MEASURING BRAIN CHANGES IN HEARING LOSS AND ITS REMEDIATION

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Hearing and the brain: Translating research into practice

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Plan of Talk

(1) Hearing loss and brain function

(2) How does the brain interpret signals from a cochlear implant?

(3) MEG III: A new window into brain function in cochlear implant recipients

Hearing loss and brain function

Hearing loss alters the functioning of the central auditory system – and higher cognitive and linguistic centers of the brain – in ways that are not currently understood and in ways that are not necessarily reversed even if hearing can be restored.

These alterations have important implications for both clinical and basic science.

- **Clinical implications**: Central alterations are crucial determinants of the success of cochlear implants
- **Basic science implications**: By providing input into a system that has experienced profound deprivation, cochlear implants provide a unique opportunity to evaluate the effects of cortical reorganization and plasticity in the human brain

Sensory deprivation as an experimental tool

- Altering or interrupting the normal flow of sensory information provides a powerful tool for studying the functional organisation of the brain.
- Over the last century, neuroscientists have been richly rewarded by studying the consequences of such manipulations in animals and humans.

Sensory deprivation as an experimental tool

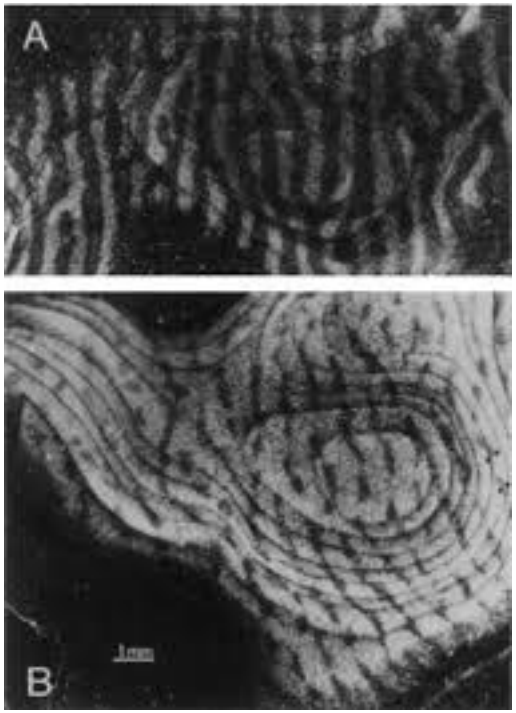
A few of the insights obtained from this approach:

(1) Cortical circuits and representations are established and maintained through **activity-driven refinement of connections** (e.g. Hubel et al. 1977; Merzenich et al., 1983)

Ocular dominance columns in macaque area 17

Normal Adult

Right eye surgically closed from 2 weeks
Label in left eye

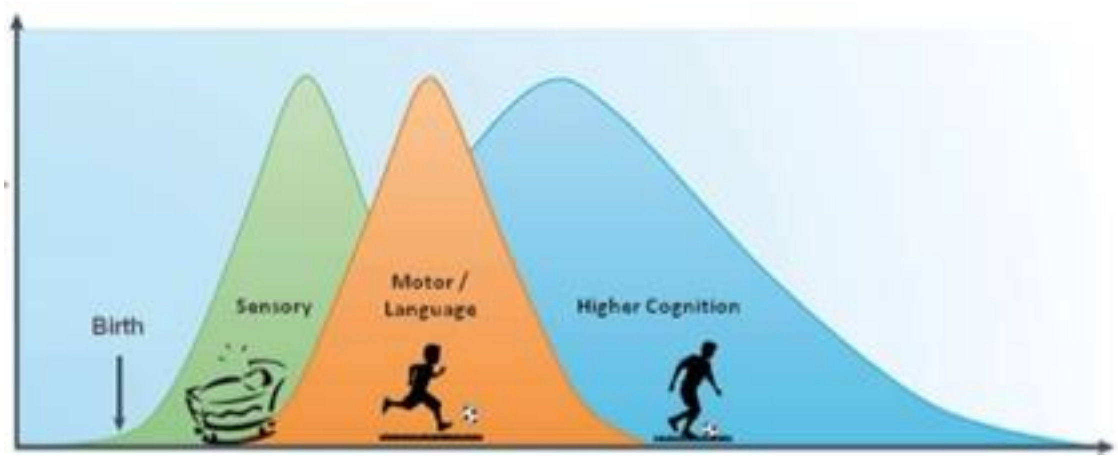


Sensory deprivation as an experimental tool

(2) There are **critical or sensitive periods** during which a system must receive appropriately patterned inputs to attain normal function (e.g. Hubel and Weisel, 1968; Hubel, Weisel and LeVay, 1977);

