Cortical Neuroplasticity in Adult Onset Age-Related Hearing Loss

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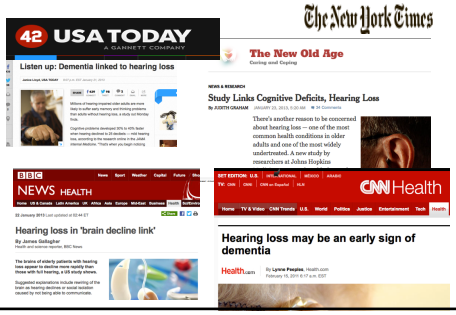
Recent research suggests that hearing loss is a significant risk factor for all-cause dementia (including Alzheimer's disease) (Lin et al.,2011, 2012,2014)



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

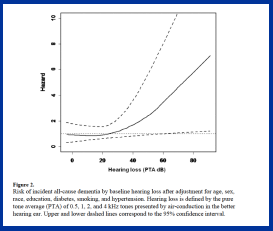


Figure 2.
Risk of incident all-cause dementia by baseline hearing loss after adjustment for age, sex, race, education, diabetes, smoking, and hypertension. Hearing loss is defined by the pure tone average (PTA) of 0.5, 1, 2, and 4 kHz tones presented by air-conduction in the better hearing ear. Upper and lower dashed lines correspond to the 95% confidence interval.

Lin et al., 2011

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

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

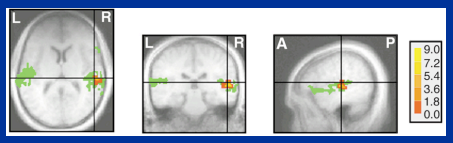
Compensatory Plasticity

A well-known form of cortical re-organization that occurs with sensory deprivation is compensatory cross-modal plasticity.

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

Visual Cross-Modal Plasticity

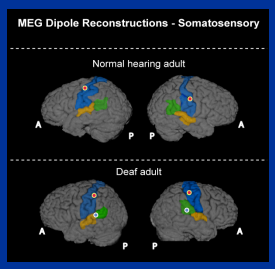
fMRI activity in deaf adults in response to visual stimuli



Visual activity in auditory cortex at STS

Finney et al., 2001

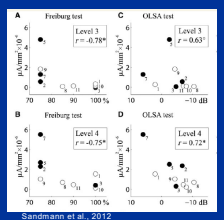
Somatosensory Cross-Modal Plasticity



Sharma et al., 2007

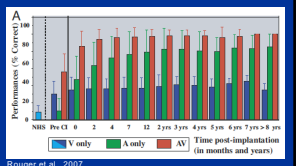
Cross Modal Plasticity: Deaf Adult Cochlear Implant Users

Worse speech only outcomes



Sandmann et al., 2012

Better multisensory outcomes



Rouger et al., 2007

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?

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 (ages 38-74 years).

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

QuickSiN Clinical test of Speech Perception in Noise.

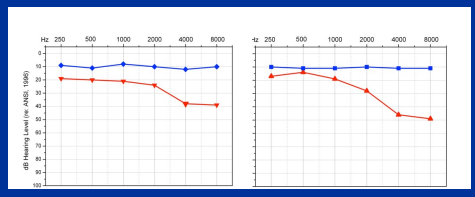
Tests of Global Cognitive Functioning and Executive Functioning (e.g., Working Memory, Processing Speed).

Depression Screener.

