

Recording electrophysiology in deep brain structures

Dr. Christian Herff

c.herff@maastrichtuniversity.nl



Epilepsy

- Epilepsy is a group of neurological disorders characterized by epileptic seizures.
- Epileptic seizures are episodes that can vary from brief and nearly undetectable periods to long periods of vigorous shaking.
 - These episodes can result in physical injuries
- In epilepsy, seizures tend to recur and, as a rule, have no immediate underlying cause.
- Isolated seizures that are provoked by a specific cause such as poisoning are not deemed to represent epilepsy

Prevalence

- 50 million people have epilepsy (2018) (0.5-1% of population)
- Nearly 80% of cases occur in the developing world.
- 125,000 deaths annually (2015)
- Cause of most cases of epilepsy is unknown.
 - 60% idiopathic epilepsy (has no identifiable cause)
- Some cases occur as the result of:
 - brain injury
 - Stroke
 - brain tumor
 - infections of the brain
- Epileptic seizures are the result of excessive and abnormal neuronal activity in the cortex of the brain.
- Epilepsy can often be confirmed with an electroencephalogram (EEG)

- Seizures are controllable with medication in about 70% of cases.
- In those whose seizures do not respond to medication, **surgery or neuromodulation** may then be considered



Seizure Classification

- Where in the brain does the seizure start?
 - Focal onset (only one side of the brain)
 - Generalized onset
 - Unknown
- Level of Awareness
 - Aware
 - Impaired Awareness
- Does the seizure involve movement
 - Motor seizures
 - Non-motor seizures

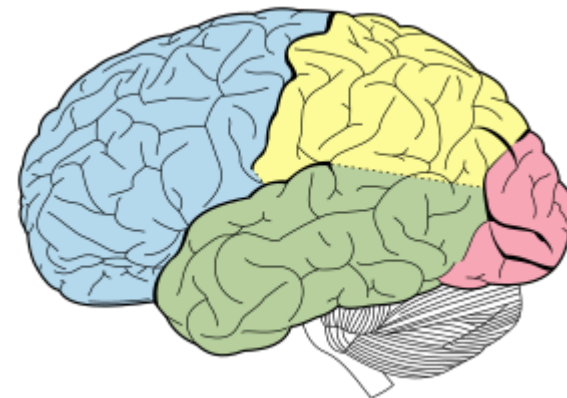


Epilepsy Surgery

- Neurosurgical procedure where an area of the brain involved in seizures is either resected, disconnected or stimulated
- Requires detailed knowledge of epileptogenic zone (seizure focus)
- Only for focal seizures

Temporal Lobe Epilepsy

- Most common form (30%)
- Seizures originate in temporal lobe, hippocampus or insula
- Often caused by Hippocampal sclerosis
- Patients often feel seizures coming from gut, followed by foul taste in the mouth
- Hard to control with medication



Frontal Lobe Epilepsy

- Very different types of seizures
- Complex automatisms, even speech
- Short duration of confusion after seizure indicates frontal lobe epilepsy