Windows of plasticity in brain development

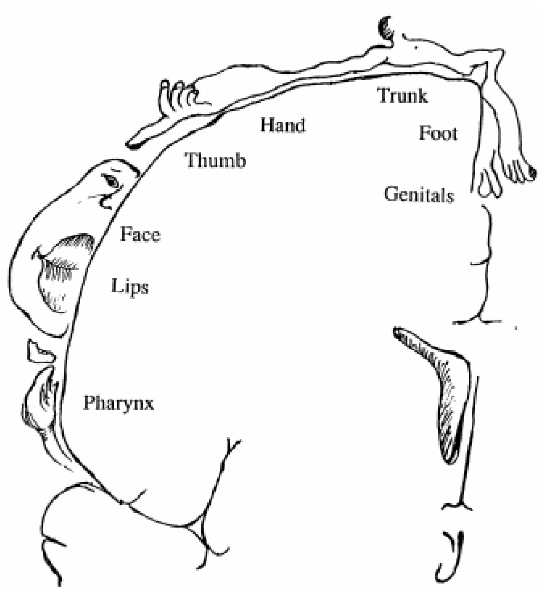
Plasticity



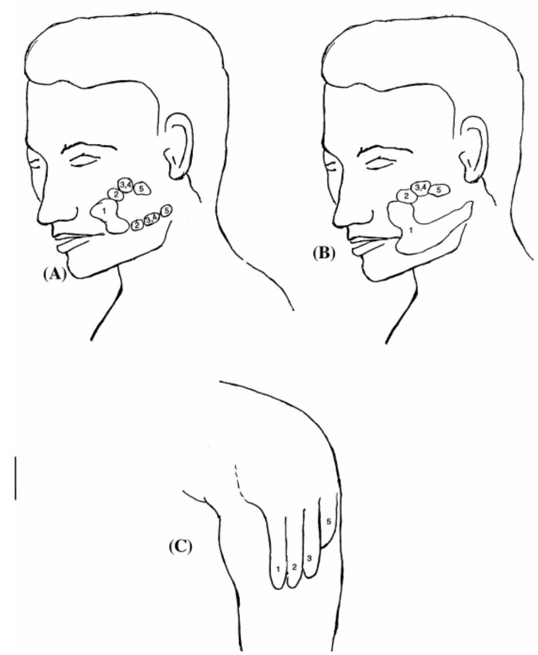
Development

Sensory deprivation as an experimental tool

(3) The **adult brain retains a substantial capacity for functional reorganisation** (plasticity) of sensory representations (Merzenich et al., 1983; Ramachandran, 1993).



