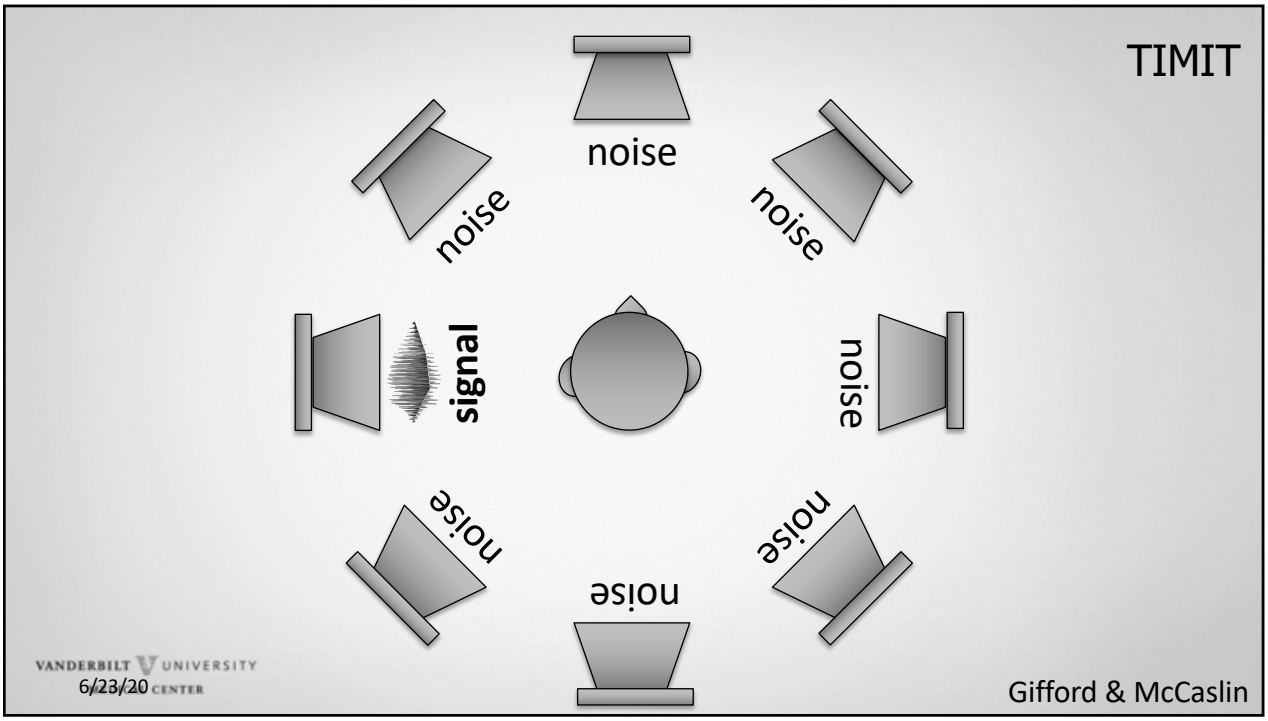
58


TIMIT
noise
noise
noise
signal
noise
noise
noise
noise
VANDERBILT UNIVERSITY
6/23/20 CENTER
Gifford & McCaslin