Parietal Lobe Epilepsy

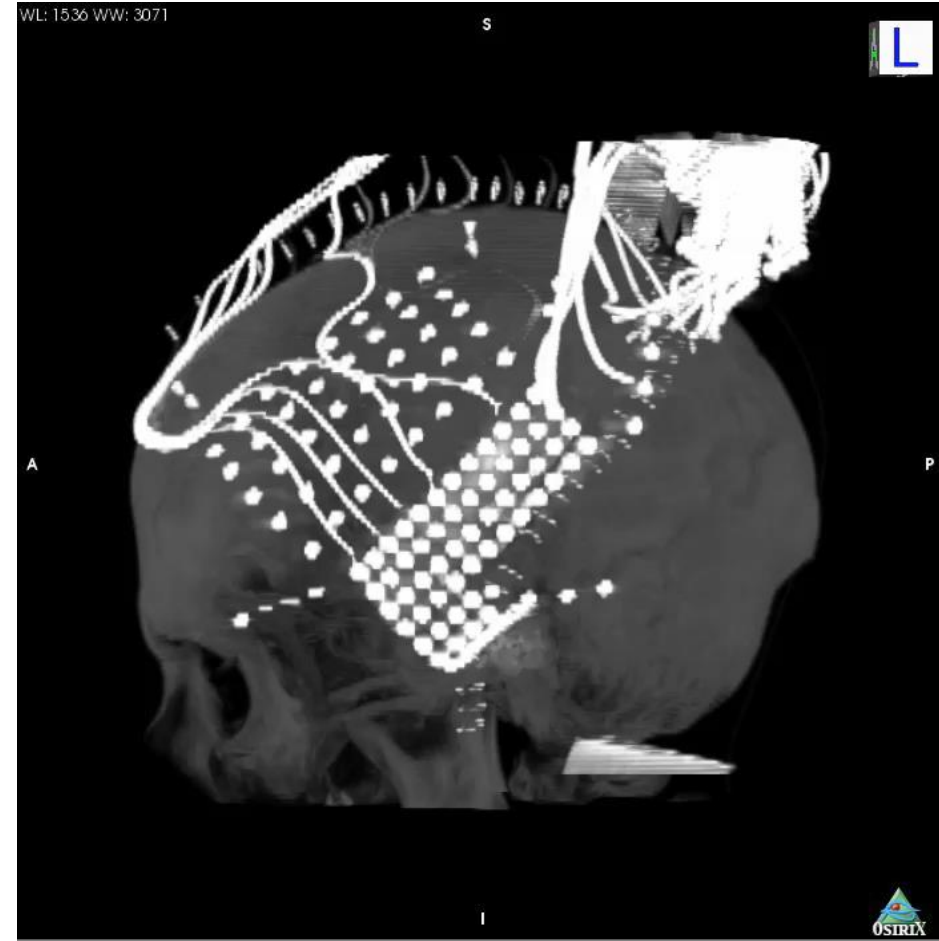
- Numbness
- Tingling
- Needle pricks

Occipital Lobe Epilepsy

- Most rare form (only 5-10%)
- Start with visual hallucinations, geometric figures or even temporary blindness

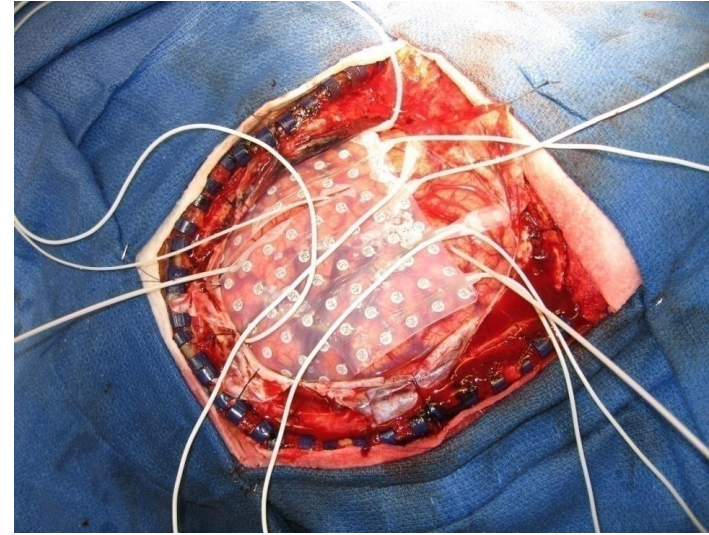
Electrocorticography

- Placement of electrodes on the brain surface (Penfield & Jasper, Montreal 1950s)
- Clinical grids 2mm radius, 1cm spacing
- Craniotomy (a surgical incision into the skull) is required



