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Neurocognitive Brain Changes in Hearing Loss: Effects of Early Intervention with Hearing Aids

Anu Sharma, PhD

University of Colorado, Boulder

Anu Sharma, PhD

Anu Sharma, Ph.D. is Professor in the Department of Speech Language and Hearing Science and Fellow in the Institute for Cognitive Science and Center for Neuroscience at University of Colorado, Boulder, USA. Her research focuses on examining brain and behavioral outcomes in children and adults with hearing loss who are fitted with hearing aids and/or cochlear implants. She has over 75 scientific publications and she has given over 200 invited and keynote addresses on her research including the Carhart Memorial Lecture at the American Auditory Society the Marion Downs lecture twice at the American Academy of Audiology and the Ted Evans Lecture at the British Academy of Audiology. Her research is funded by the United States National Institutes of Health.

Disclosures

- **Presenter Disclosure**: Financial: Dr. Sharma is employed by the University of Colorado at Boulder. Dr. Sharma's research has been funded by the National Institutes of Health and the Hearing Industry Research Consortium. She received an honorarium for this course. Non-financial: Dr. Sharma has no relevant non-financial relationships to disclose.
- **Content Disclosure**: This learning event does not focus exclusively on any specific product or service.
- **Sponsor Disclosure**: This course is presented by the American Auditory Society in partnership with AudiologyOnline.

Learning Outcomes

After this course, participants will be able to:

- Describe cortical neurophysiological changes in hearing loss.
- Describe cognitive changes in hearing loss.
- Discuss the cortical changes from early intervention with hearing aids and cochlear implants in persons with hearing loss.

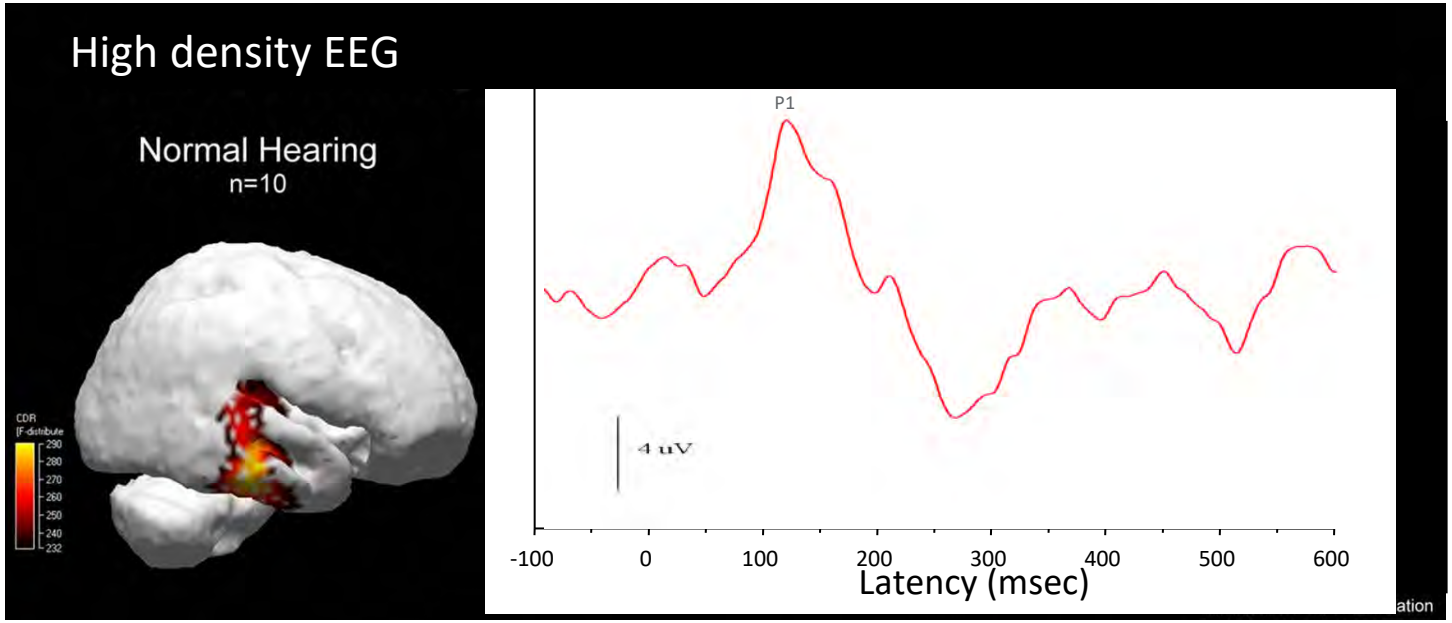
What are the central consequences of hearing loss?

Developmental Neuroplasticity

Neuroplasticity in age-related hearing loss

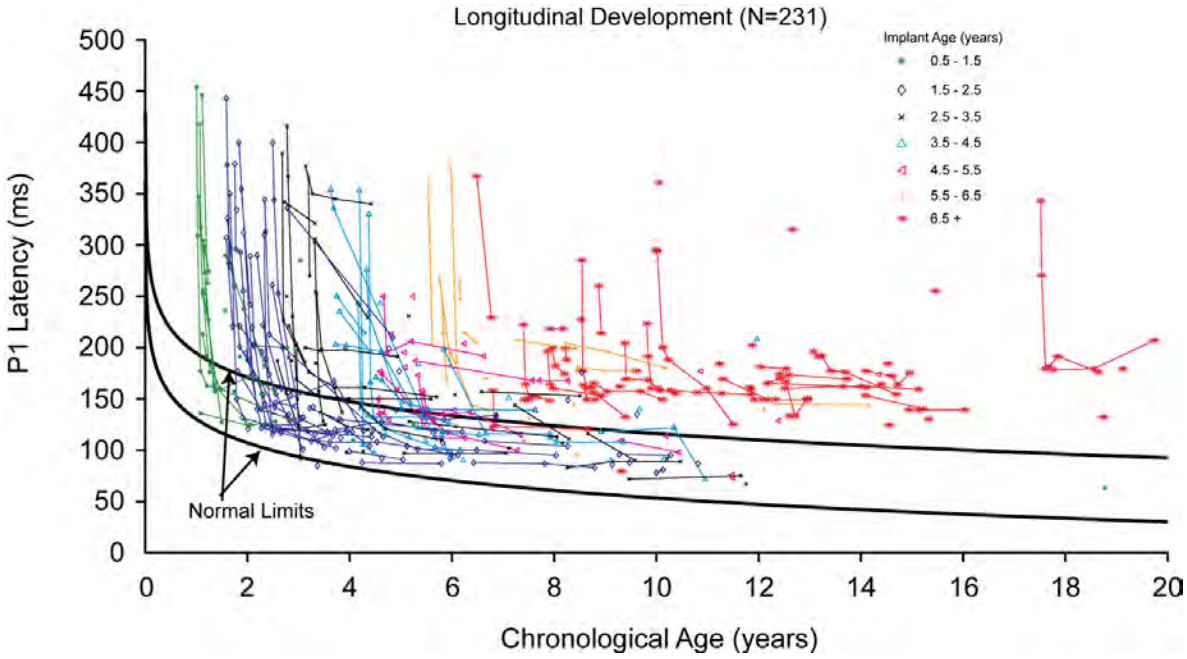
A basic tenet of neuroplasticity is that the brain will change or re-organize following sensory deprivation.

P1 Cortical Auditory Response Biomarker



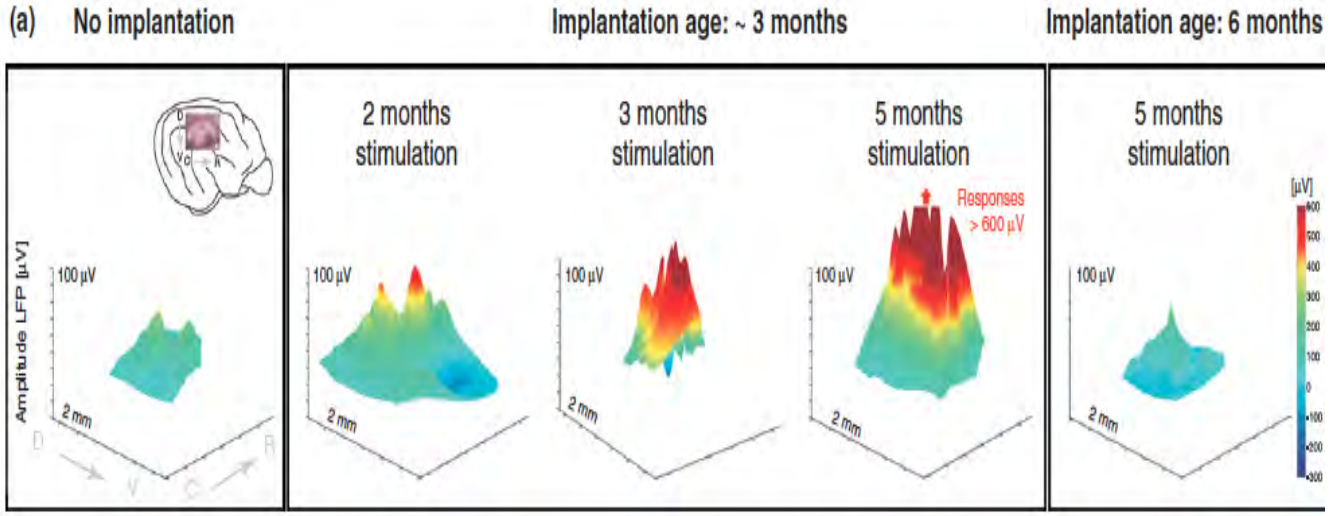
P1 has input from primary auditory cortex and cortico-cortical loops.

Individual Developmental Trajectories n=(231)



Sharma et al., 2007

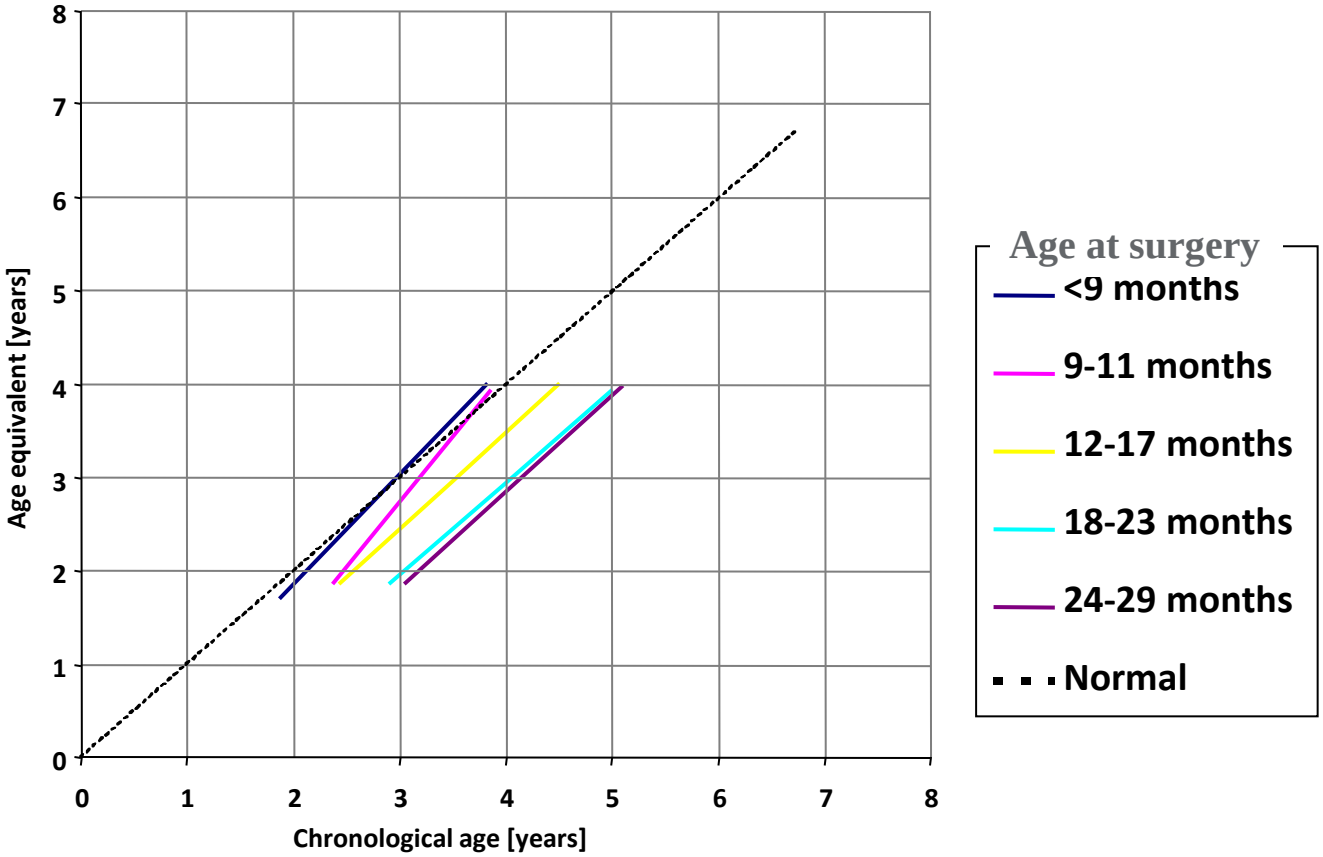
Cortical Activation Map in Primary Auditory Cortex: Deaf Cats

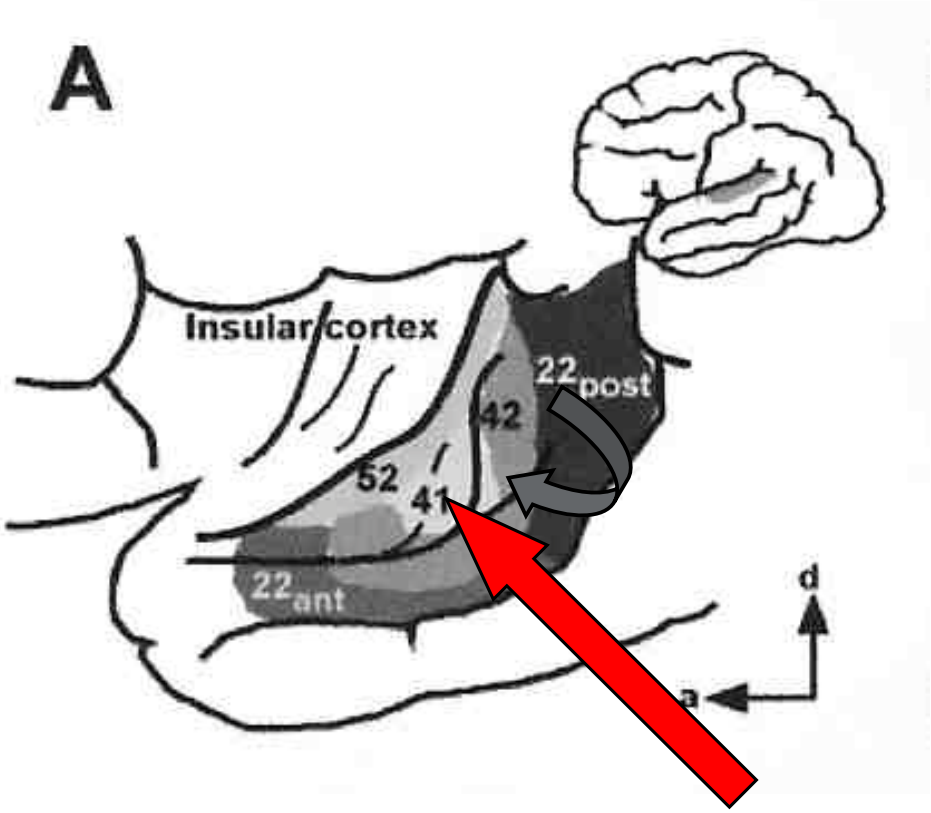


Kral and Sharma, TINS 2012

Implantation early within an early sensitive period *(best by age 1yr)* allows for the most favorable outcomes for children with cochlear implants.