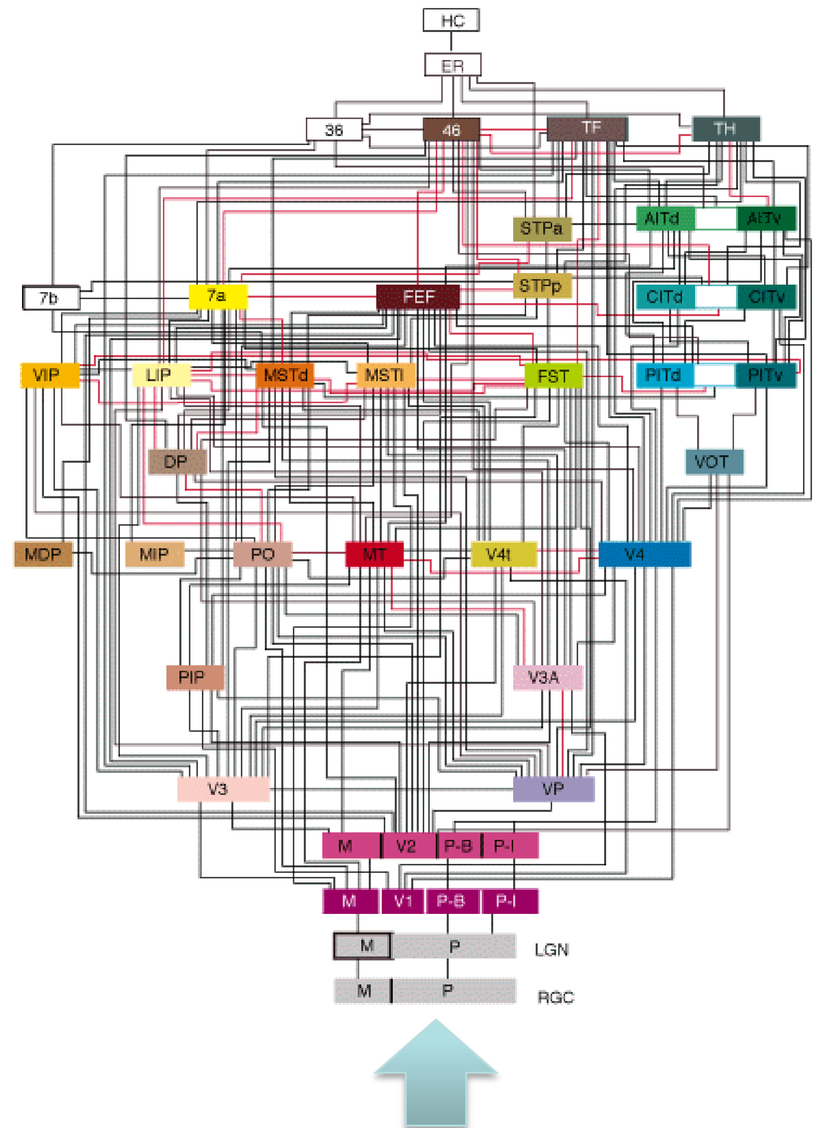
Somotosensory Homonculus



Phantom Limb Perception

Sensory deprivation as an experimental tool

(4) The **effects of sensory deprivation can cascade** through the brain, altering functioning at multiple levels of processing (Maurer & Hensch, 2012; Kolb & Teskey, 2010)



Sensory Input

Cochlear implants and the human brain

The advent of cochlear implants provides us with a novel and powerful experimental approach to study

- the ***effects of deafness*** on the human auditory system
- the ***capacity of the system to re-organise*** after the re-establishment of sensory inputs
- ***variations in this capacity*** over the lifespan
- ***functional interactions*** of the auditory system with higher order cognitive systems including reading and language

A top-down approach

- The main work in cochlear implant research to date has been directed at replicating the function of the cochlea, a "bottom-up" approach
- As the technological capacity to bypass the cochlea has increased, it has become increasingly clear that implant performance depends not only on the quality and clarity of the input signal, but also ***on the ability of the brain to interpret that signal***

Wilson and Dornan (2008): "A fundamentally new approach may be needed to help those patients presently at the low end of the performance spectrum… They may have ***compromised 'auditory brains'*** as suggested by…many recent findings."

A top-down approach

An emerging theme

- Incorporate a “top-down”, cognitive neuroscience-based approach to better understand how the cochlear implant and the human brain interact.
- Deafness does not simply remove the auditory input; it has a fundamental impact on organisation at cortical levels far removed from the auditory periphery.

Significance

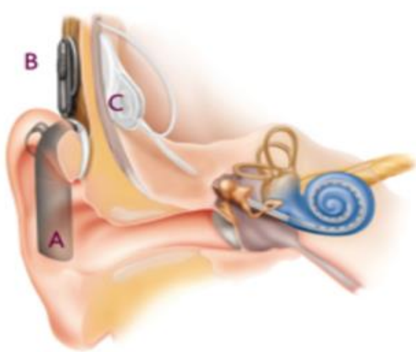
- Taking a more comprehensive approach to cochlear implant research has important implications for both clinical rehabilitation and basic cognitive science, and is likely to have translational benefits for other disorders of language, reading and cognition.