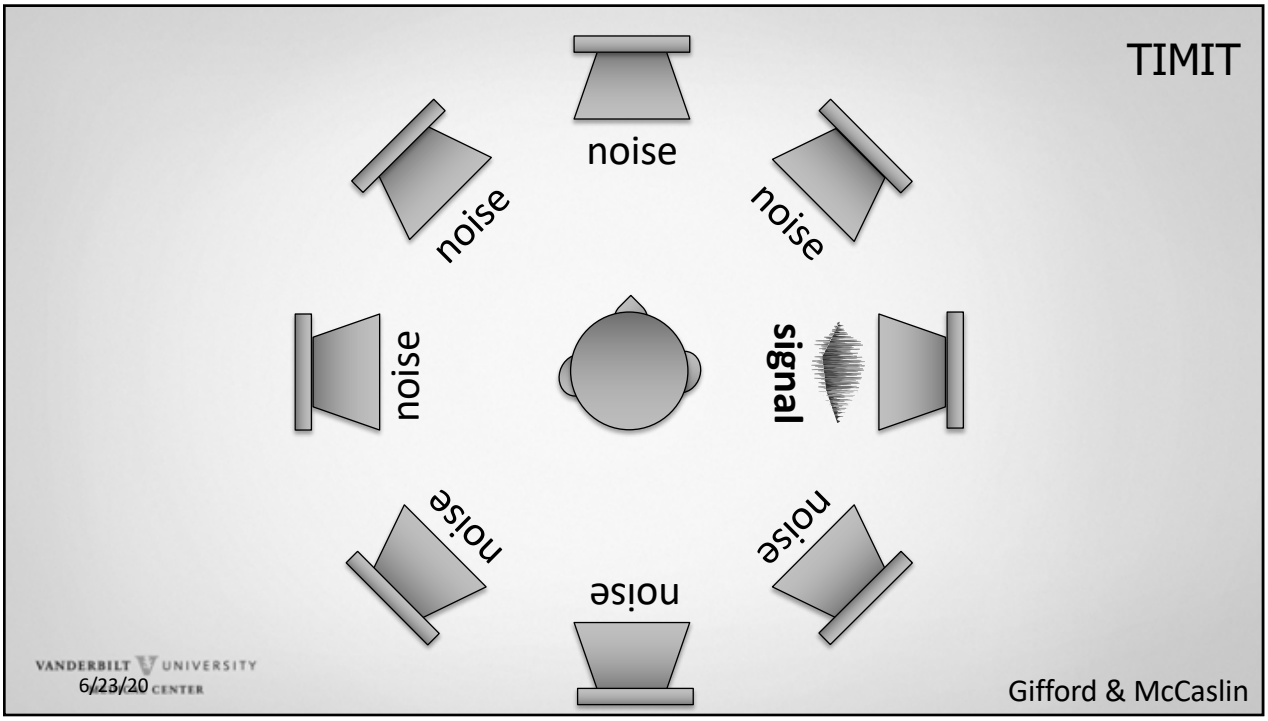
59


TIMIT
noise
signal
noise
noise
noise
noise
noise
VANDERBILT UNIVERSITY
6/23/20 CENTER
Gifford & McCaslin

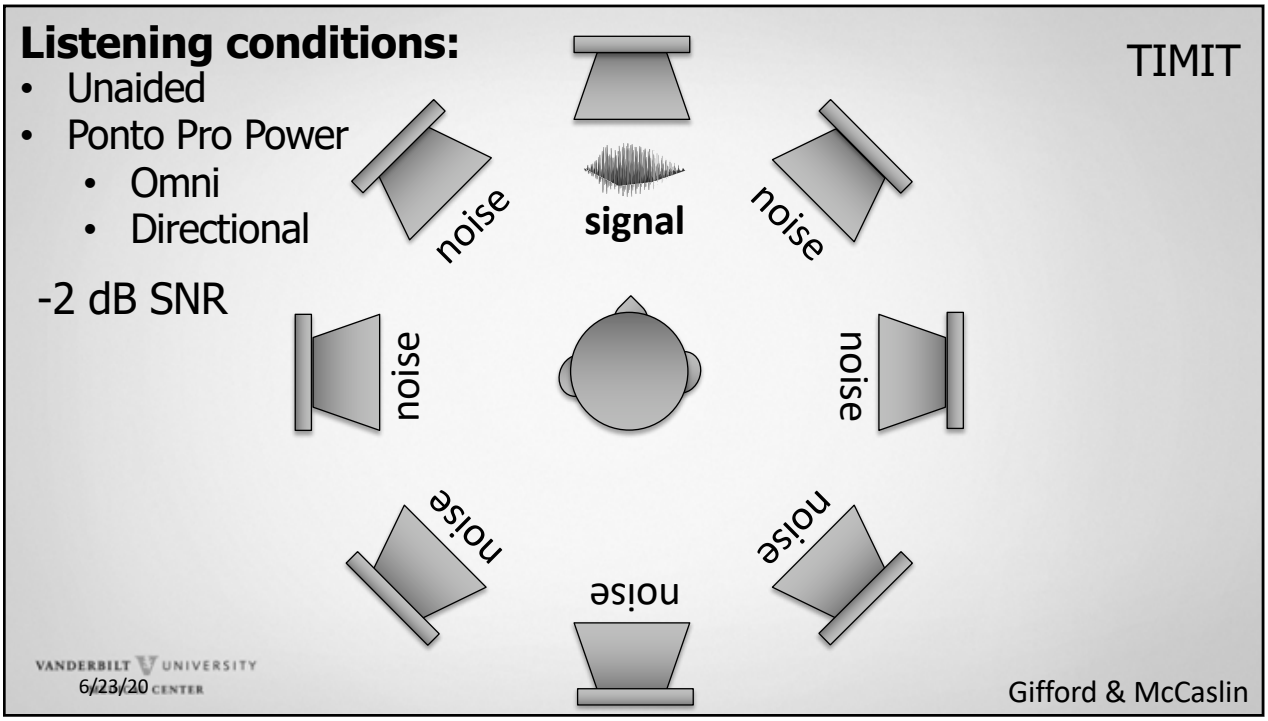
60


TIMIT
noise
noise
noise
signal
noise
noise
noise
noise
VANDERBILT UNIVERSITY
6/23/20 CENTER
Gifford & McCaslin