Spoken Language Progression: Reynell III




A
Insular cortex
22post
42
52
41
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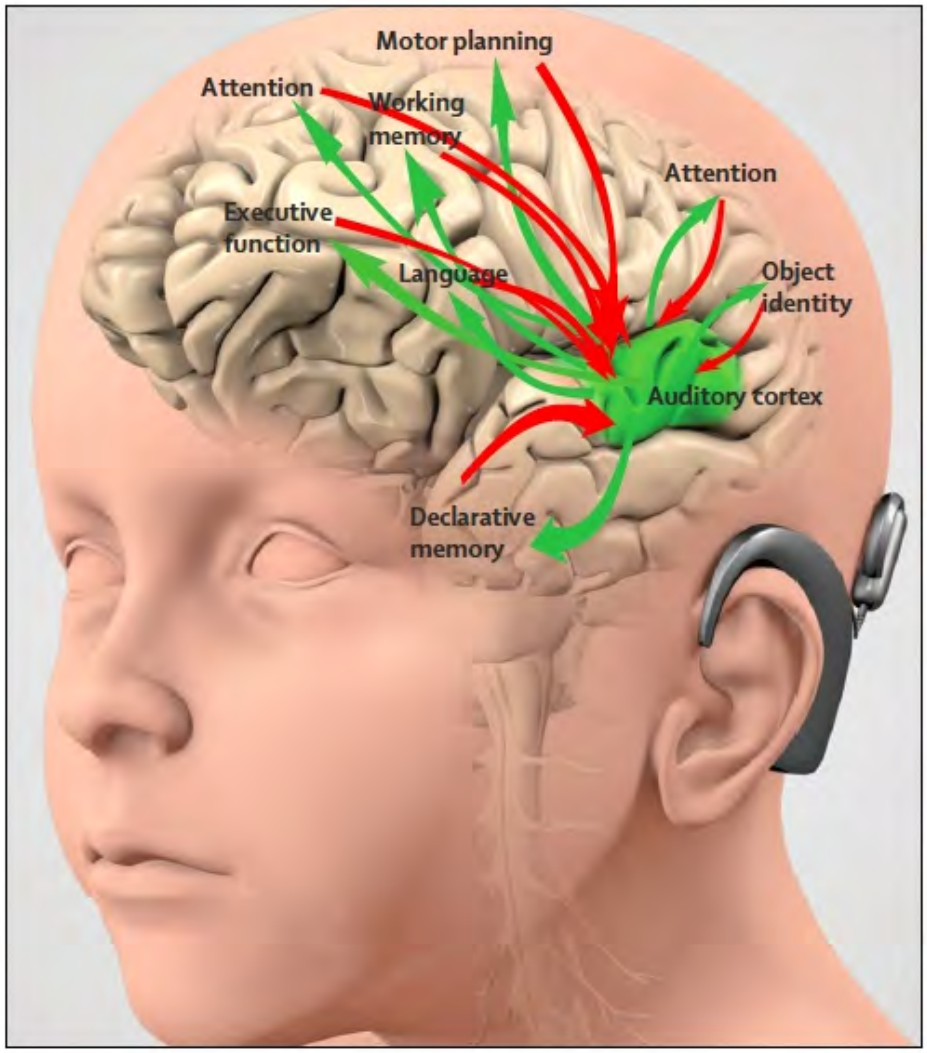
a

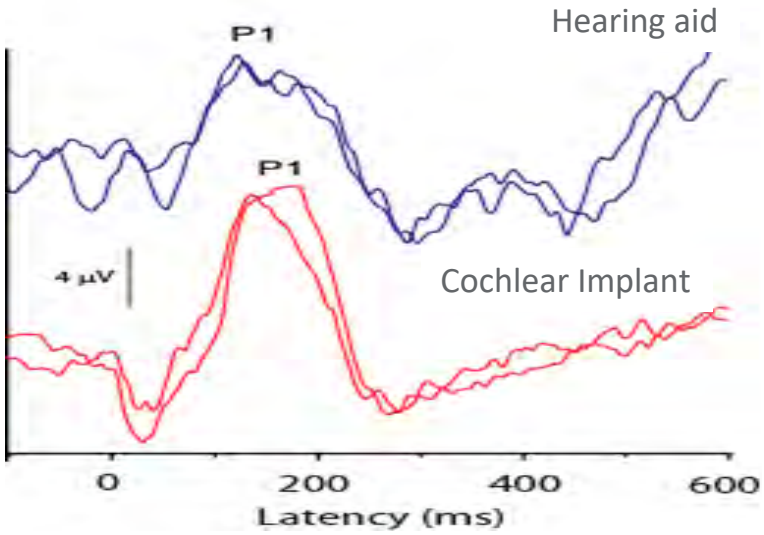
Hearing loss affects downstream cognitive function.



With Permission Andrej Kral

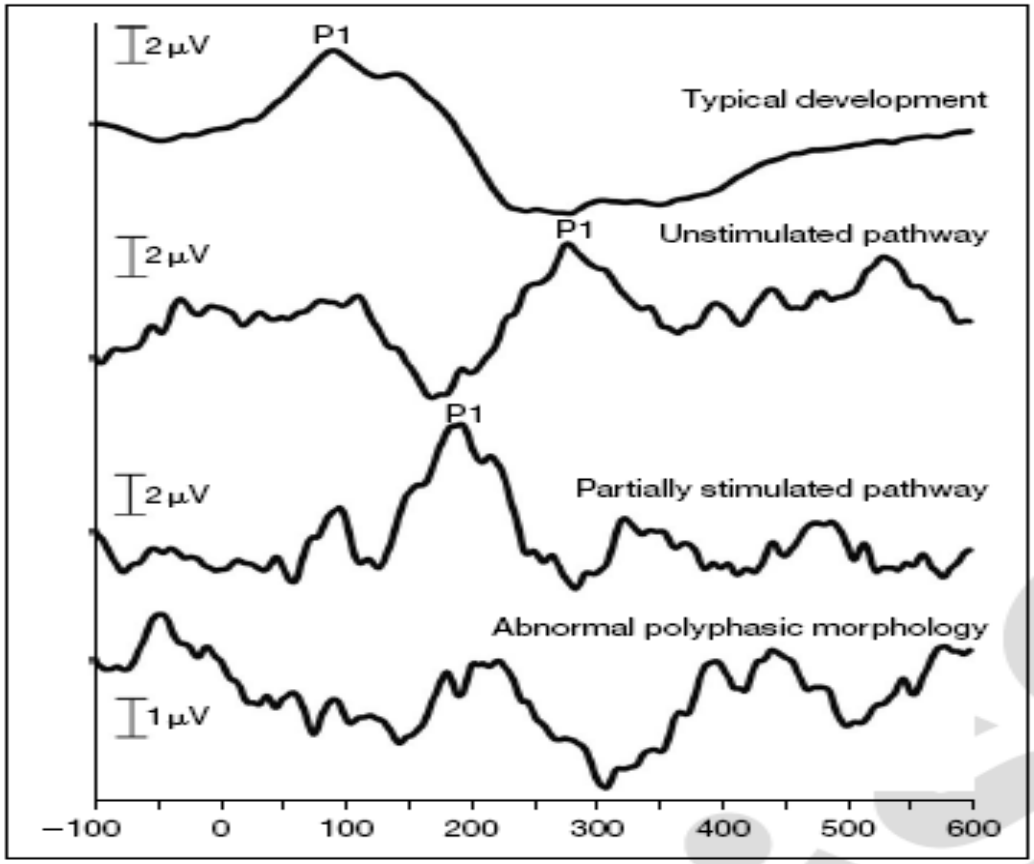
Can we use central auditory system neuroplasticity to help with clinical decision making in newborns and infants?

P1 biomarker of auditory cortical maturation



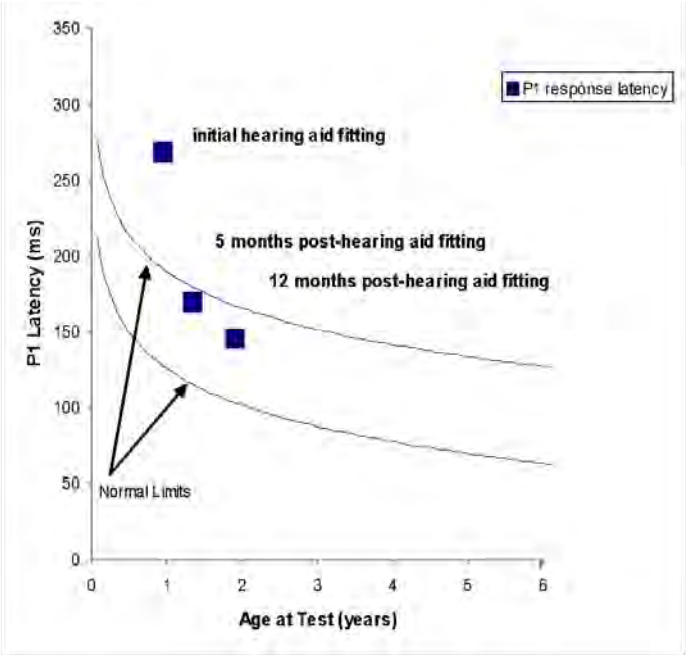
Sharma et al., JAAA (2005)

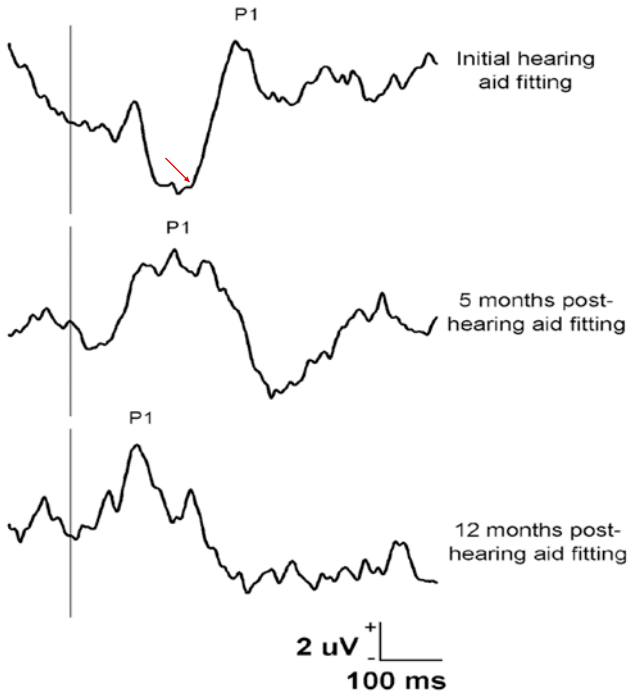
Auditory cortical responses examined in several hundred children with normal hearing and hearing loss



Sharma and Dorman 2006

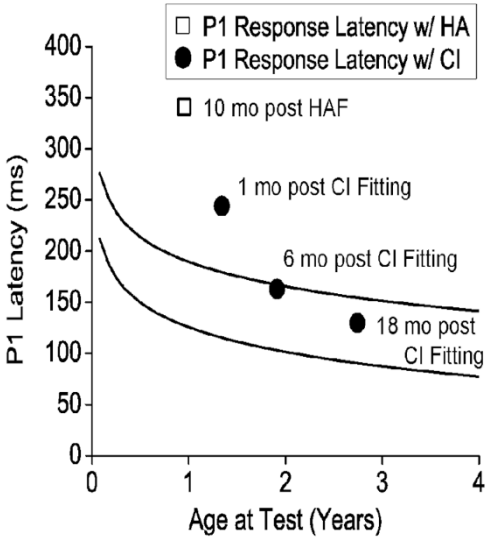
Neuroplastic changes following hearing aid fitting in infants