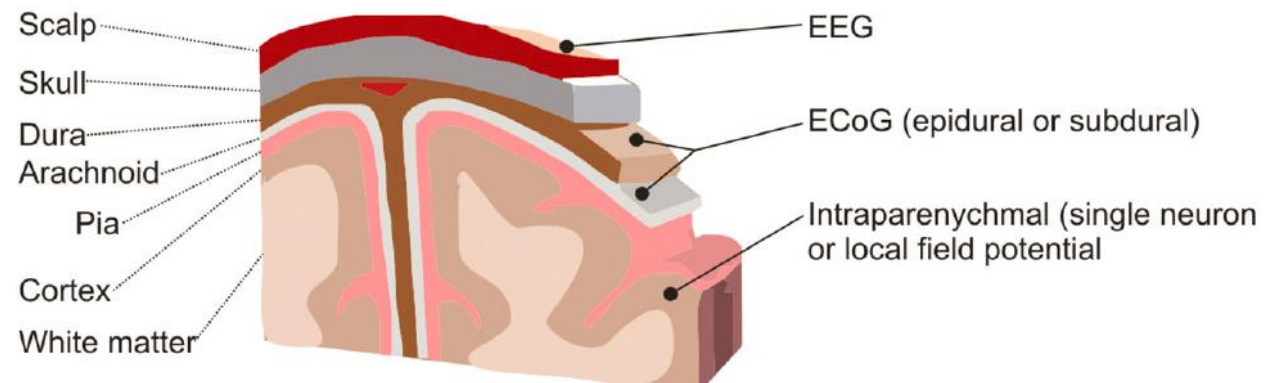
ECoG

- Grids/strips can be placed above or below the dura



Layers

Signal Source



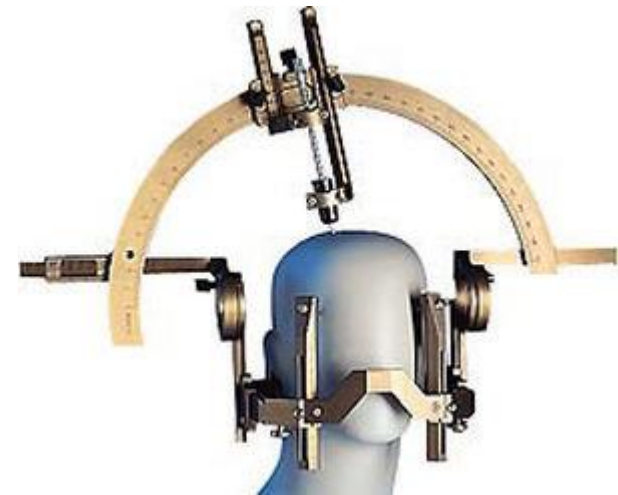
Stereoelectroencephalography

- First presented by Talairach and Bancaud

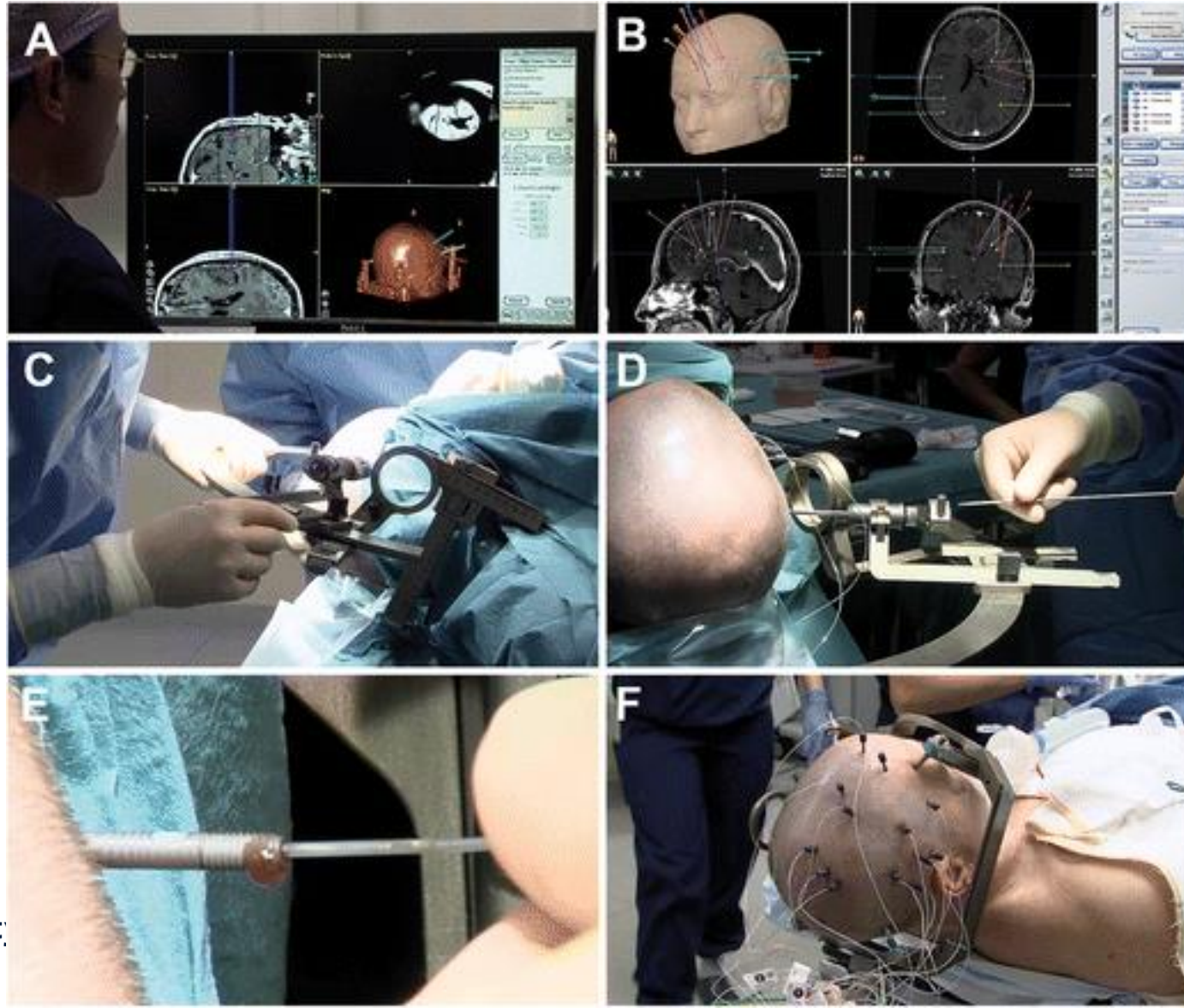
(J. Talairach, J. Bancaud, G. Szikla, et al.:

Approche nouvelle de la neurochirurgie de l'épilepsie. Méthodologie stéréotaxique et résultats thérapeutiques (= Neurochirurgie. 20, Suppl. 1). Masson, Paris 1974, S. 1–240.)

- Implantation of depth electrodes into the brain
- Identification of epileptogenic zone
- Very safe procedure
- Stereotactic procedure