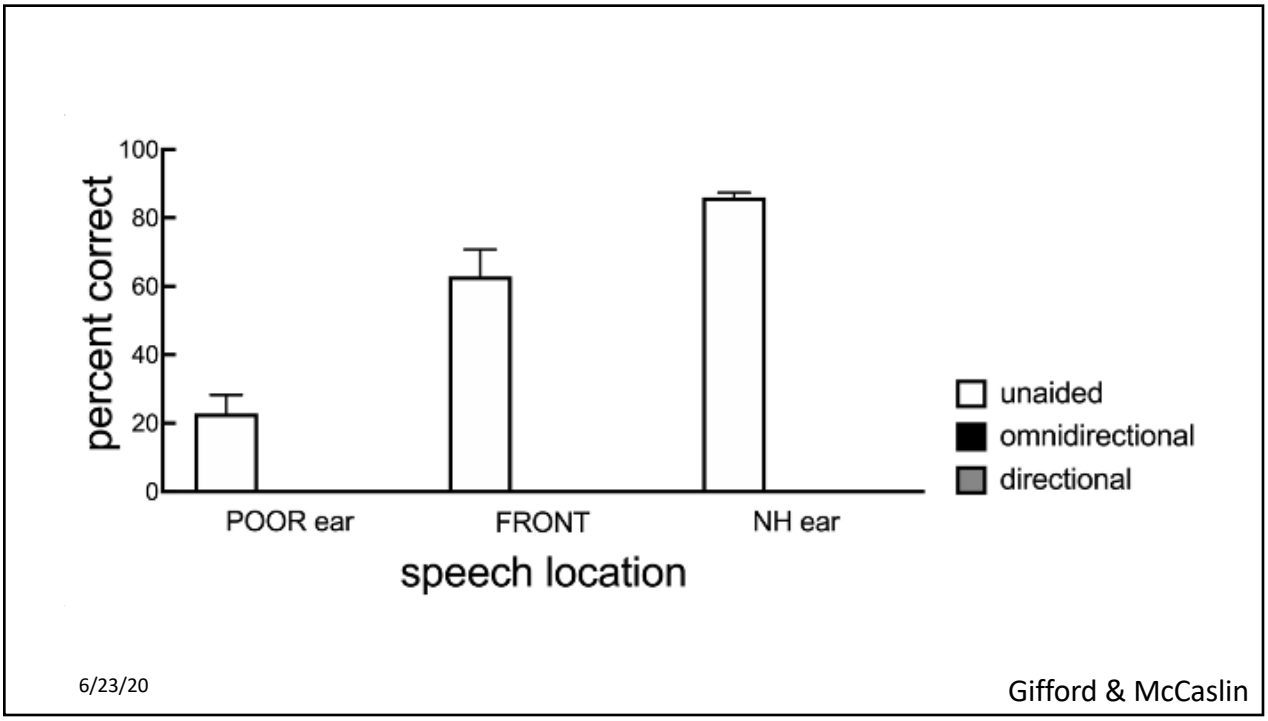
61


TIMIT
noise
noise
noise
noise
signal
noise
noise
noise
VANDERBILT UNIVERSITY
6/23/20 CENTER
Gifford & McCaslin