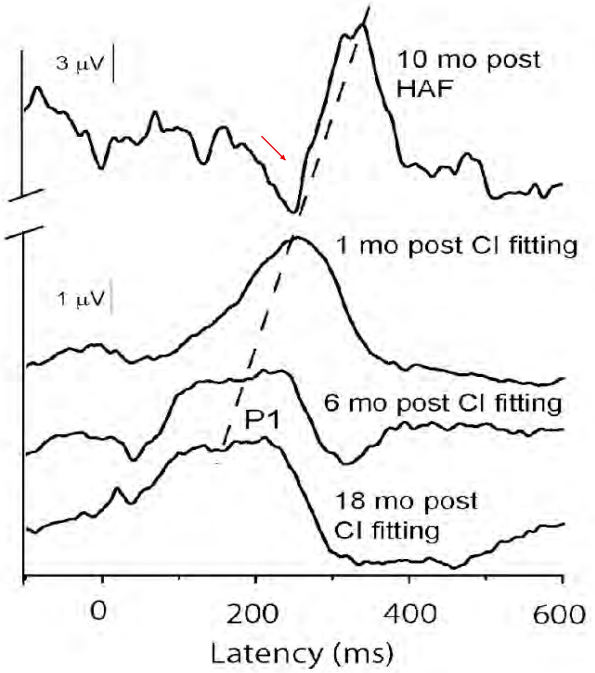




Sharma et al., 2007

Neuroplastic changes following cochlear implant fitting in infants





Sharma et al., 2007

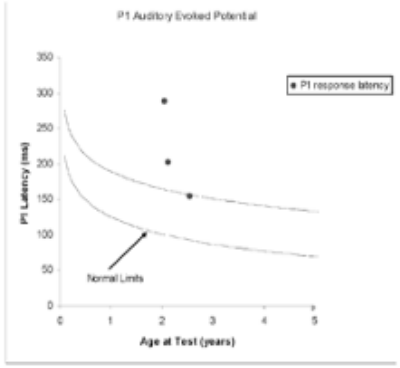
Name.
CCCD#: 68280
Date of Birth: 3-5-2002
Date(s) of Test: 3-25-2004, 4-22-2004, 9-24-2004
Date of Cochlear Implant Initial Stimulation: 3-25-2004
Implant Type: Med-El
Appros. Implant Experience at Test: Initial stimulation, 1 month, 6 months

P1 Auditory Evoked Potential Testing

Auditory evoked potentials reflect EEG activity in response to sound stimulation. The latency of the P1 auditory evoked potential reflects synaptic propagation through the thalamo-cortical portions of the central auditory pathways. P1 latencies are considered to be an index of the maturation of the central auditory pathways.

The P1 response was recorded non-invasively using a 5-electrode montage with Cz as the active electrode and the mastoid serving as the reference. A separate eye channel (lateral outer canthus referenced to superior outer canthus) was used for eye-blink rejection and a common ground electrode was placed on the forehead. The response was elicited using a "ba" speech stimulus presented through a speaker. A's cochlear implant speech processor was set at a level through which the sound could be heard at a comfortable loudness level.

Results



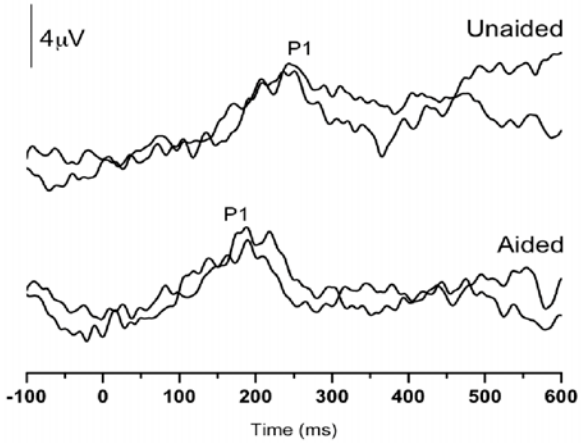
Impressions

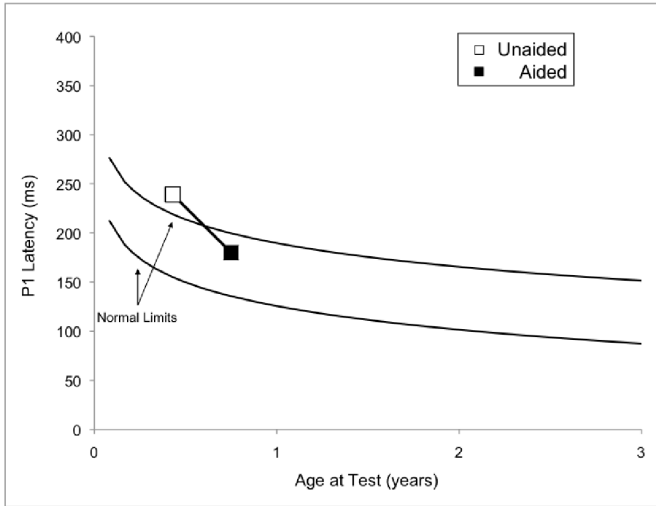
Al has shown a 134 msec decrease in P1 latency since the time of her initial cochlear implant fitting in March 2004. This decrease in P1 latency has moved Abigail just within the expected latency range for a normal hearing child of a similar age. An age-appropriate P1 response latency suggests intact development of auditory thalamo-cortical areas.

Recommendations

1) Abigail should continue to be monitored electrophysiologically at regular intervals (i.e. every 6-9 months), and behaviorally to assess acquisition of auditory and speech skills.
2) Abigail should continue to wear her cochlear implant speech processor for all waking hours, except when bathing or swimming.

Auditory Neuropathy Spectrum Disorder Case A

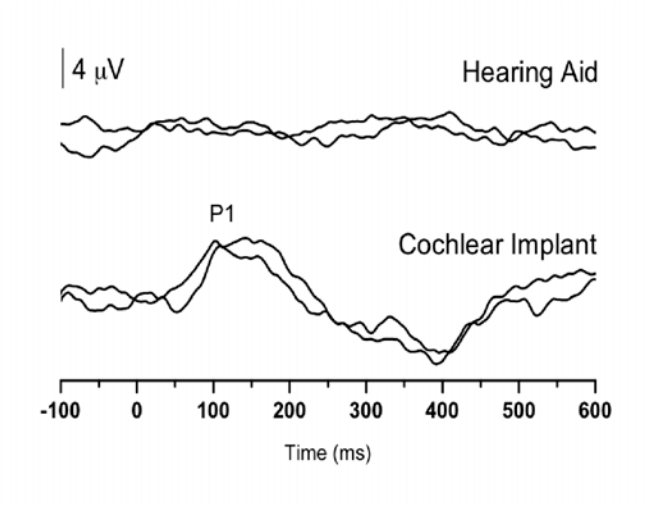


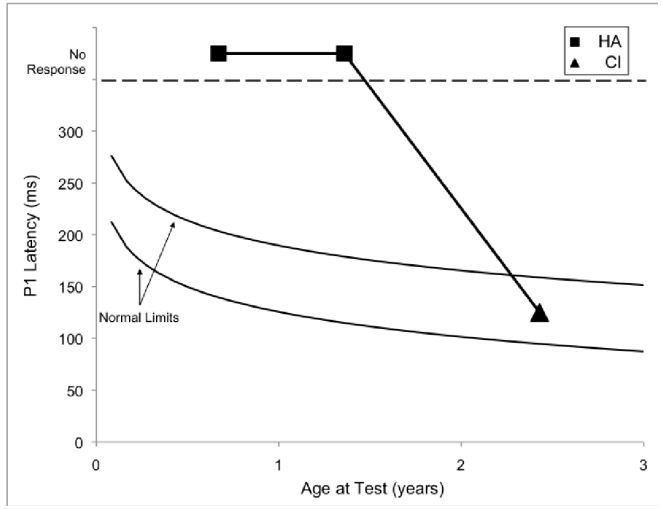


IT MAIS: 39/40 with hearing aid experience

Performing well with hearing aids, will continue to monitor

Auditory Neuropathy Spectrum Disorder Case B





P1 was absent with hearing aids and normal with cochlear implants.

Cardon, Campbell and Sharma 2012; Sharma and Cardon, 2015

SUMMARY

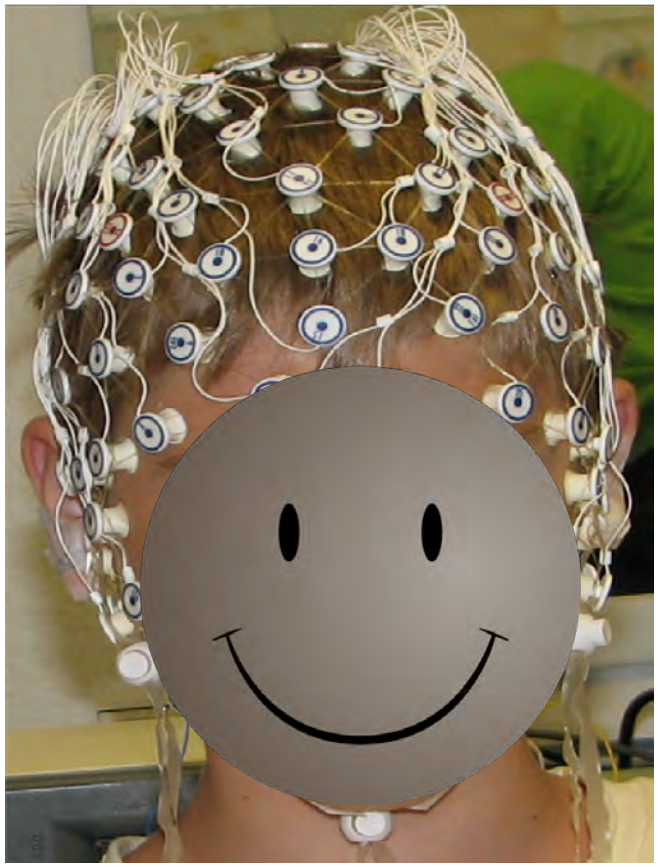
Cortical biomarkers are useful in assessing neuroplastic changes in the clinical management of children with hearing loss who have multiple disabilities and ANSD.

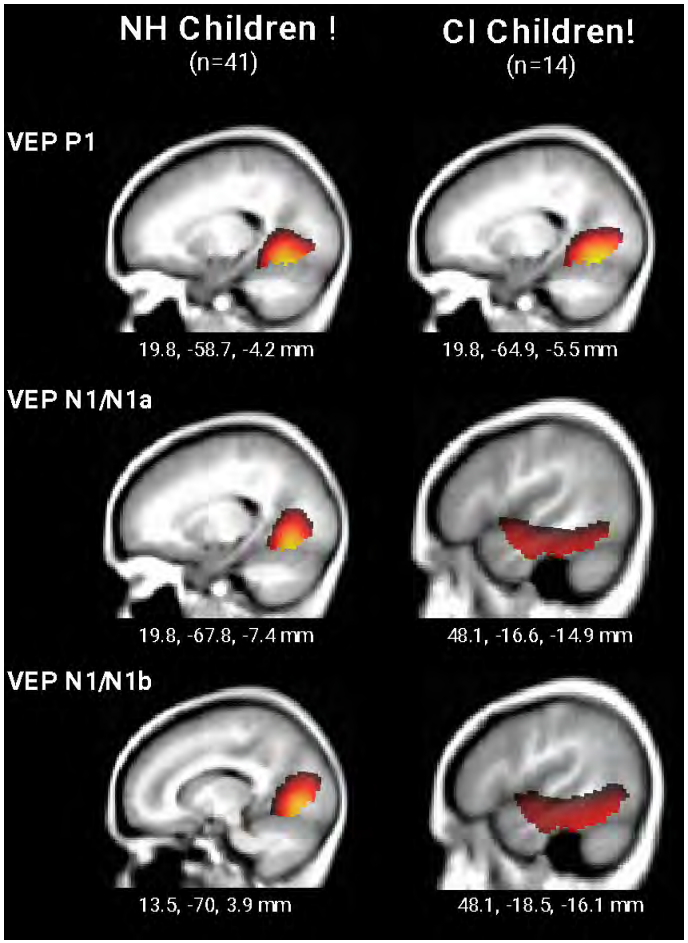
Compensatory Plasticity

A form of neuroplasticity that occurs with sensory deprivation is compensatory cross-modal plasticity.

For example, in deafness, auditory cortical areas can be recruited by the visual modality for visual processing.

Visual cross-modal plasticity in cochlear implanted children



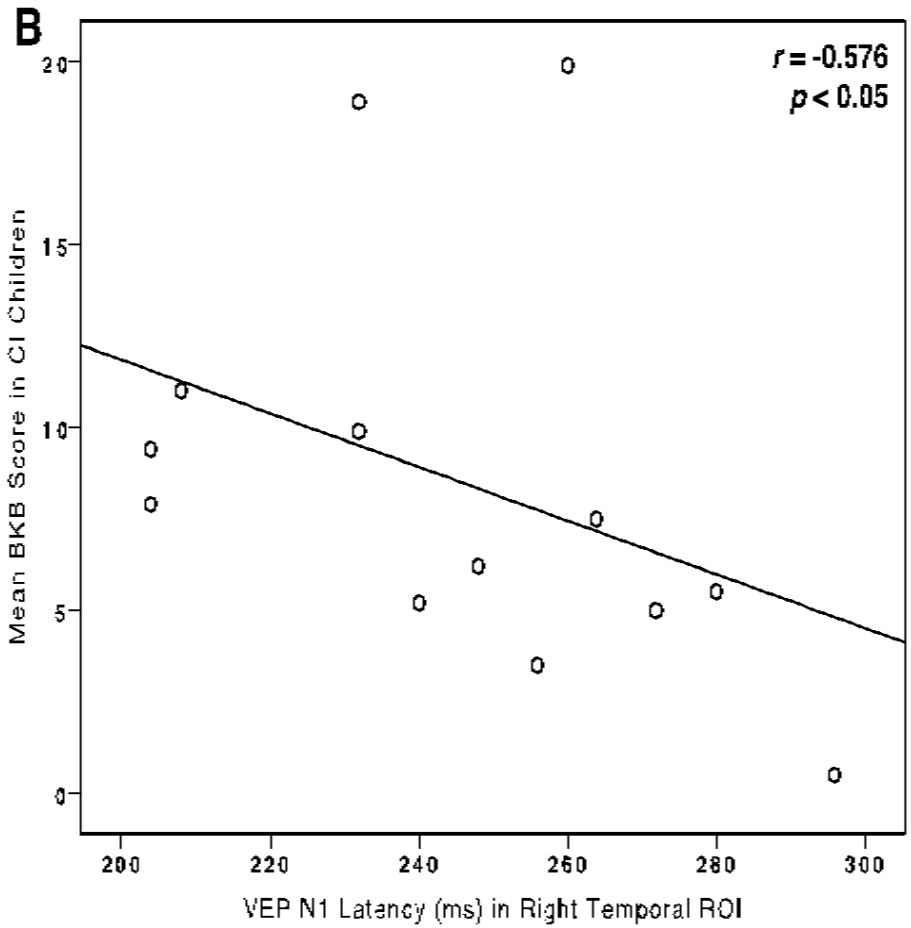


Current Density Reconstructions

Suggestive of cross-modal plasticity between visual and auditory systems.