A top-down approach

- Asks: “What does the brain need for **effective input**, given the brain changes due to a lack of natural inputs?”
- “Effective” patterns of stimulation might be different than those specified by a focus on replicating the signals from the normally functioning auditory nerve.
- Effective rehabilitation strategies will increasingly rely on research that disentangles the relative roles of the sensory periphery and the higher level functions of the cerebral cortex

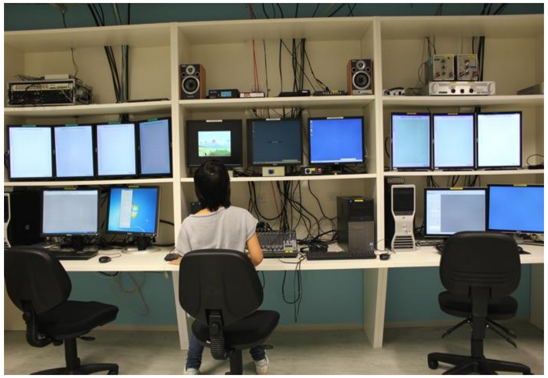
A barrier to top-down research

- A fundamental barrier to a top-down approach to cochlear implant research has been a paucity of methods for measuring brain function in implant recipients.
- The ferromagnetic materials and electronic components in most commercial cochlear implants are incompatible with neuroimaging methods like fMRI and MEG.



KIT-Macquarie Brain Research Lab

Magnetoencephalography (MEG): A functional brain imaging technique. Better temporal resolution than fMRI, better spatial resolution than EEG.

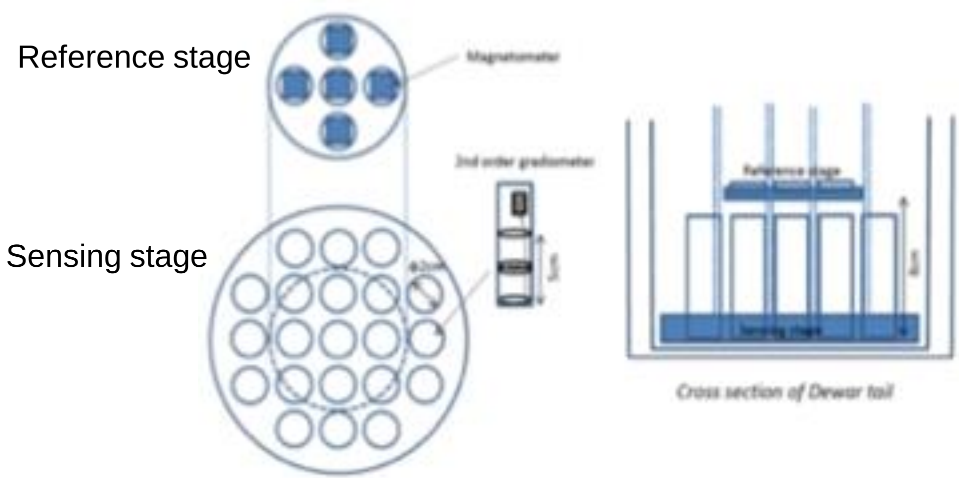


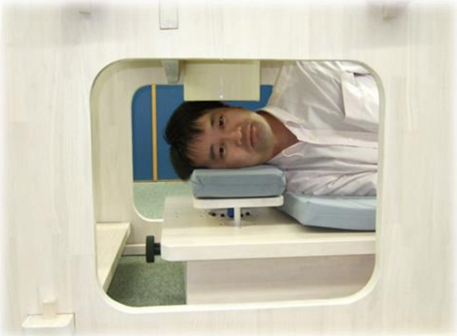
- **MEG I** (Adults): 160 channels, 1st order axial gradiometers

- **MEG II** (Children): 120 channels, 1st order axial gradiometers

A new window into brain function of CI recipients

MEG III (cochlear implant recipients)