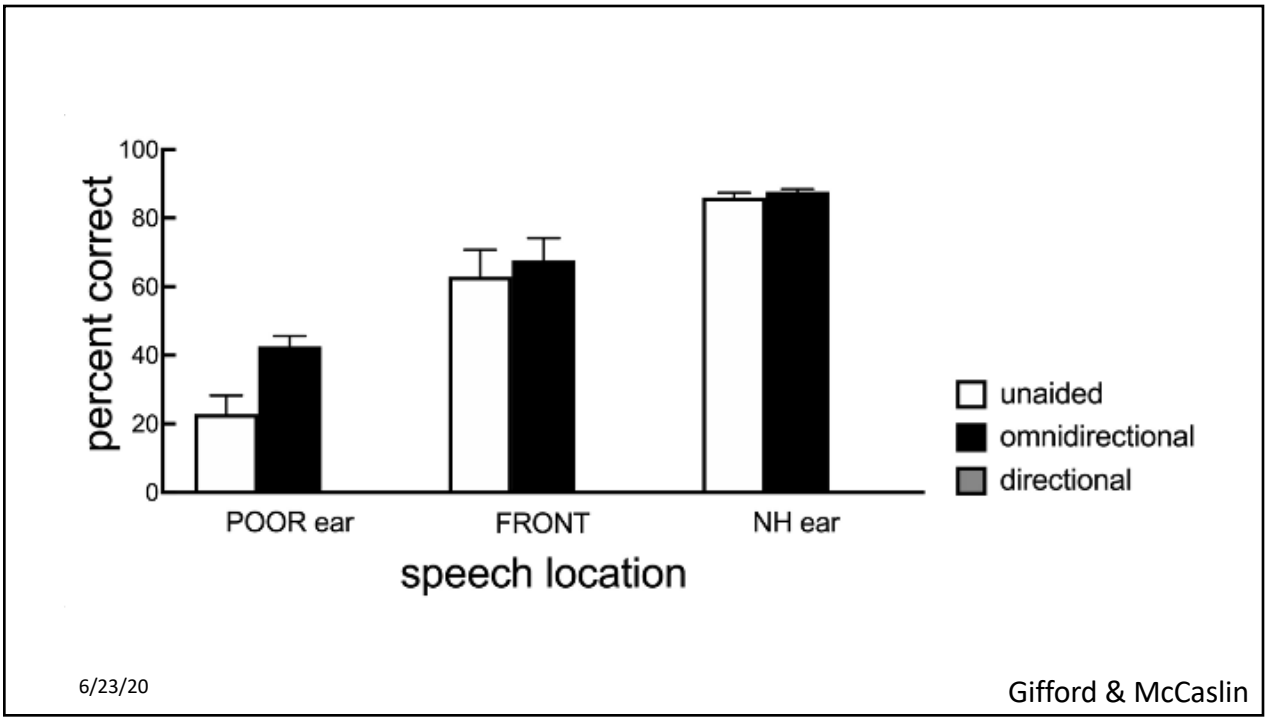
62


Listening conditions:
• Unaided
• Ponto Pro Power
• Omni
• Directional
-2 dB SNR
TIMIT
noise
signal
noise
noise
noise
noise
noise
noise
VANDERBILT UNIVERSITY
6/23/20 CENTER
Gifford & McCaslin