Campbell and Sharma, PloS One 2016

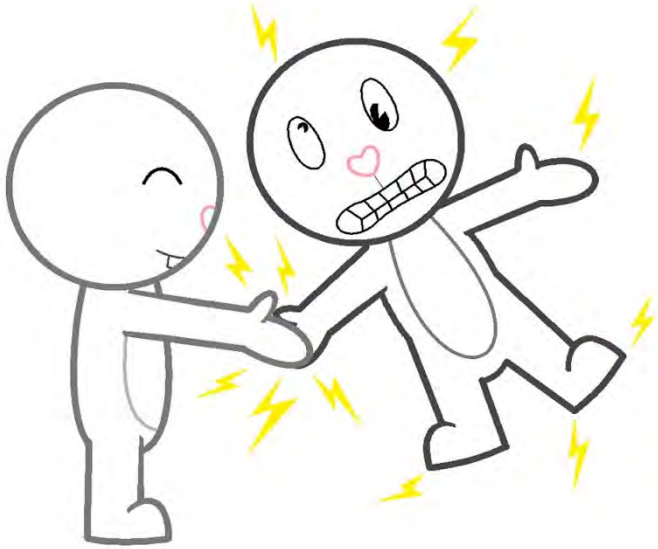
Worse performance with the cochlear implant is associated with greater cross-modal plasticity from vision.



Campbell and Sharma, 2016

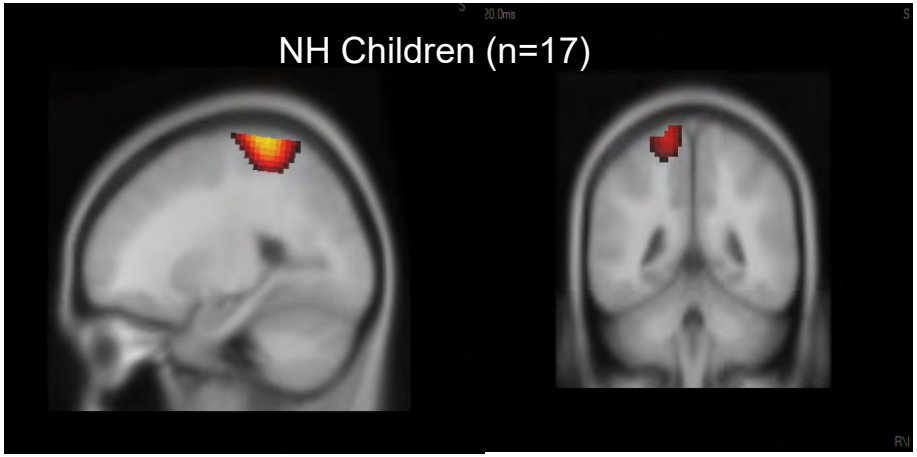
Somatosensory Stimulation

Vibrotactile stimulation of right hand



Cortical Activations to Somatosensory Stimulation

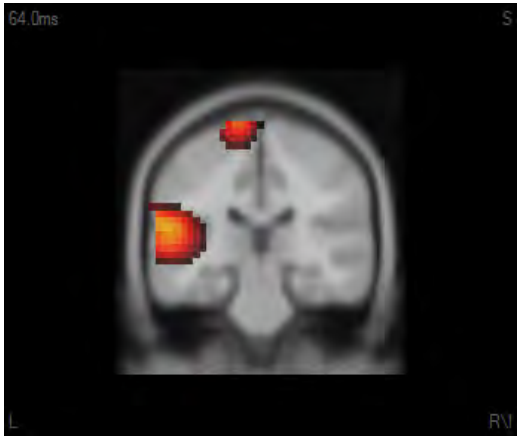
NH Children (n=17)



Areas Activated

Post-central Gyrus (BA 1-3, 5)
Pre-central Gyrus (BA 4)

CI Children (n=12)

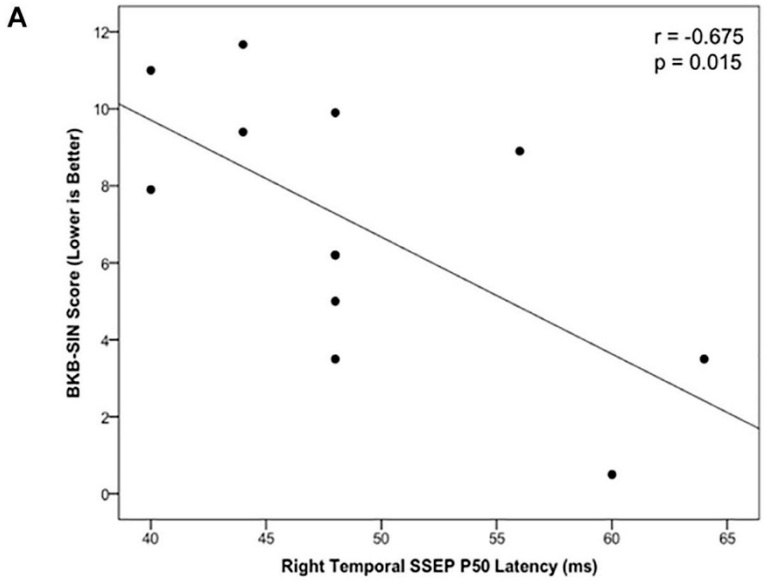


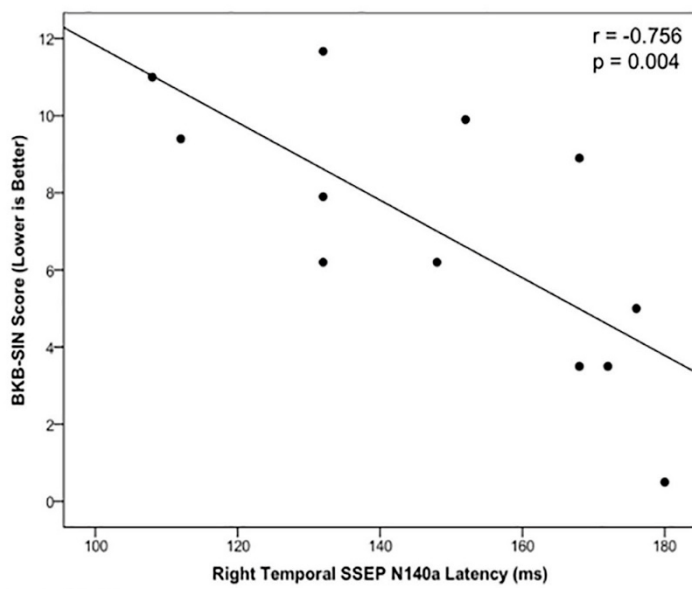
Evidence of temporal activation by somatosensory stimuli in CI children.

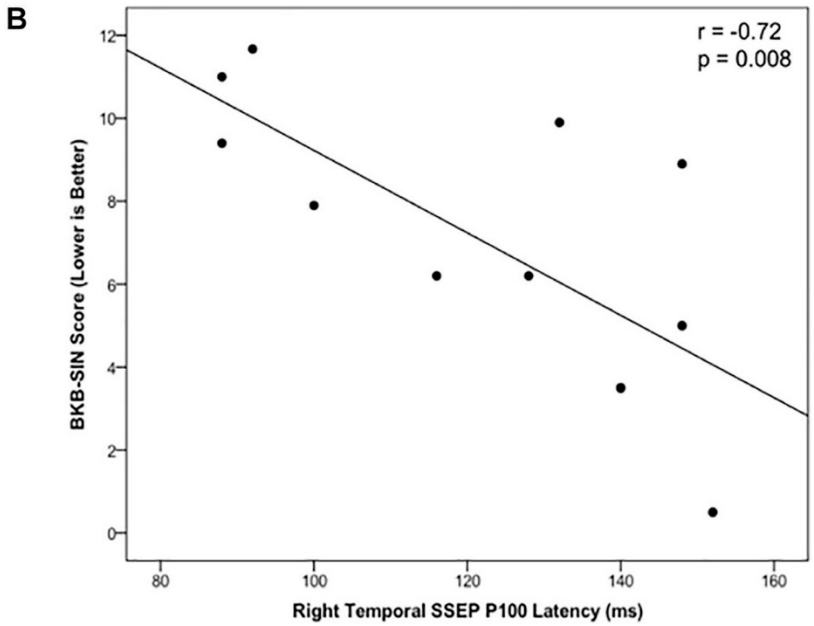
Superior Temporal Gyrus (STG; BA 22)
Middle Temporal Gyrus (MTG; BA 21, 39, 19)
Supramarginal Gyrus
Superior and Inferior Parietal Lobules (BA 40)
Post-central Gyrus (BA 1-3 & 7)
Pre-central Gyrus (BA 4)

Cardon and Sharma, Frontiers in Neuroscience 2019

Worse performance with the cochlear implant is associated with greater somatosensory cross-modal plasticity.

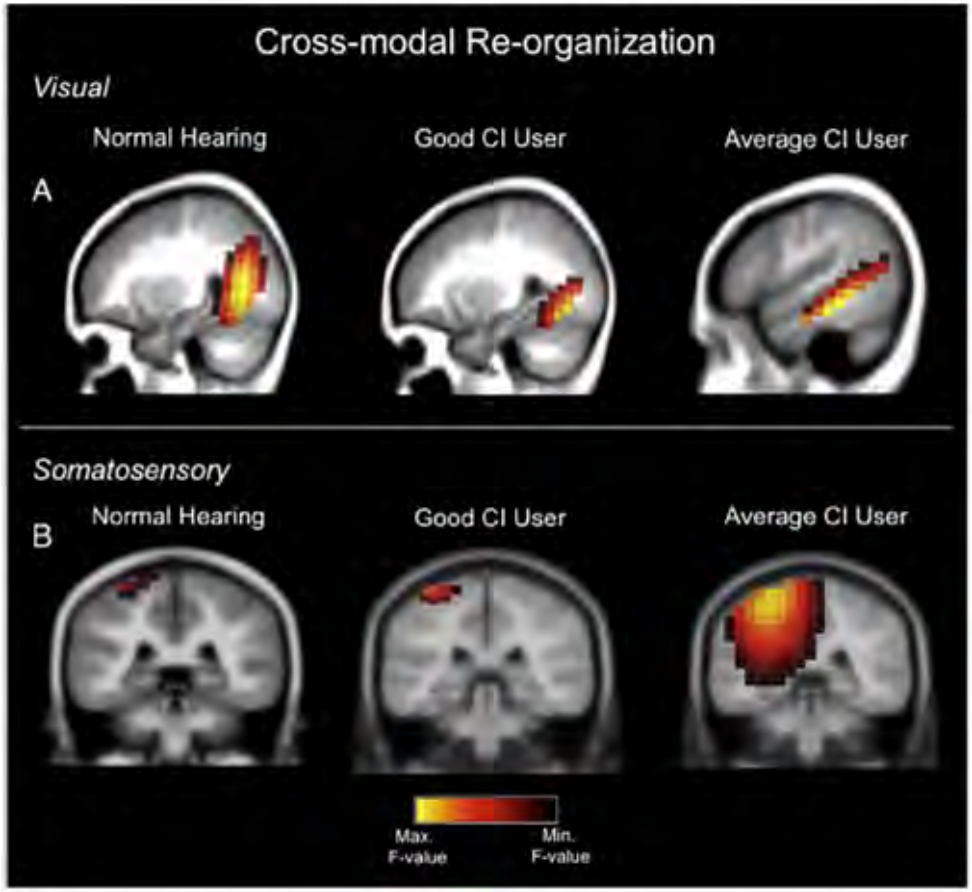






Cardon and Sharma (2019) Frontiers in Neuroscience

Cross-modal plasticity in individual children



Sharma et al., 2014 Intl J Psychophys

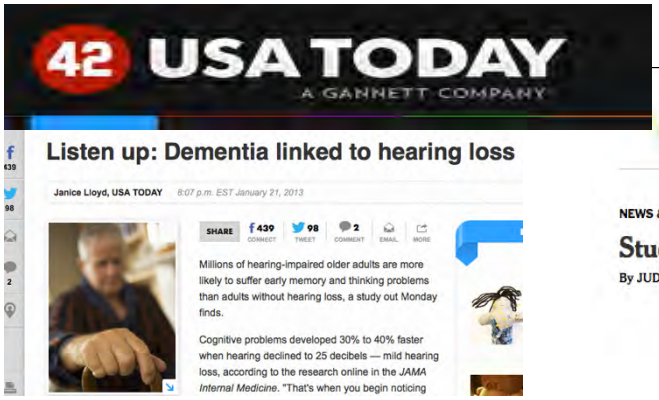
So far, studies have shown evidence of cross-modal plasticity *only* in congenitally and profoundly deaf individuals.

Could it be possible that cortical re-organization starts in much earlier stages of hearing loss?

If so, at what degree of hearing loss would cross-modal plasticity apparent?

Neuroplasticity in age-related hearing loss

Recent research suggests that hearing loss is a significant risk factor for all-cause dementia (including Alzheimer's disease)(Lin et al.,2011, 2012,2014)



Risk of Dementia Increases with Hearing Loss (n=639)

Lin et al., 2011

Mild hearing loss: 2 fold increase
Moderate hearing loss: 3 fold increase
Severs hearing loss: 5 fold increase

Hearing loss may account for up to 9% of the possibly modifiable risk for dementia (Livingston et al., 2020)

Possible reasons for the link between hearing loss and cognitive decline

- *Common link in the aging process.*
- *Social Isolation.*
  - Untreated hearing loss in seniors has been linked to depression, social isolation.
- *Decreased Cognitive Reserve.*
  - Sensory deprivation taxes the brain by changing its normal resource allocation possibly affecting neural/cognitive reserve.