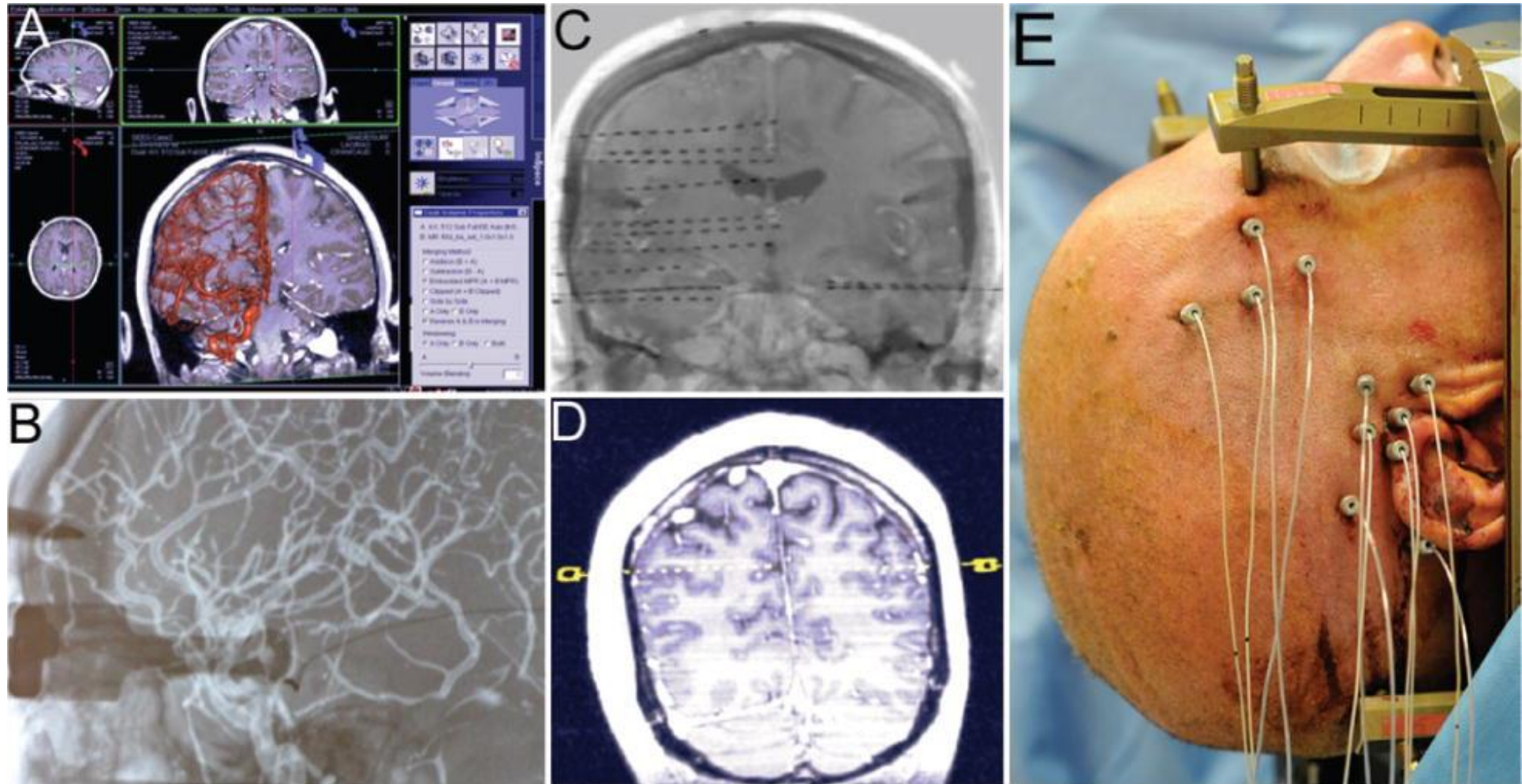
SEEG



van der Loo, Lars E., et al.
"Methodology, outcome,
safety and in vivo accuracy
in traditional frame-based
stereoelectroencephalogra-
phy." *Acta
neurochirurgica* 159.9
(2017): 1733-1746.



SEEG



Gonzales-Martinez, et al. "Stereotactic placement of depth electrodes in medically intractable" (2014).