MEAN AUDIOGRAMS n=17

◆Normal Hearing Group
▼Hearing Loss Group

Right Ear | Left Ear

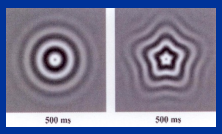


Campbell and Sharma (2014)PloS One

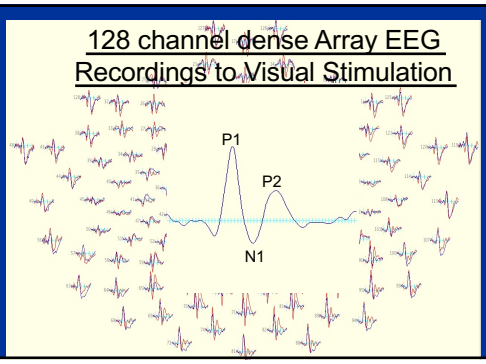
Visual stimulation

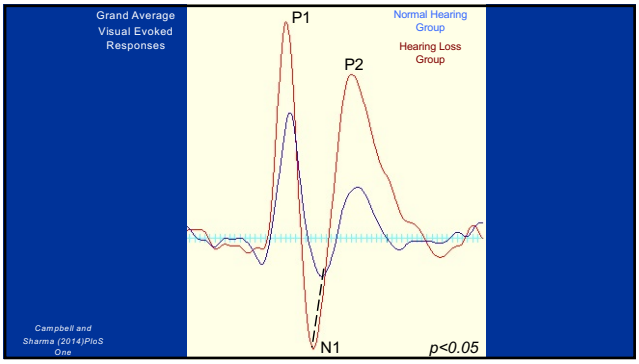
High-density EEG recordings

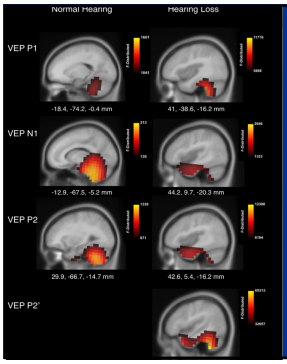
Visual gradient & motion stimuli



128 channel dense Array EEG Recordings to Visual Stimulation





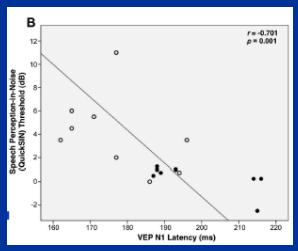


Visual cross-modal re-organization in mild-moderate age-related hearing loss

Campbell and Sharma (2014)PloS

Relationship of visual cross-modal plasticity to speech perception?

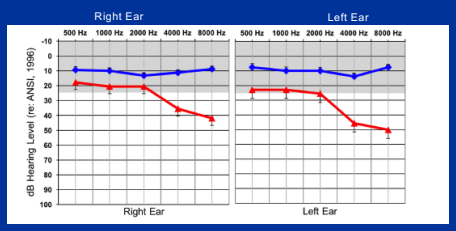
Worse speech perception-in-noise is associated with greater cross-modal plasticity



Campbell and Sharma (2014)PloS One

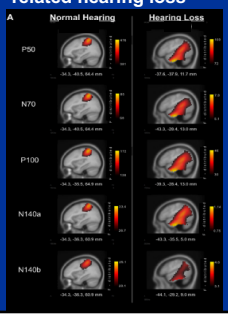
Somatosensory Stimulation

MEAN AUDIOGRAMS n=19



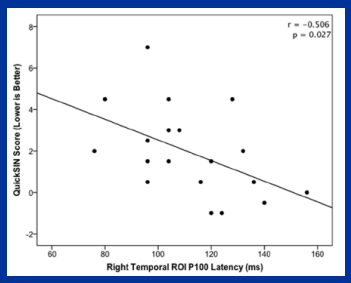
Cardon and Sharma (2018)Frontiers in Neuroscience

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



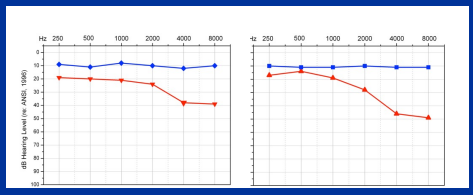
Cardon and Sharma (2018)Frontiers in Neuroscience

Auditory Stimulation

MEAN AUDIOGRAMS (n=17)

◆Normal Hearing Group
▼Hearing Loss Group

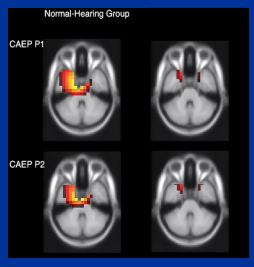
Right Ear



Left Ear

Campbell and Sharma (2013) Frontiers in Systems Neuroscience

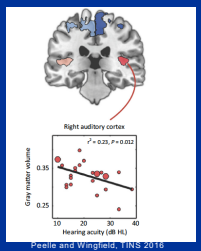
Auditory Stimulation: Cortical Activations



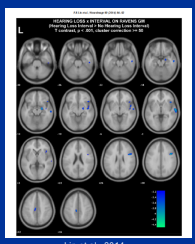
Temporal Activation **Limited Temporal Activation**

Campbell and Sharma (2013) Frontiers in Systems Neuroscience

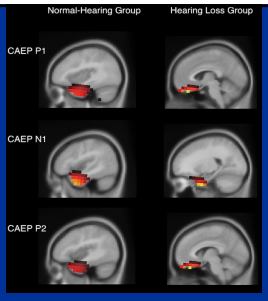
Gray matter volume decreases in right auditory cortex as a function of hearing loss.



Peelle and Wingfield, TINS 2016



Lin et al., 2014



Auditory Stimulation:

Temporal Activation

Frontal Activation

Campbell and Sharma (2013) Frontiers in Systems Neuroscience

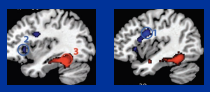
Frontal and pre-frontal areas are involved in:

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) .