Neuroplasticity of Age-Related Hearing loss

How does the brain adapt, adjust and compensate for age-related hearing loss?

What does degraded auditory input sound like?

Courtesy Michael Dorman

Aim

To explore cortical re-organization associated with mild-moderate age-related hearing loss.

Campbell and Sharma (2013) Frontiers in System Neuroscience, Campbell and Sharma (2014) PloS One,, Sharma and Glick Brain Sciences 2015; Glick and Sharma Hearing Research 2017, Cardon and Sharma, Frontiers in Neuroscience, 2018

Methods

To date, 96 adults with age-related hearing loss and NH controls.

Auditory, *Visual* and *Somatosensory* stimulation paradigms.

QuickSiN Clinical test of Speech Perception in Noise.

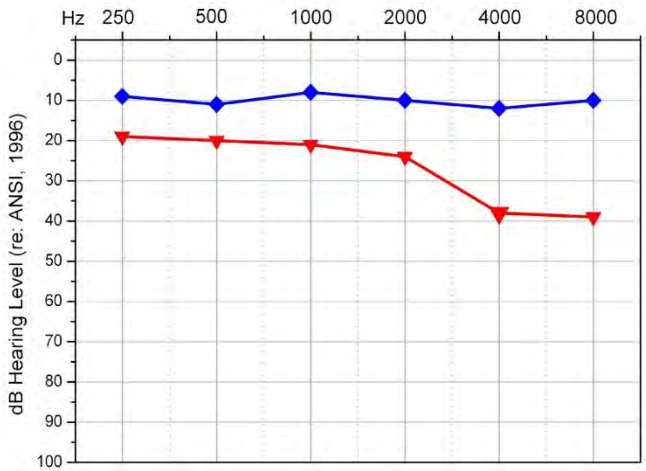
Tests of Global Cognitive Functioning and Executive Functioning (e.g., Working Memory, Processing Speed).

Depression Screener.

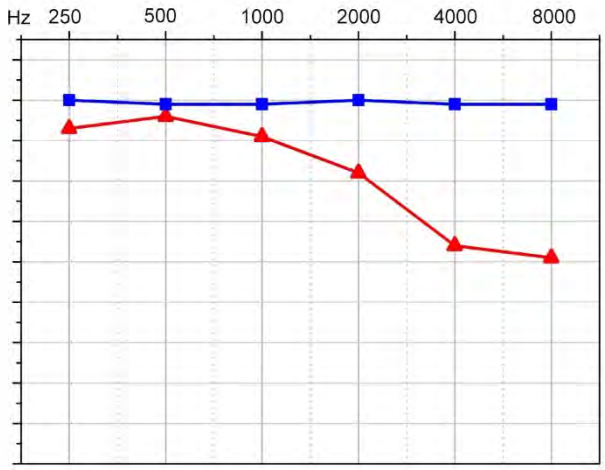
MEAN AUDIOGRAMS n=17

Normal Hearing Group
Hearing Loss Group

Right Ear



Left Ear

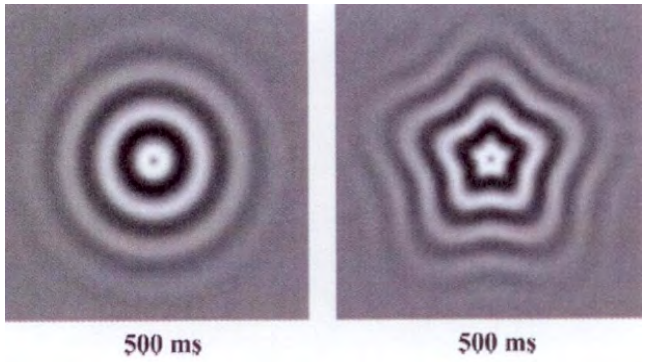


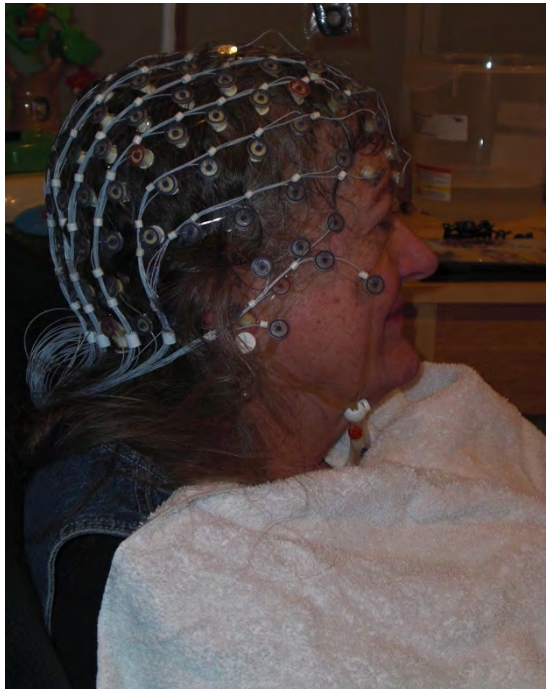
Campbell and Sharma (2014)PloS One

Visual stimulation

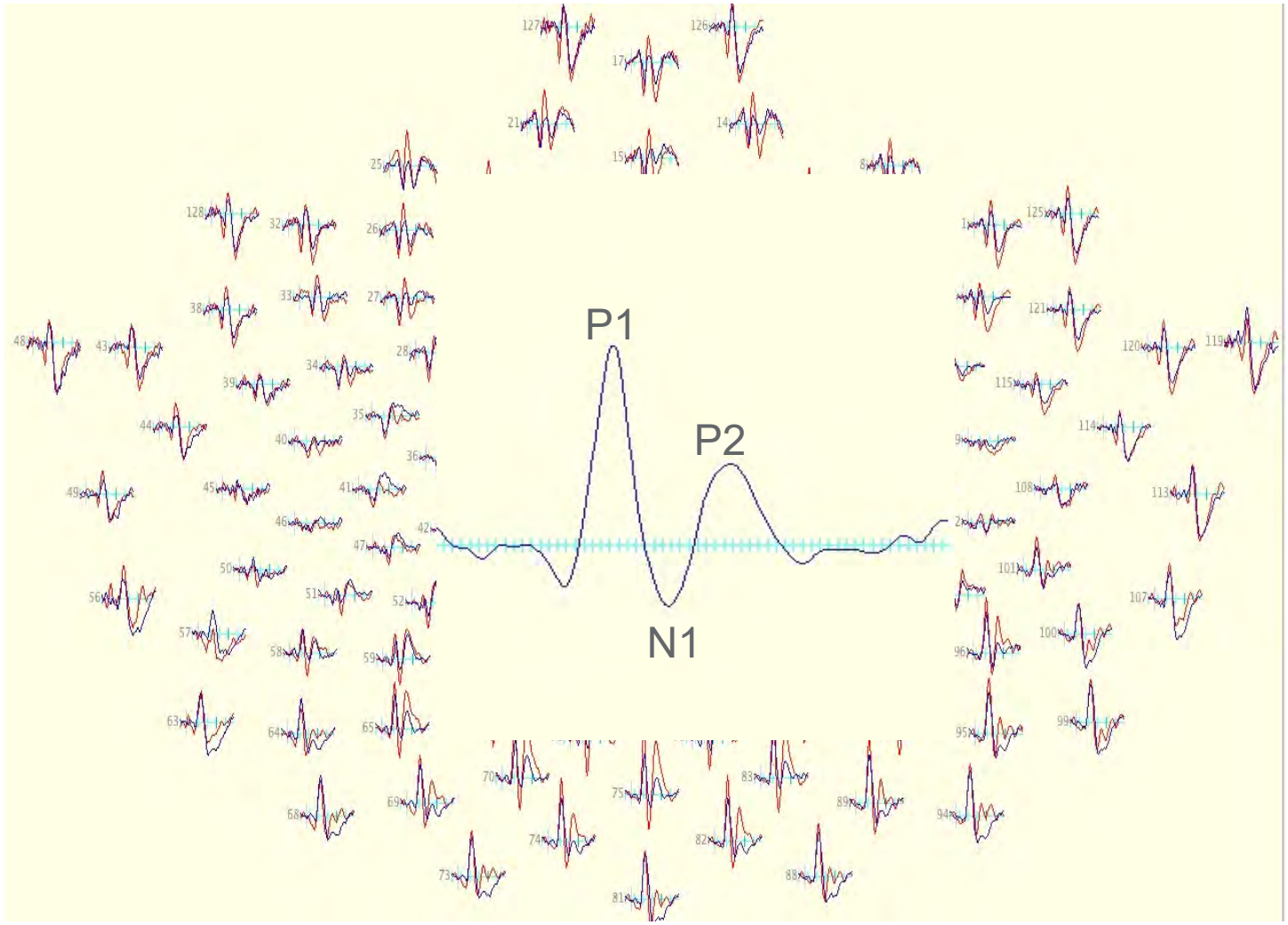
High-density EEG recordings

Visual gradient & motion stimuli

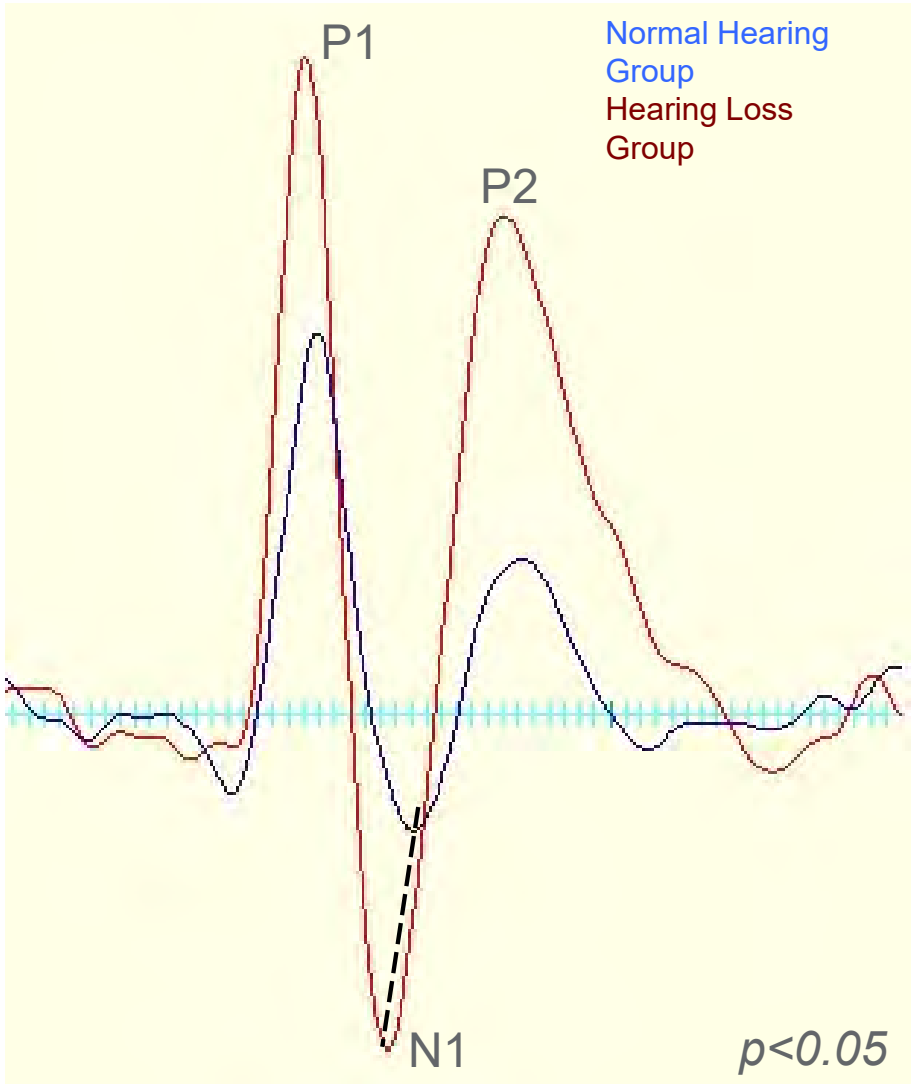




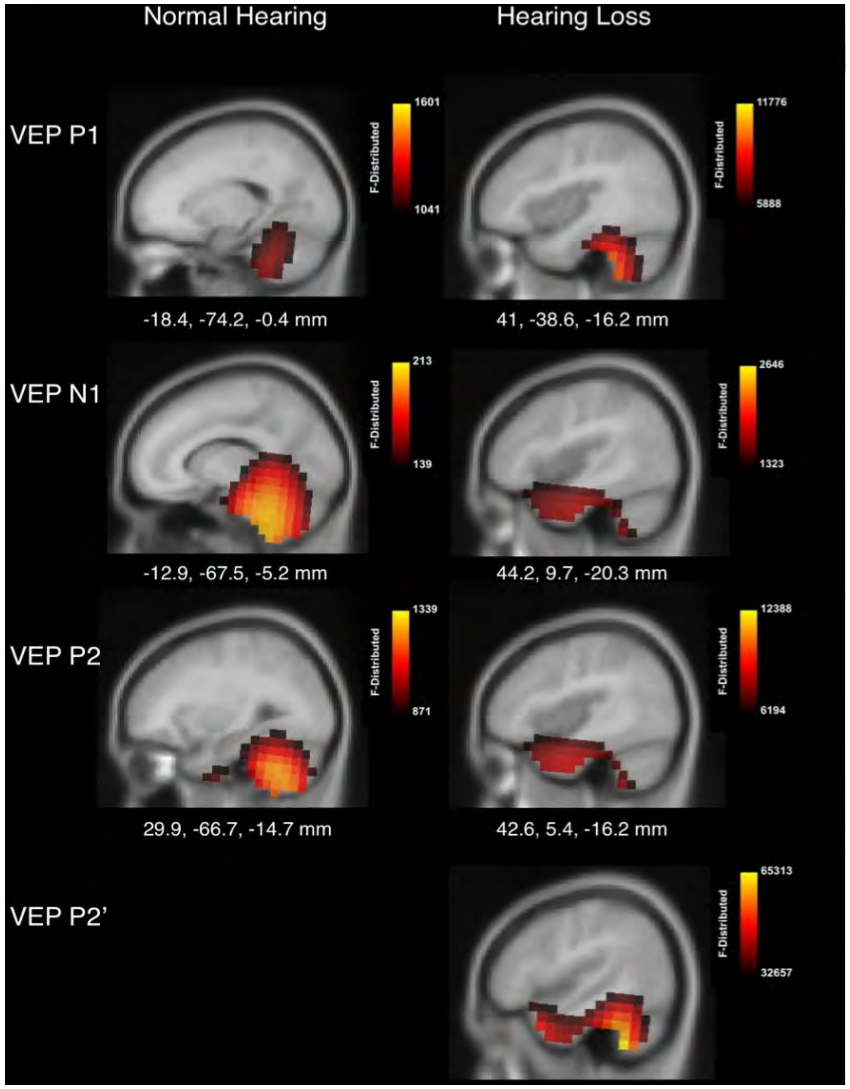
128 channel dense Array EEG Recordings to Visual Stimulation