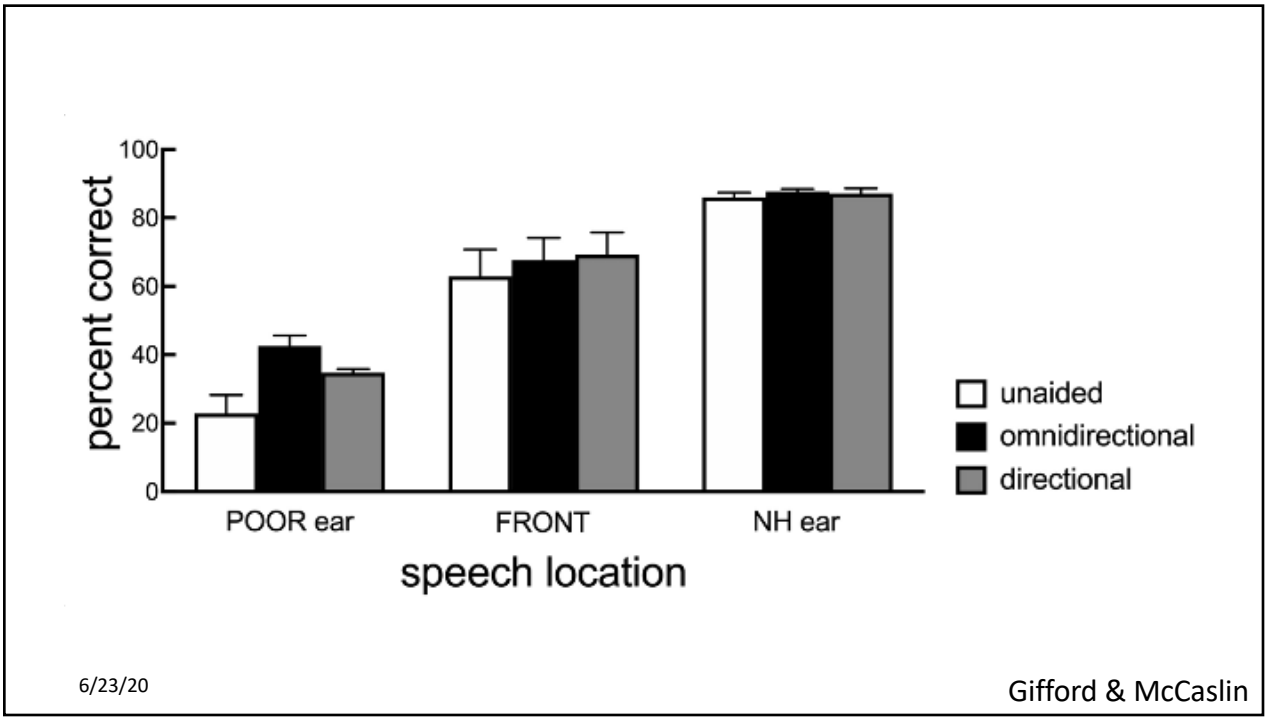
63


percent correct
100
80
60
40
20
0
POOR ear
FRONT
NH ear
speech location
unaided
omnidirectional
directional
6/23/20
Gifford & McCaslin

64


100
80
60
40
20
0
percent correct
POOR ear
FRONT
NH ear
speech location
unaided
omnidirectional
directional
6/23/20
Gifford & McCaslin

65

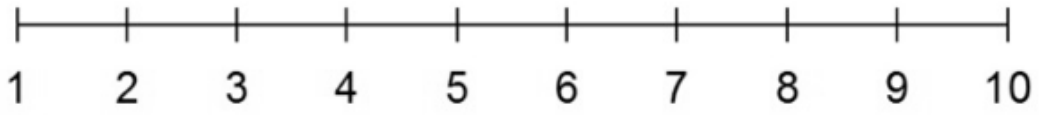

100
80
60
40
20
0
percent correct
POOR ear
FRONT
NH ear
speech location
unaided
omnidirectional
directional
6/23/20
Gifford & McCaslin

66

Percent correct vs. effort expended

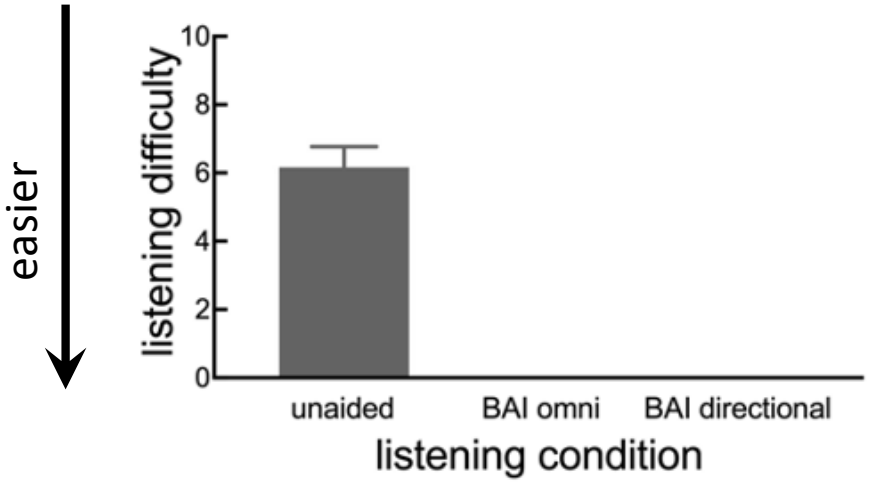
How difficult was understanding the speech in this listening task?