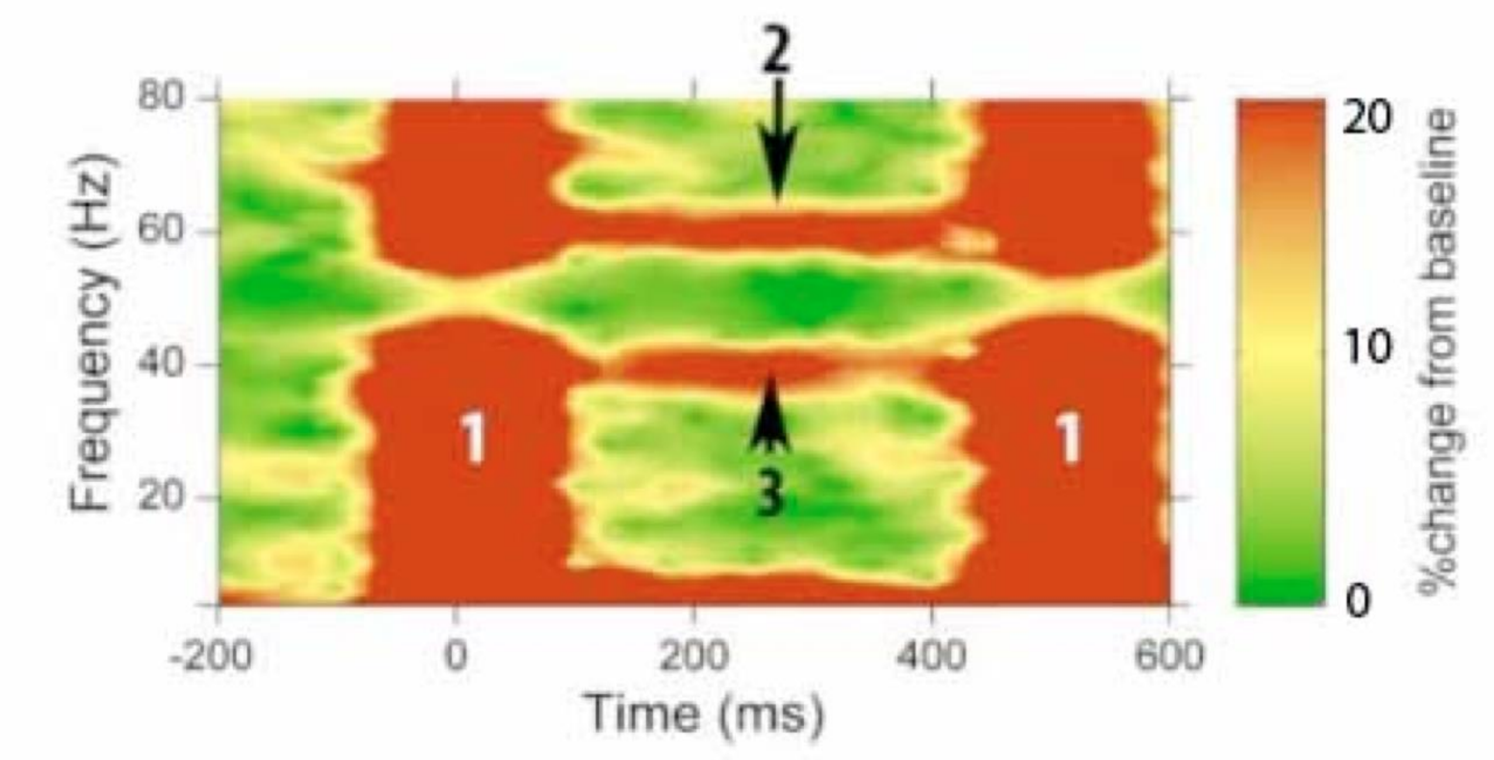
Three important aspects of design:

(1) Second order gradiometers for sensing stage;

(2) Reference stage consisting of multiple fluxgate magnetometers;

(3) Recording contralateral to implant.