Networks involving frontal and pre-frontal cortex areas are activated during effortful listening.

Noise-Vocoded Words



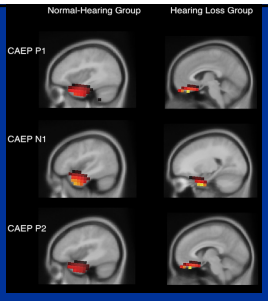
Left inferior frontal gyrus network, frontal operculum; anterior insula, pre-central gyrus, associated with listening effort.

Hervais-Adelman et al., 2012

Words in Noise

Cingulo-opercular network (medial frontal cortex, anterior insula, frontal operculum

Vaden et al., 2013; 2015



Temporal Activation

Frontal Activation

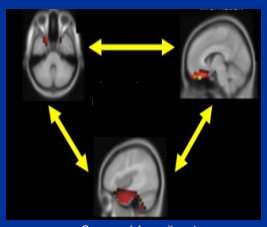
Our data show that frontal cortical areas are activated even during passive listening in age-related hearing loss.

This suggests that possibly all listening is effortful for persons with age-related hearing loss .

Campbell and Sharma (2013) Frontiers in Systems Neuroscience

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

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*)

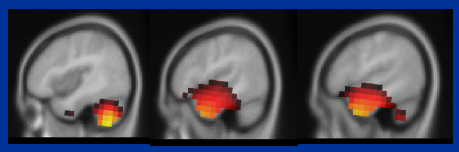
There is evidence of deprivation-induced neuroplastic changes in early stage hearing loss.

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?

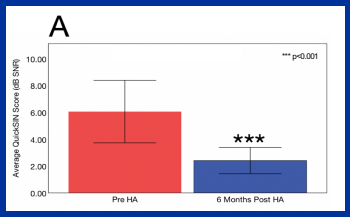
Six Month Clinical Trial with Hearing Aids for Mild-Moderate Hearing loss

HEARING AID FITTING AND VERIFICATION

- 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.

Improvement in Speech Perception in Noise

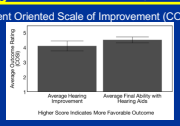
(pre vs post hearing aid use n=21)



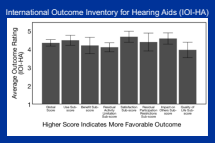
Are there improvements in cognitive functioning after 6 months of hearing aid use?

Hearing Aid Outcome Questionnaires

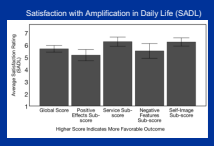
Client Oriented Scale of Improvement (COSI)



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

Early and appropriate intervention allows for reversal of cross-modal plasticity and good cognitive outcomes.

However is this always the case?

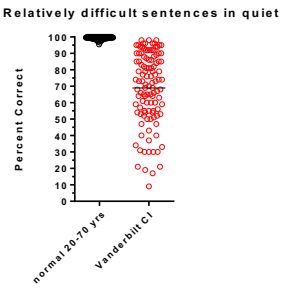
Long-term hearing aid users from local clinics

Participants had moderate-severe hearing loss and were underfit with amplification. Speech Intelligibility Index (SII) of 0.44.

Amplification needs to be appropriately fit to provide the gain needed for reversing cross-modal plasticity and improving cognitive outcomes.

What about cochlear implants?

Cochlear Implants in Adults

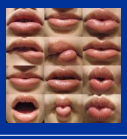


Courtesy Michael Dorman

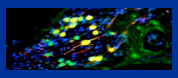
Simulation of successful cochlear implantation

Courtesy Michael Dorman

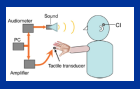
- When intelligibility is poor—how can we harness neuroplasticity to improve real world outcomes?



Training paradigms which take advantage of better auditory-visual integration? Or training working memory or executive function so cognitive spare capacity can be distributed more efficiently?



Enhancing neuroplasticity in combination with intervention using pharmacology or stem cells?



Tactile Aid was applied to the index finger which converted fundamental frequency to vibrations.

Huang et al., 2017, Nature Scientific reports

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

SUMMARY

Diminished and degraded speech input in age-related hearing loss results in cortical compensation.

Evidence of compensatory cross-modal re-organization from visual and somatosensory modalities in untreated mild-moderate hearing loss.

Further, there is a decrease in auditory cortex activation, and additional activation of frontal networks suggesting suggestive of effortful listening.

Overall, our data suggest that sensory deprivation changes the normal cortical resource allocation and is associated with cognitive deficits.

CONCLUSIONS

Compensatory cortical networks appear to be activated in early stages of age-related, adult-onset hearing loss.

Appropriate and early intervention with well-fitted hearing aids and cochlear implants may be useful in restoring normal cortical resource allocation.

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