Seizure Activity in Electrophysiology

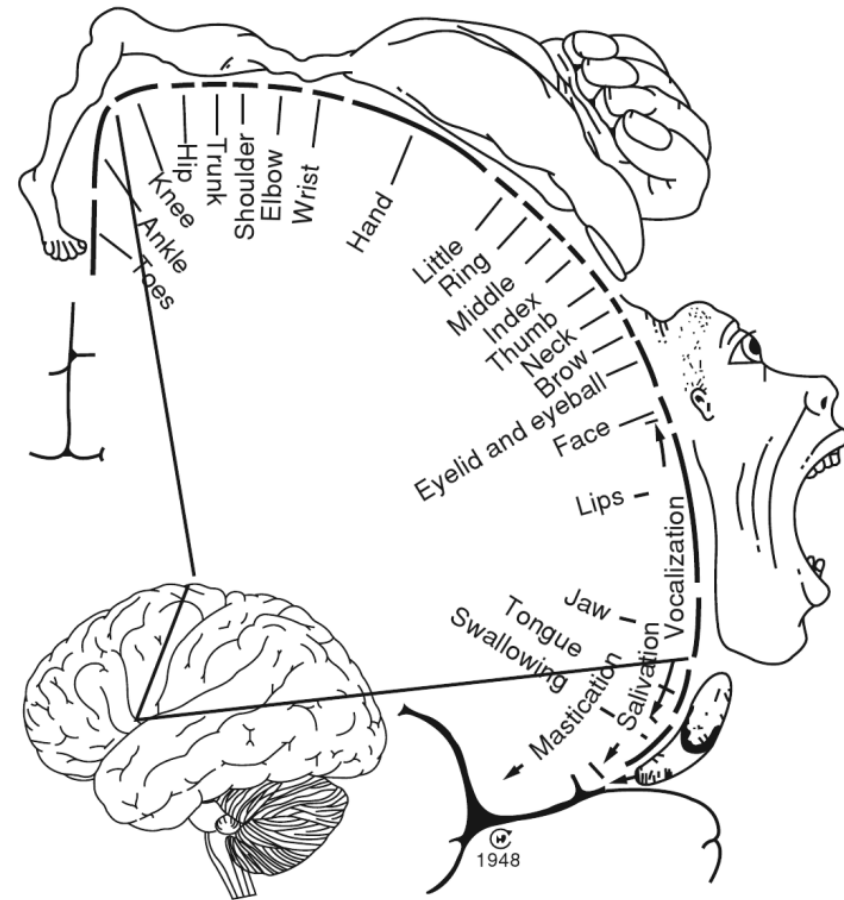


Cortical Stimulation Mapping

- Aims to localize the function of specific brain regions through direct electrical stimulation of the cerebral cortex
- Current levels and density are an important consideration in all cortical stimulation mapping procedures.
- Current density must be sufficient to stimulate neurons, yet low enough to protect brain tissue from damaging currents.
- Currents are kept at safe levels and are only given as short bursts, slowly increase in intensity and duration until a response (such as a muscle movement) can be tested.
- Current intensity start around bursts of 1 mA and gradually increased by increments of 0.5 to 1 mA, current is applied for a few seconds

Motor mapping

- Functional testing of movement during cortical stimulation:
- Active movement and inhibition of movement.
 - Precentral gyrus of the frontal lobe is stimulated, specific muscles in the body will contract based on the location of the brain that receives the electric signal.
 - Stimulation on one side of the brain will cause a contraction on the contralateral, or opposite, side of the body.