1 = no difficulty at all
10 = most difficulty imaginable



6/23/20

67

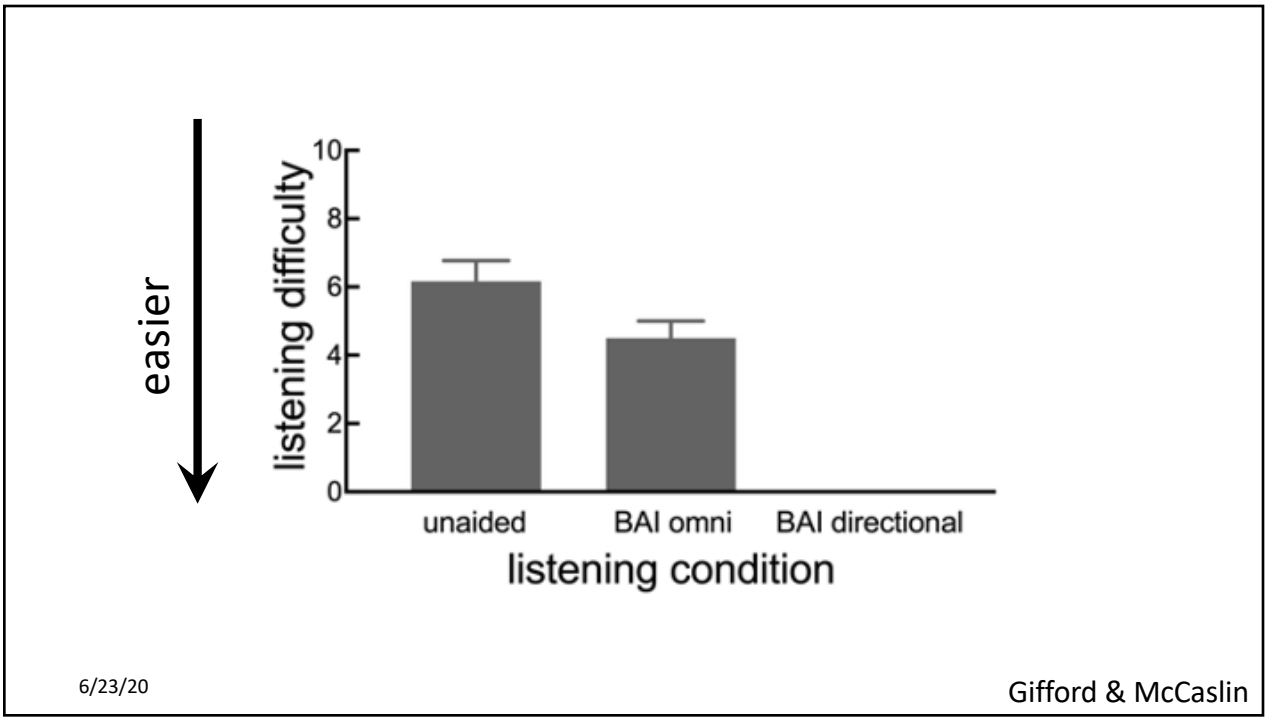


6/23/20

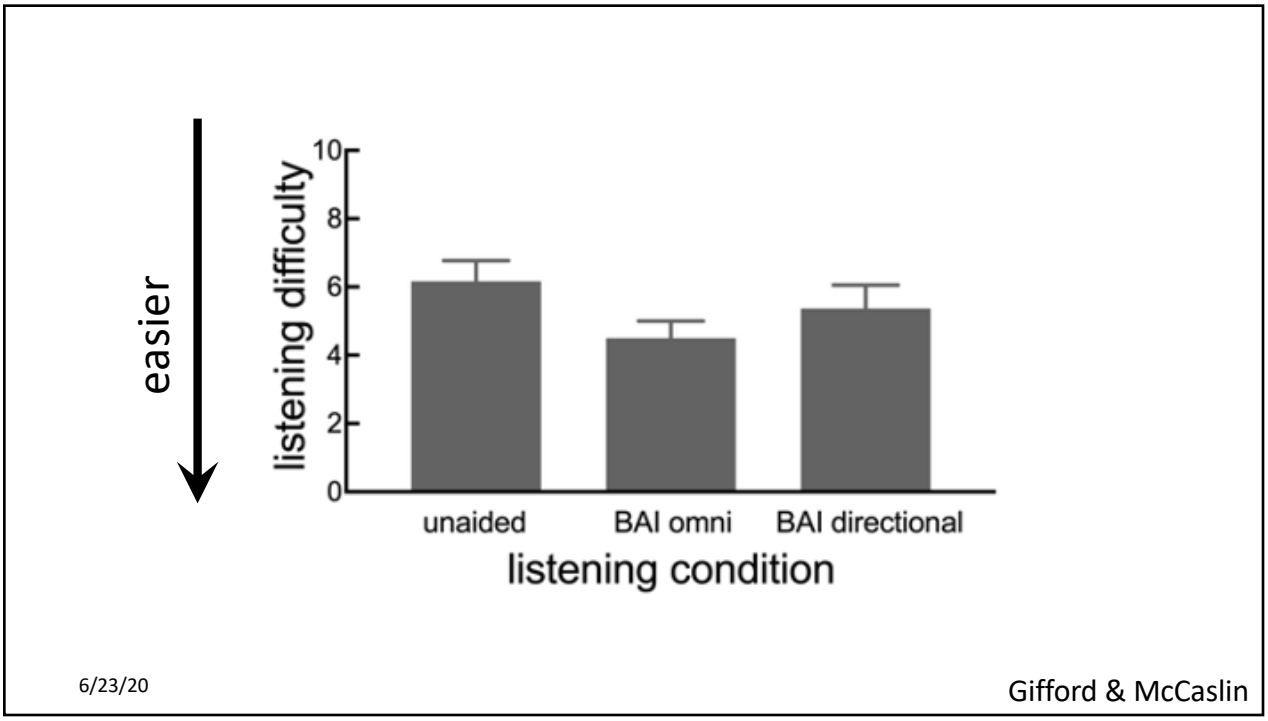
Gifford & McCaslin

68

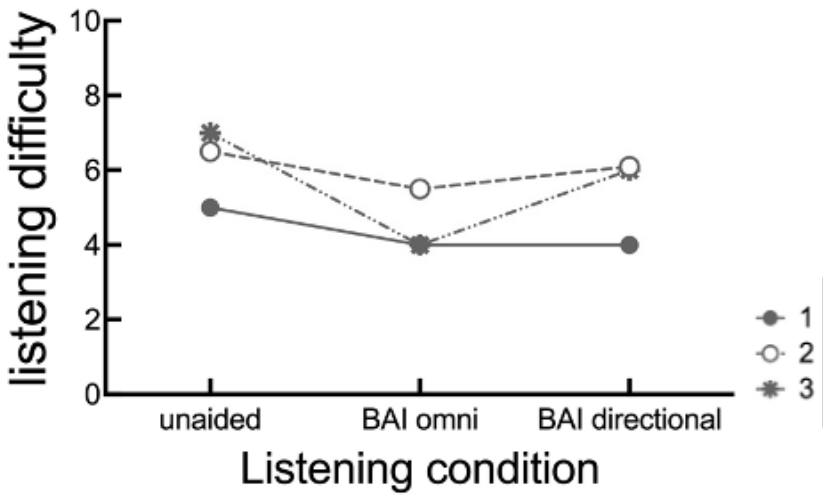
hip with


easier
listening difficulty
10
8
6
4
2
0
unaided
BAI omni
BAI directional
listening condition
6/23/20
Gifford & McCaslin

69


easier
listening difficulty