Grand Average Visual Evoked Responses



Campbell and Sharma (2014) PloS One

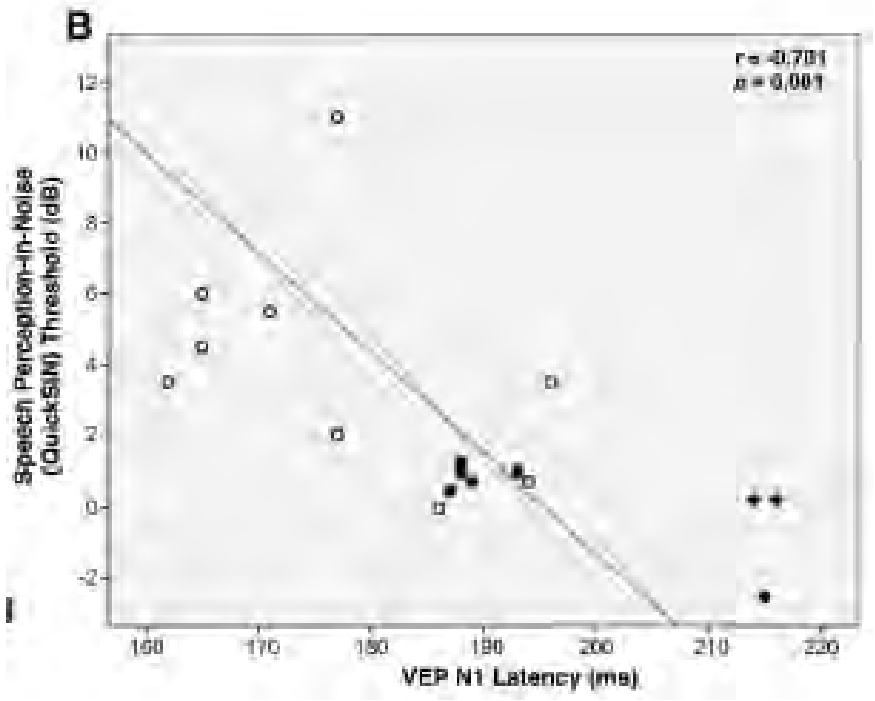


Visual cross-modal re-organization in mild-moderate age-related hearing loss

Campbell and Sharma (2014)
PloS One

Relationship of visual cross-modal plasticity to speech perception?

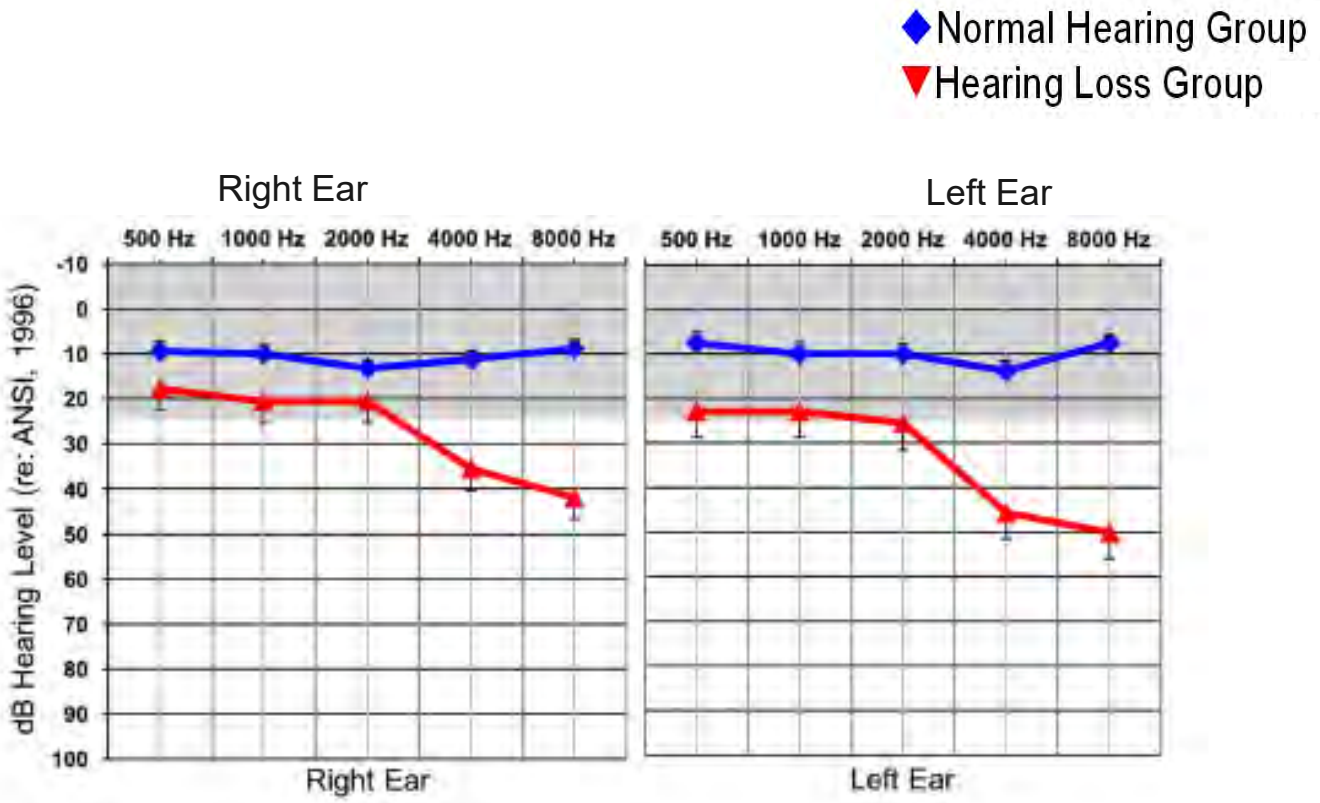
Worse speech perception-in-noise is associated with greater cross-modal plasticity



Campbell and Sharma (2014)
PloS One

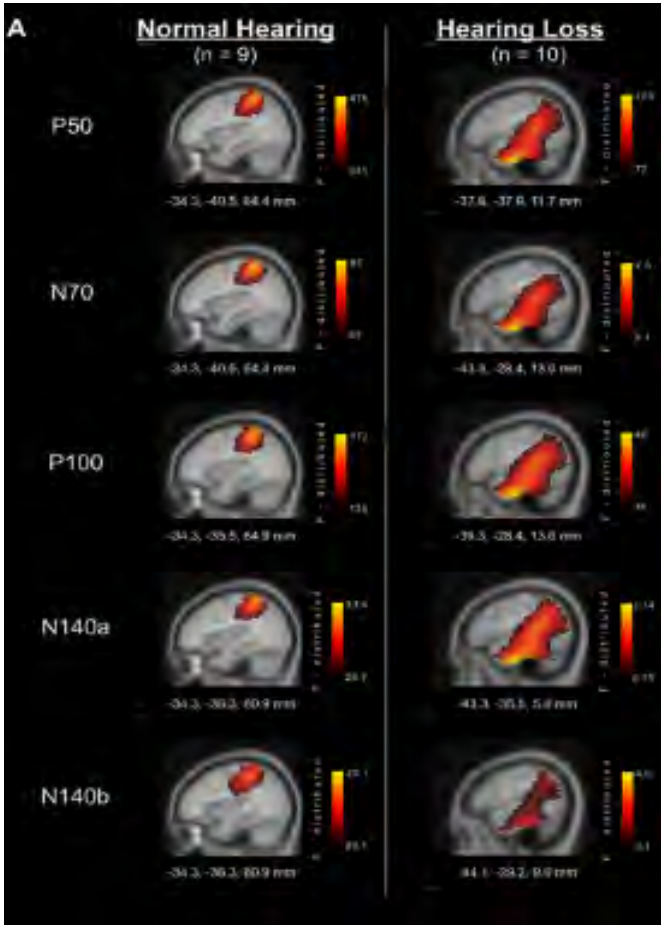
Somatosensory Stimulation

MEAN AUDIOGRAMS n=19



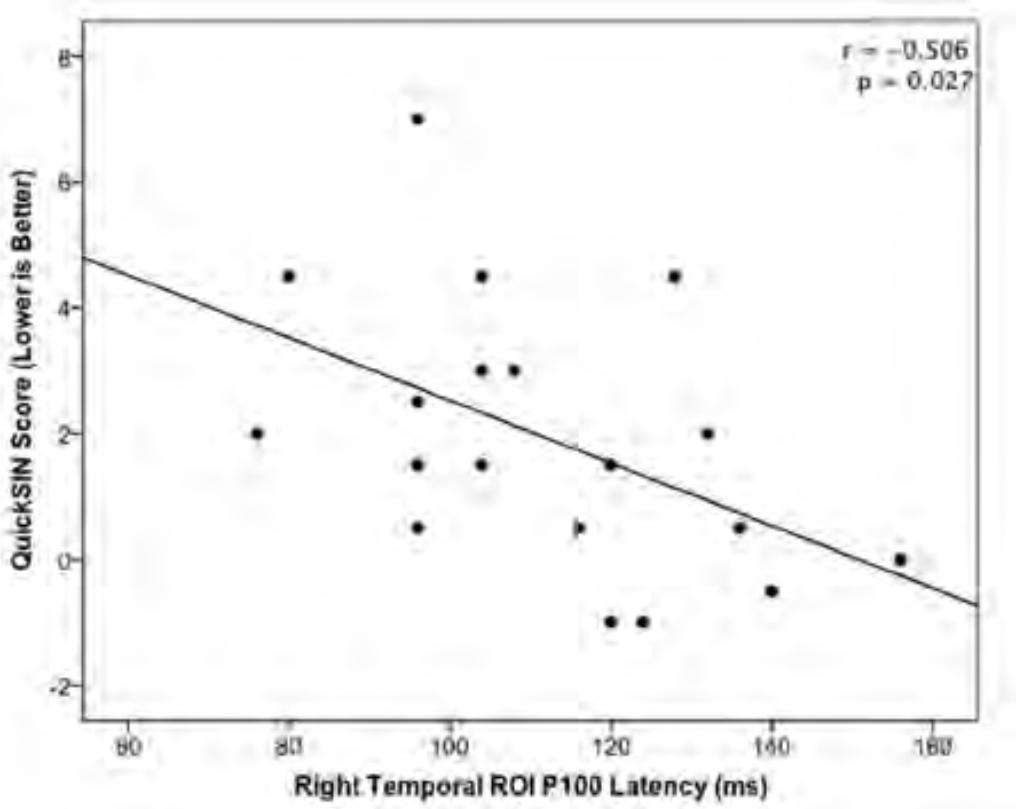
Cardon and Sharma (2018) Frontiers in Neuroscience

Somatosensory cross-modal re-organization in mild-moderate age-related hearing loss



Cardon and Sharma (2018) Frontiers in Neuroscience

Worse speech perception-in-noise is associated with greater cross-modal plasticity



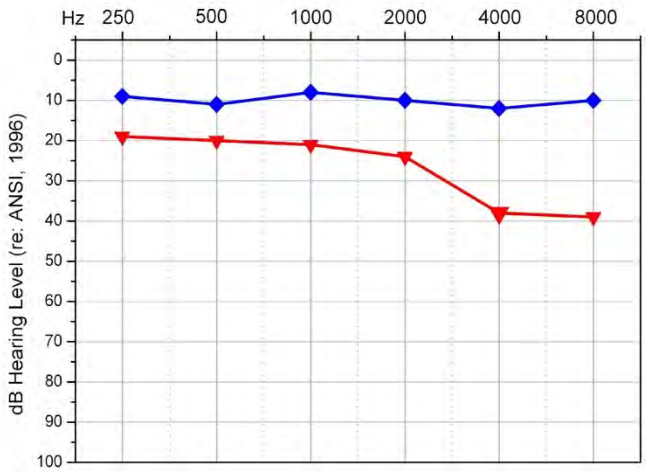
Cardon and Sharma (2018) Frontiers in Neuroscience

Auditory Stimulation

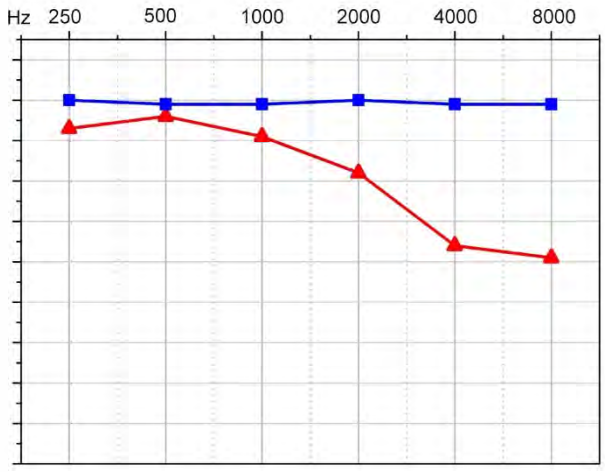
MEAN AUDIOGRAMS (n=17)