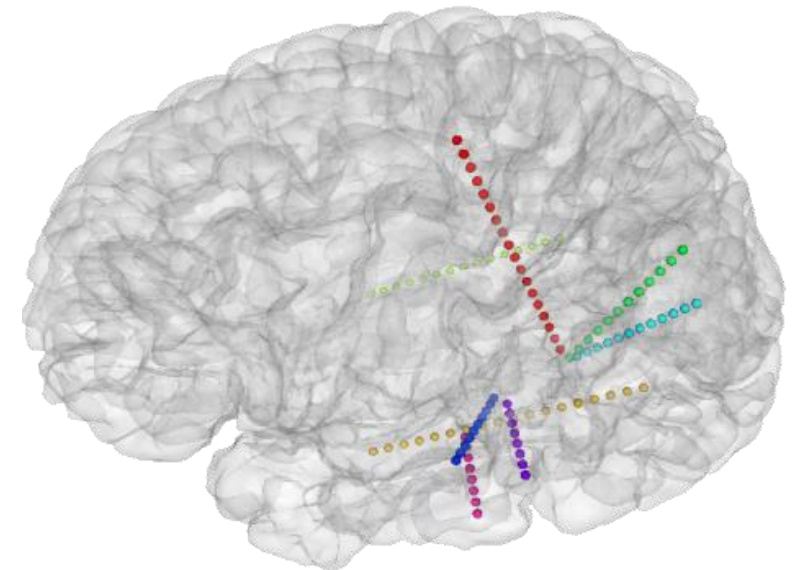
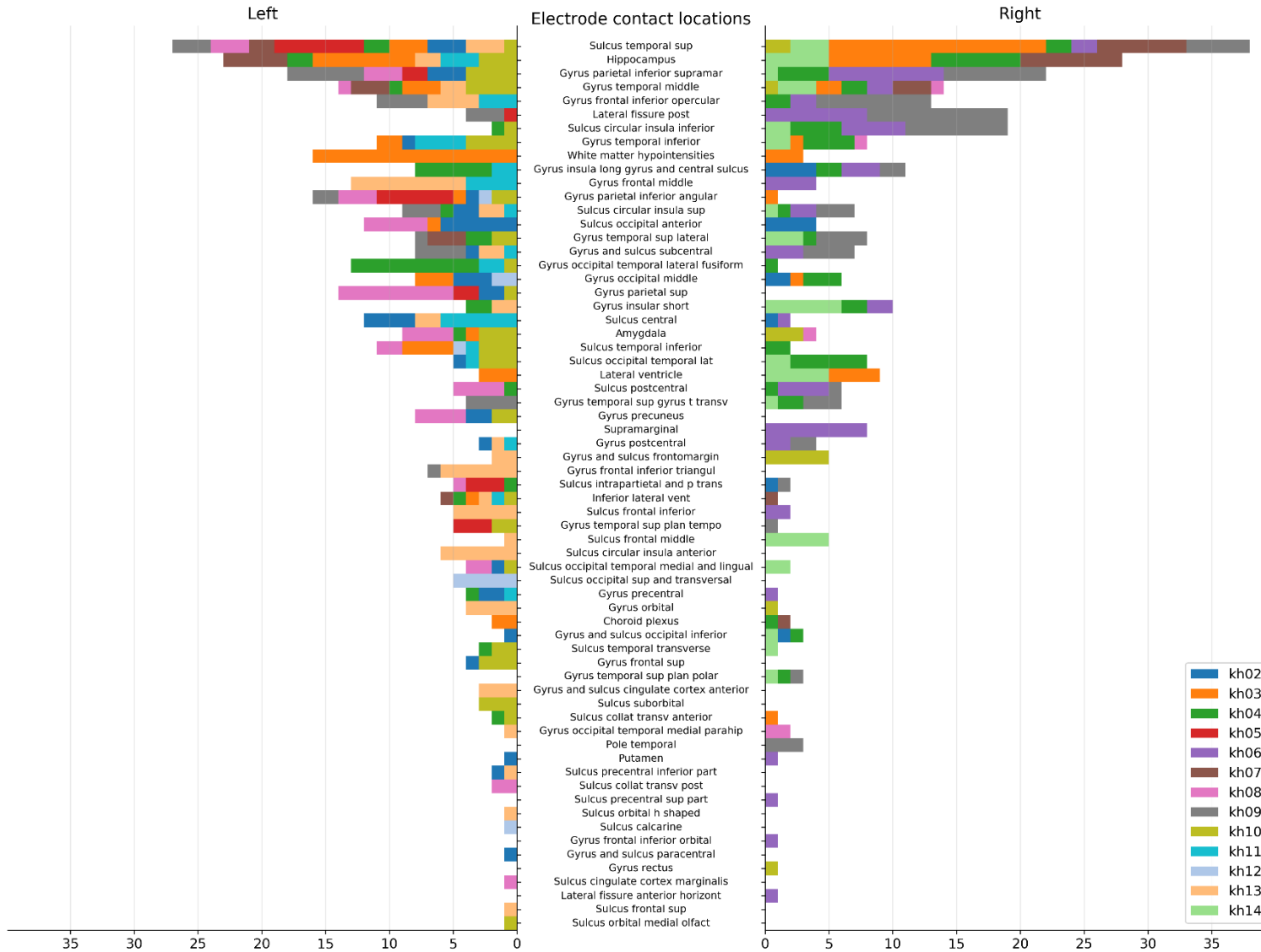
Stimulation Example



[Ambrož Bajec-Lapajne](https://www.youtube.com/watch?v=obiARnsKUAo)