10
8
6
4
2
0
unaided
BAI omni
BAI directional
listening condition
6/23/20
Gifford & McCaslin

70



Gifford & McCaslin

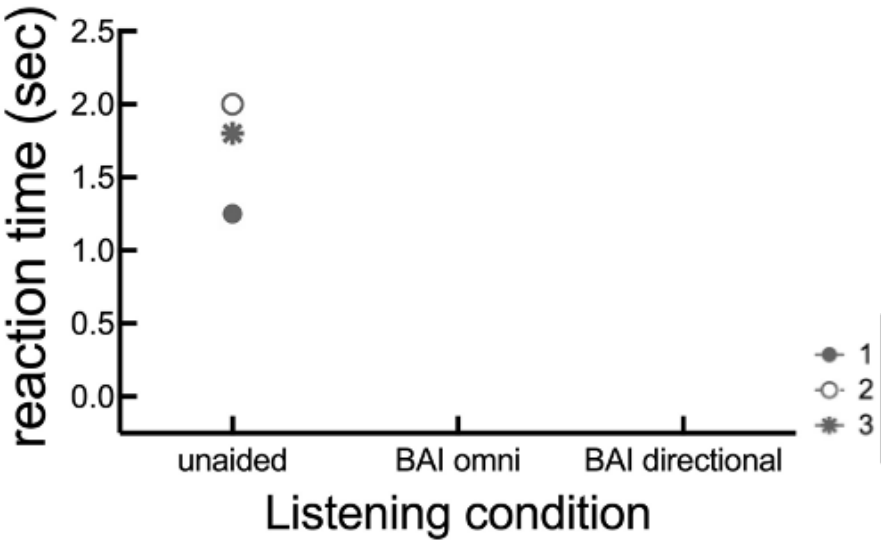
Response time: listening effort

Houben et al. (2013). Int J Audiol, 52: 753-61.

Pals et al. (2015). J Acoust Soc Am, 138:EL187-92.

van den Tillaart-Haverkate et al. (2017). Trends Hear. Jan-Dec 2017;21:2331216517716844.