Normal Hearing Group
Hearing Loss Group

Right Ear

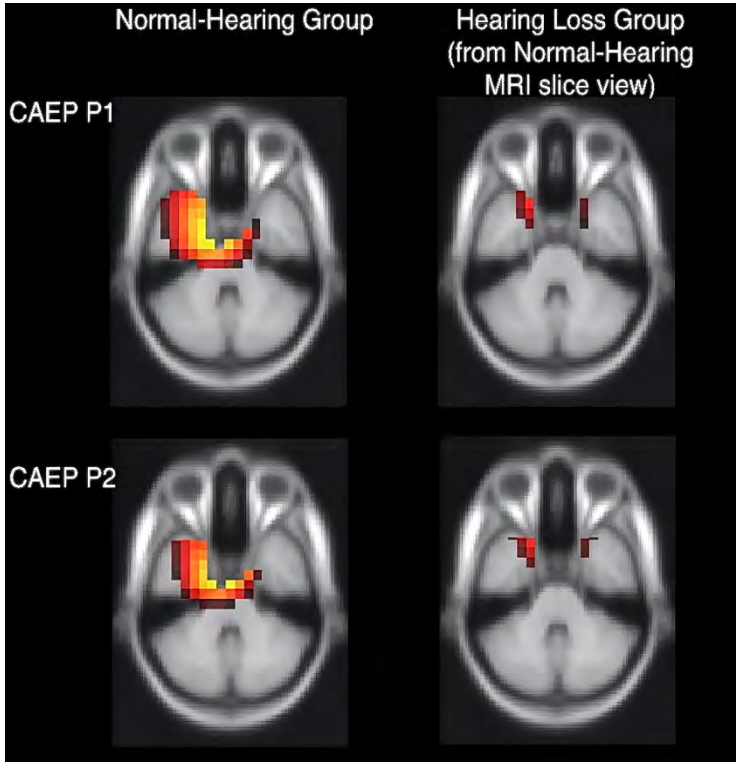


Left Ear



Cardon and Sharma (2018) Frontiers in Neuroscience

Auditory Stimulation: Cortical Activations



Temporal Activation

Limited Temporal Activation

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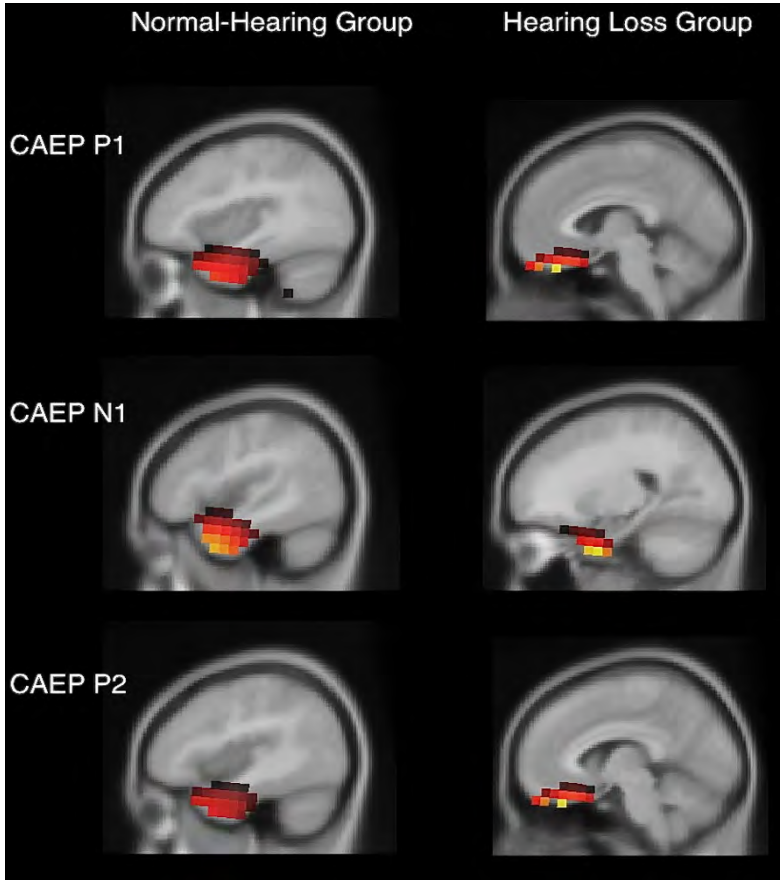

Auditory Stimulation:

Temporal Activation

Frontal Activation

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Frontal and pre-frontal areas are involved in: working memory & executive function, and have been associated with increased listening effort.

(Fakhri et al., 2013, Ong et al., 2013, Obleser et al., 2011, Vagharchakian et al., 2012, Bach et al., 2010, Takeuchi et al.,2013,Talati and Hirsch 2005, Davis and Johnsrude2003, 2007; Peele et al., 2010).

Cortical Re-organization in Mild-Moderate Age-Related Hearing Loss

Reduced auditory cortical activation

Frontal activation to compensate for effortful listening

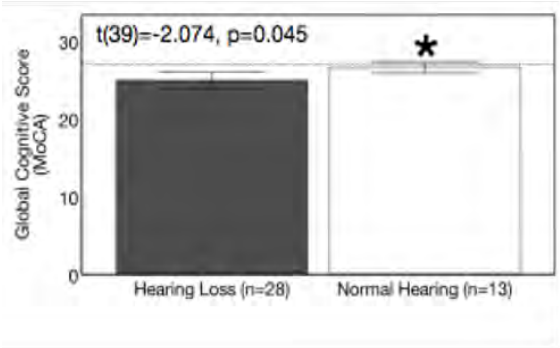
Cross-modal recruitment by vision

Glick and Sharma (2017) Hearing Research

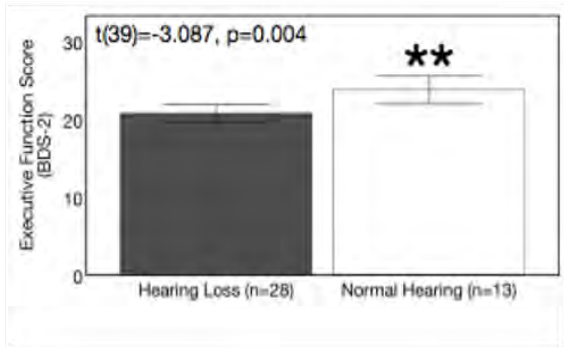
Cognitive function

Deficits in Cognitive Function in Early-Stage Mild-Moderate Hearing loss (n=28; mean age 65)

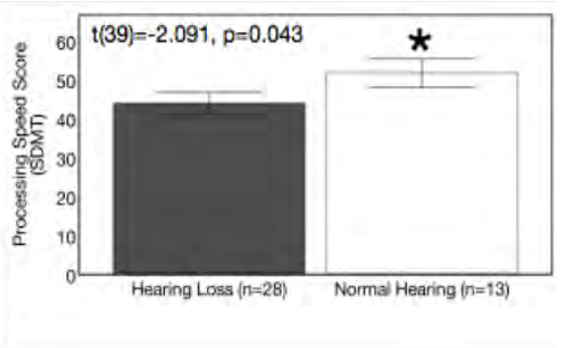
Global Cognitive Function-MoCA



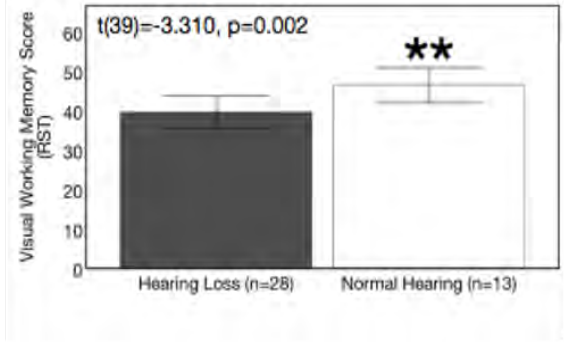
Executive Function (BDS)



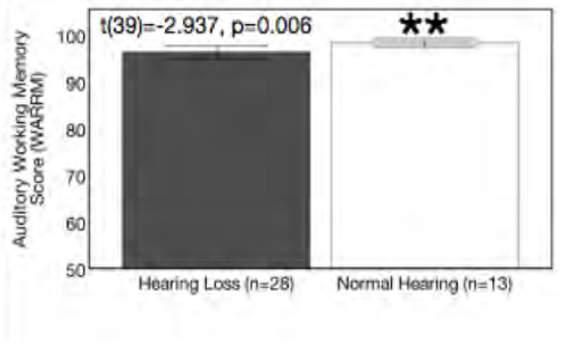
Processing Speed (SDMT)



Visual Working Memory (RST)



Auditory Working Memory (WARRM)



Glick and Sharma, 2020, Frontiers in Neuroscience

Sensory deprivation taxes the brain by changing its normal resource allocation possibly affecting cognitive spare capacity.

Decreased cognitive reserve may be a factor underlying the association between age-related hearing loss and cognitive decline (*Lin et al., 2011, 2012, 2013*)

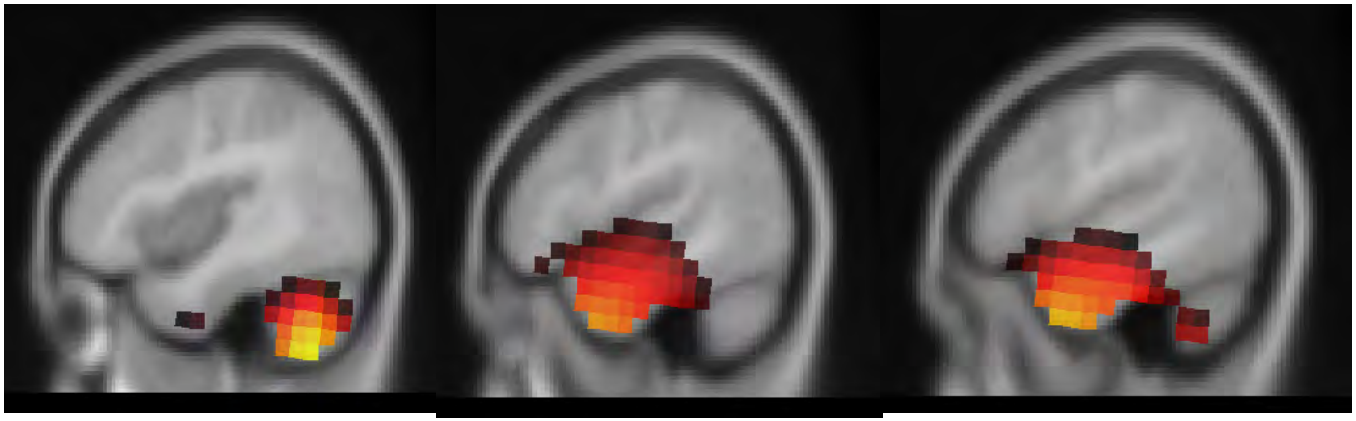
There is evidence of deprivation-induced neuroplastic changes in early stage hearing loss.

How rapidly do these changes occur after HL onset?

Visual cross-modal plasticity: Sudden SNHL case study

Mild sloping to moderate high frequency SNHL following viral infection.

Approx. onset of HL	3 months later	1 year later



Auditory-Visual SpeechReading in Noise	84%	85 %	100 %

Evidence of rapid short-term compensatory plasticity following SNHL

Glick and Sharma (2017) Hearing Research

Neuroplasticity following intervention:

Can amplification reverse compensatory cortical changes?

Six Month Clinical Trial with Hearing Aids for Mild-Moderate Hearing loss

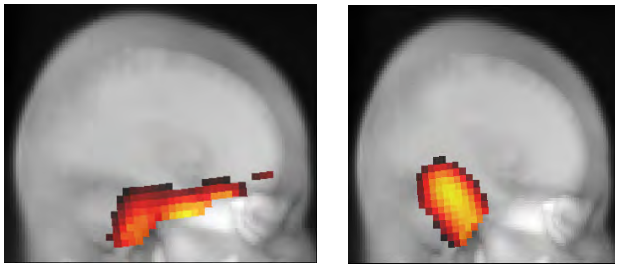
- Bilateral receiver-in-the-ear HAs
- Fit and verified to ±5 dB of NAL-NL2 prescriptive fitting targets for soft (55 dB SPL), medium (65 dB SPL) and loud (75 dB SPL) speech inputs.
- Limited advanced signal processing features (e.g. limited noise reduction, no feedback management) to promote generalizability across manufacturers and to ensure ideal frequency-gain characteristics.
- Inclusion criteria included hearing aid use for 6 hours+ daily.

Mild-Moderate Hearing Loss Six Months After Hearing Aid Use (n=21)

Visual

Before Hearing Aid

After Hearing Aid

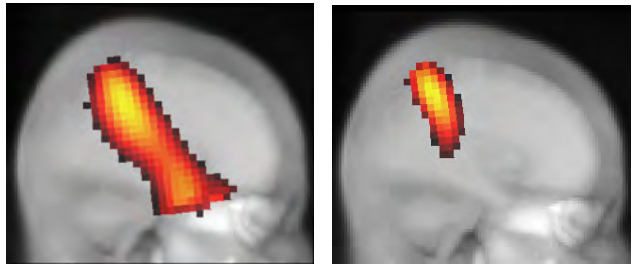


Cross-modal Re-Organization

Somatosensory

Before Hearing Aid

After Hearing Aid



Cross-modal Re-Organization

Cross modal plasticity reversed after 6 months of hearing aid use.