MEG III: Cochlear Implant Emulator



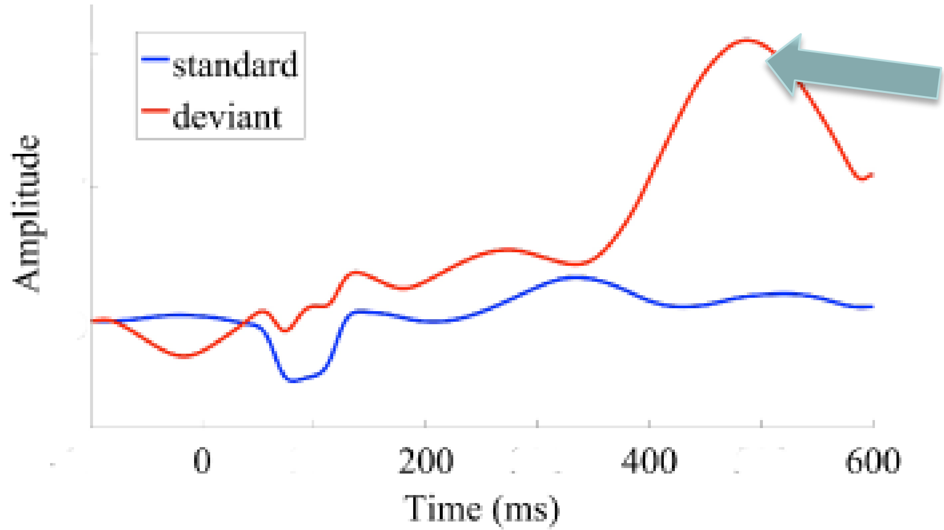
(1) Onset/offset artifacts

(2) Simulator fields frequency tagged at 60 Hz

(3) Brain fields frequency tagged at 40 Hz

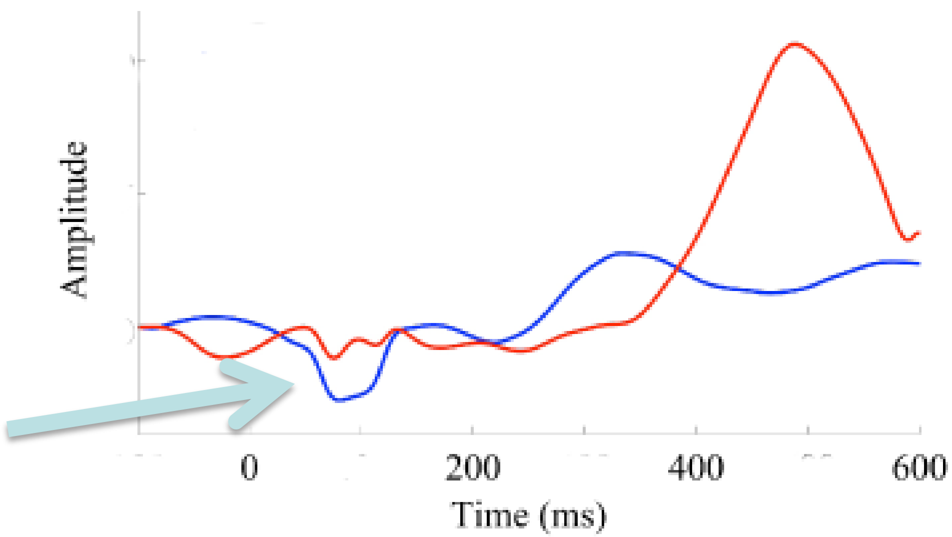
MEG III: Unilateral Cochlear Implant Recipient

Recording 1



P300m

Recording 2



CI artifact

A central challenge of the 21st century

How can the human brain communicate with artificial prosthetic devices? What are the limitations and constraints upon those communications?

MEG III:

- will advance our understanding of ***central auditory processing disorders due to hearing loss***;
- will advance our understanding of ***how the brain interprets signals from a cochlear implant***;
- provide ***objective neurophysiological targets*** for improving training strategies for cochlear implant recipients;
- will inform subsequent research on the ***bionic eye***, the ***hippocampal prosthesis***, and ***brain computer interfaces*** to mechanical output devices.

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