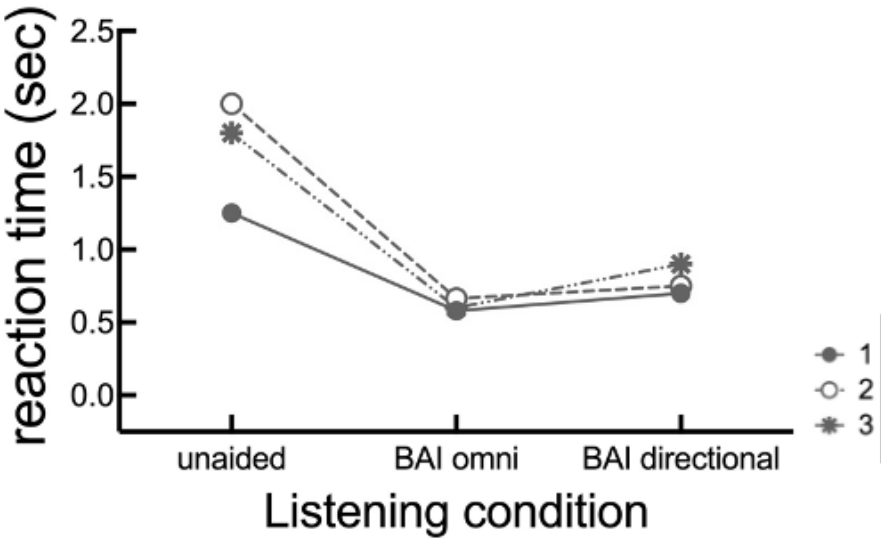
Gifford & McCaslin



6/23/20

Gifford & McCaslin

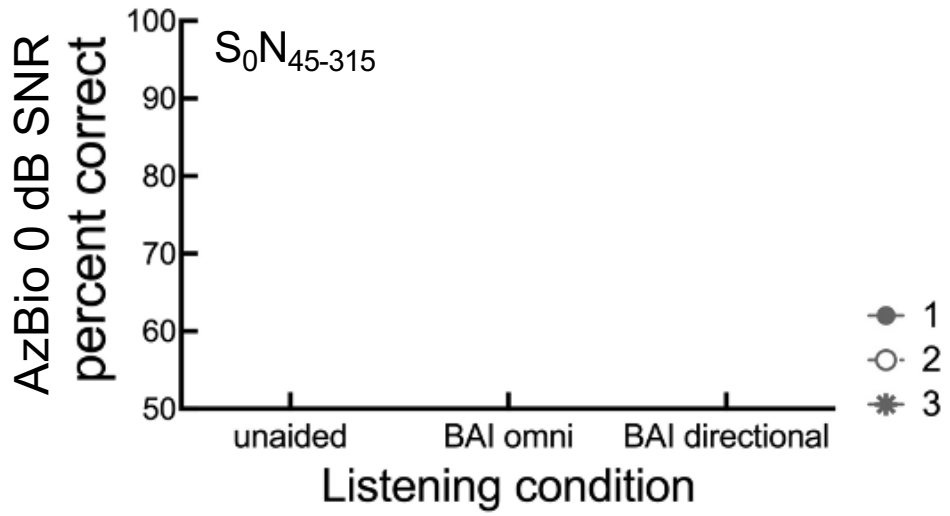
73



6/23/20

Gifford & McCaslin

74



6/23/20

Gifford & McCaslin

75

Kim et al. (2017). Otol Neurotol, 38:473–483

BAI for adults with SSD:

- Significant benefit for speech in noise
  - BAI > CROS
    - Niparko et al. (2003). Otol Neurotol, 24:73–8; Finbow et al. (2015). Otol Neurotol, 36:819–25. Wazen et al. (2003). Otolaryngol Head Neck Surg, 129:248–54.
- Improved quality of life

"The "do-nothing" solution is no longer acceptable for a number of people with SSD."

VANDERBILT UNIVERSITY CENTER

6/23/20

76

hip with

Clinical decision making

CROS & BAI:

no preservation of binaural cues

→ Poor localization

→ Neuroplastic changes (Sharma et al. 2016)

→ aural preference syndrome (Kral et al. 2013. *Brain*. 136; 180-19; Gordon et al. 2015. *Pediatrics*. 136(1):141-53)

CI:

access to *high-frequency ILDs*

→ Significantly better localization & speech rec benefits in complex conditions

→ Qualitative reports of better speech & spatial hearing abilities

→ Tinnitus suppression

77

Clinical decision making

BAI:

→ Less invasive than CI

→ Fewer insurance restrictions (age, provider)

→ Improved speech rec in noise (Speech to SSD_{ear})

→ Improved listening difficulty and effort than unaided

→ even in acute listening conditions

CI:

→ More invasive

→ Some insurance coverage restrictions

→ Less effective for long durations of deafness

78

Clinical recommendations

Adults (and children) with SSD have options:

- Short durations of deafness, poor spatial hearing, and/or tinnitus → **Cochlear implant**
- Longer durations of deafness, speech in noise difficulties, auditory fatigue, listening effort, insurance and/or medical contraindications → **BAI**

81