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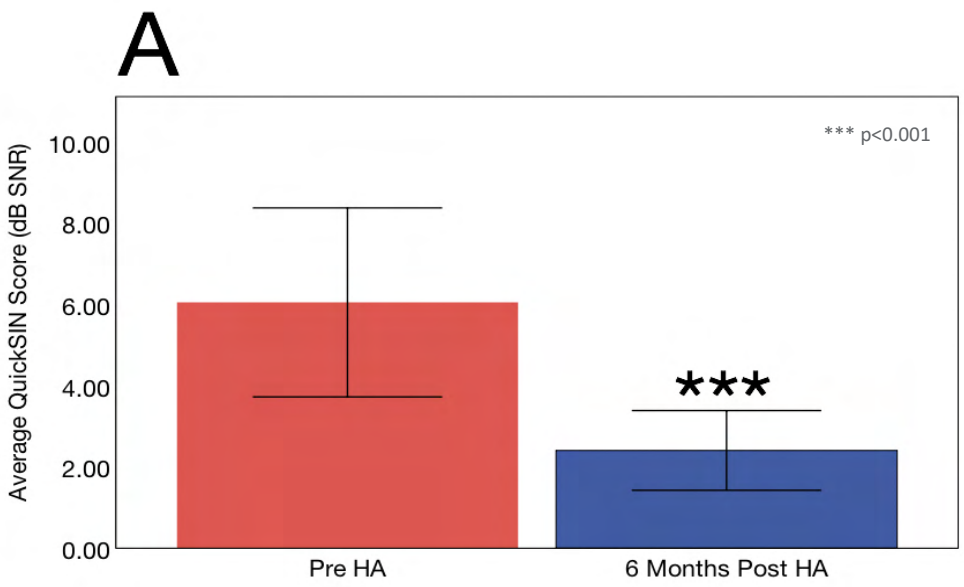
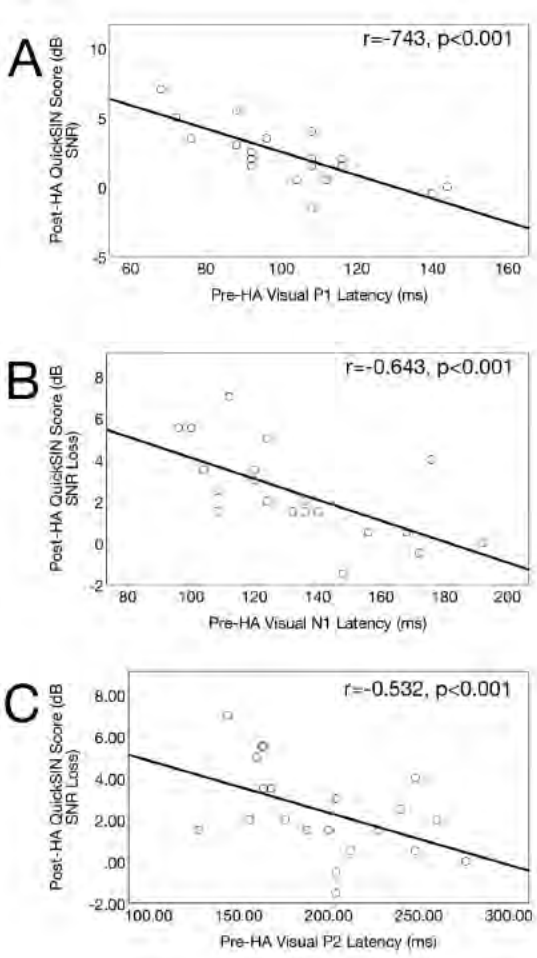
Improvement in Speech Perception in Noise

(pre vs post hearing aid use n=21)





Cross-modal plasticity before hearing aid fitting is associated with worse speech perception-in-noise outcomes with hearing aid use.

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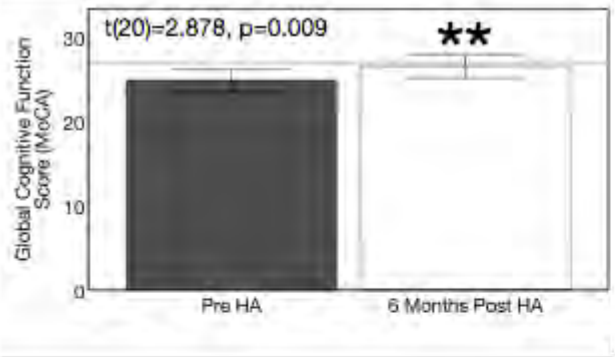
Are there improvements in cognitive functioning after 6 months of hearing aid use?

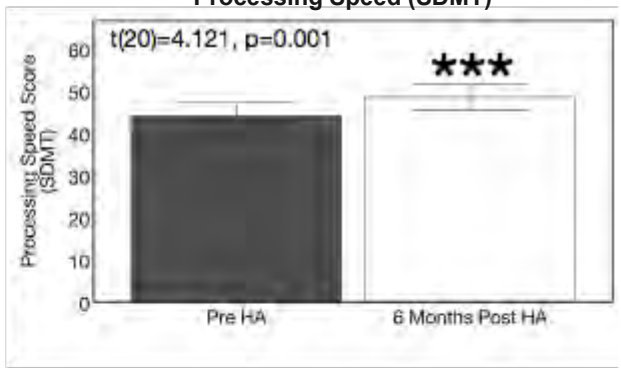
Cognitive function after 6 months of hearing aid use (n=21)

Global Cognitive Function (MoCA)



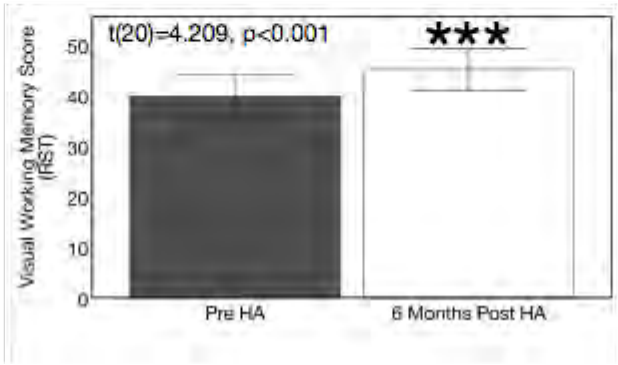
Executive Function (BDS-2)

Processing Speed (SDMT)

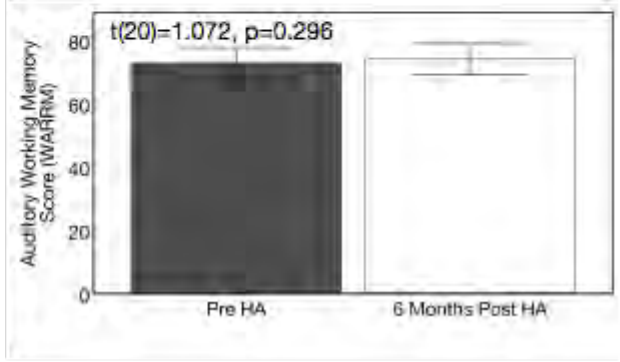


Significant improvements in global cognitive function, executive function, processing speed, and visual working memory in the hearing loss group

Visual Working Memory (RST)



Auditory Working Memory (WARRM)



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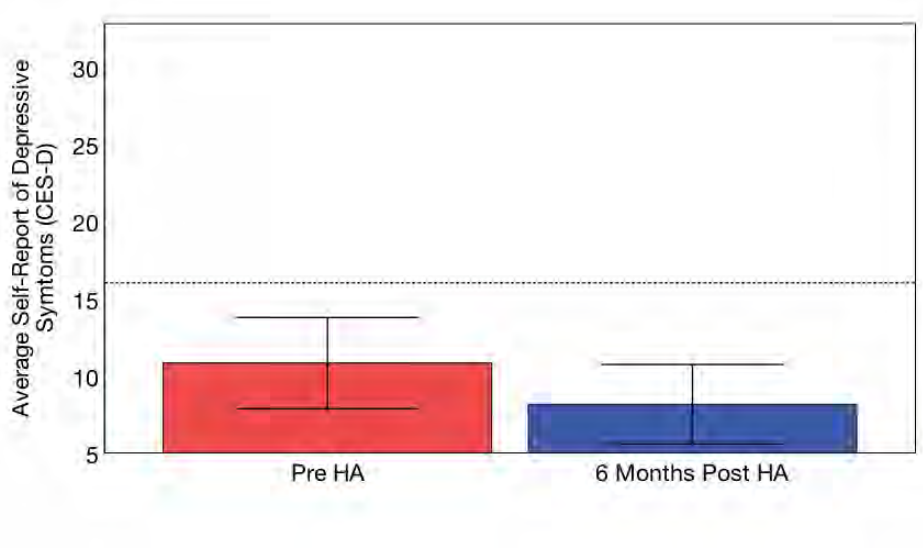
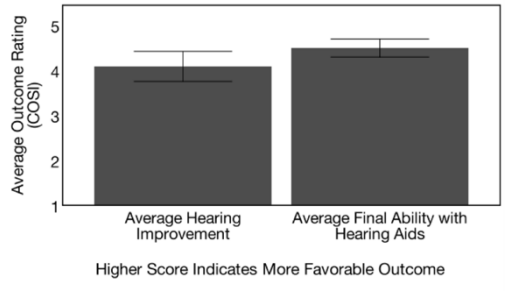
Average Depressive Symptoms (CES-D)



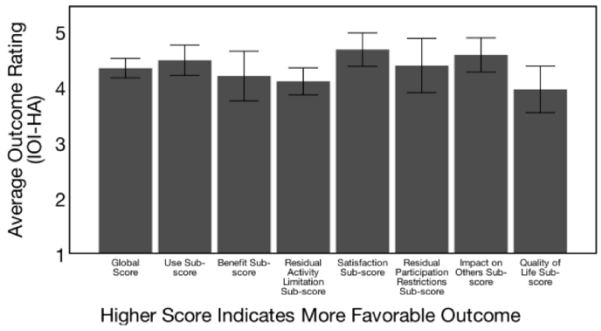
Trend for decrease in depressive symptoms after hearing aid use

Hearing Aid Outcome Questionnaires

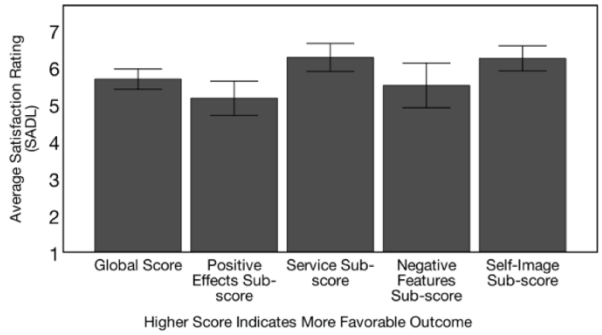
Client Oriented Scale of Improvement (COSI)



International Outcome Inventory for Hearing Aids (IOI-HA)



Satisfaction with Amplification in Daily Life (SADL)



Overall Improvement in Quality of Life with Hearing Aid Use

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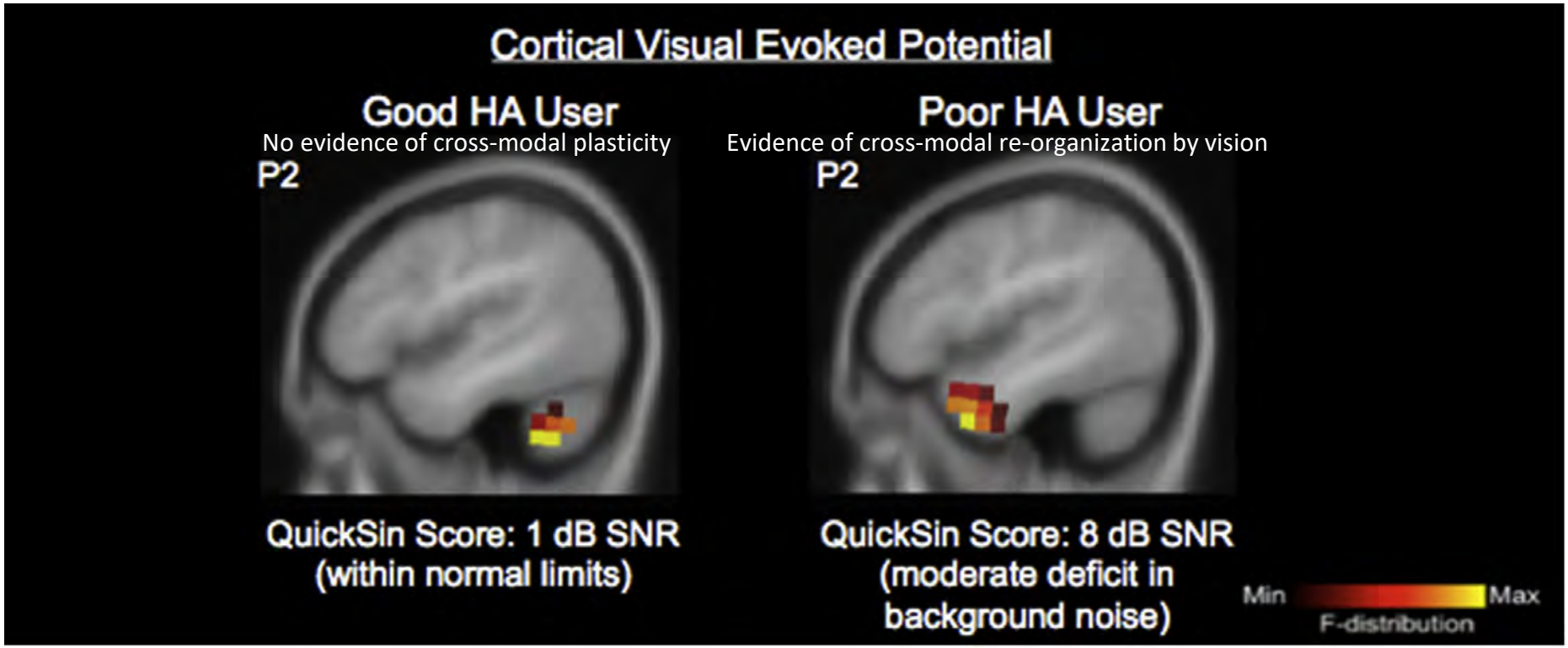
Early and appropriate intervention with amplification is needed in order to restore the gain to the auditory cortex, which likely reverses cortical re-organization and results in good cognitive outcomes.



Glick and Sharma, 2017, Hearing Research

Thank you!

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Website: https://www.colorado.edu/eeglab/

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