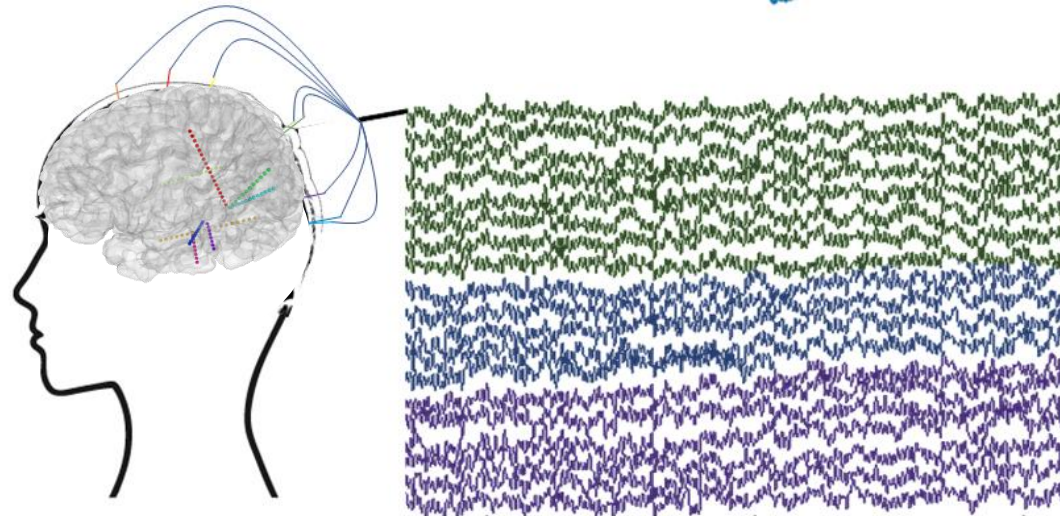
<https://www.youtube.com/watch?v=obiARnsKUAo>

Locations



Recording during Experiments

- Simultaneous recording
- Huge potential for a large variety of neuroscientific studies
- Patients greatly enjoy participation



Hippocampal Insular
Auditory

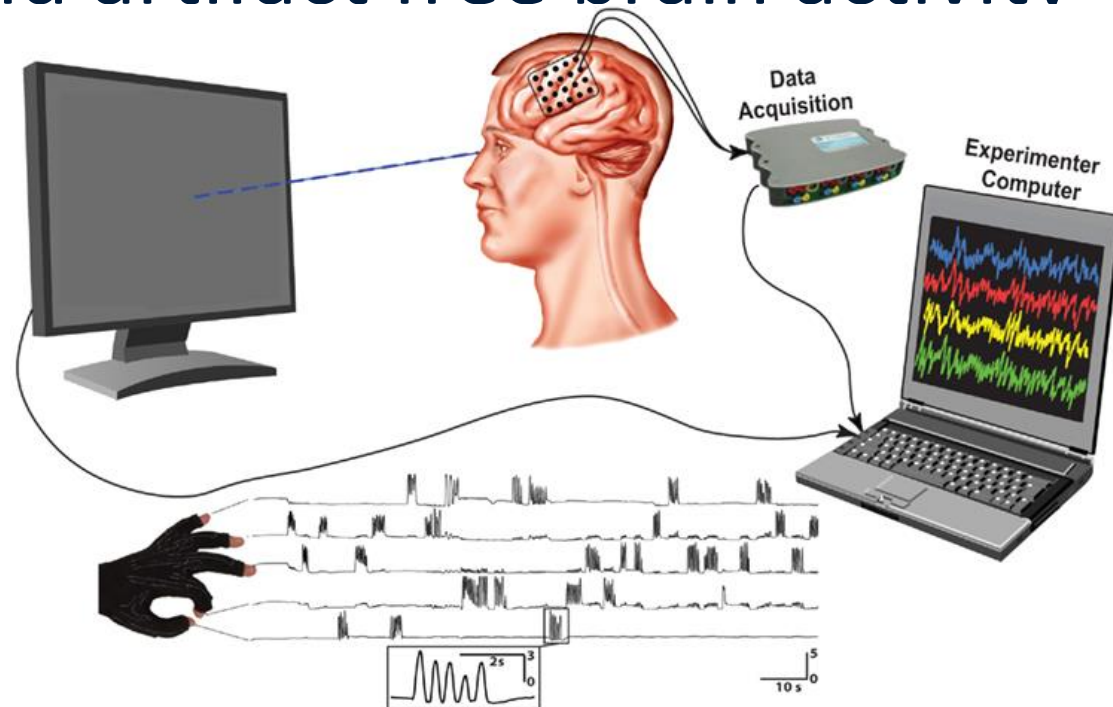


Maastricht

Herff, C., Krusienski, D. J., & Kubben, P. (2020). The Potential of Stereotactic-EEG for Brain-Computer Interfaces: Current Progress and Future Directions. *Frontiers in Neuroscience*, 14, 123.

Opportunity for Neuroscience

- Piggyback on clinical necessity
- Ask patients to perform tasks
- Investigate localized and artifact free brain activity



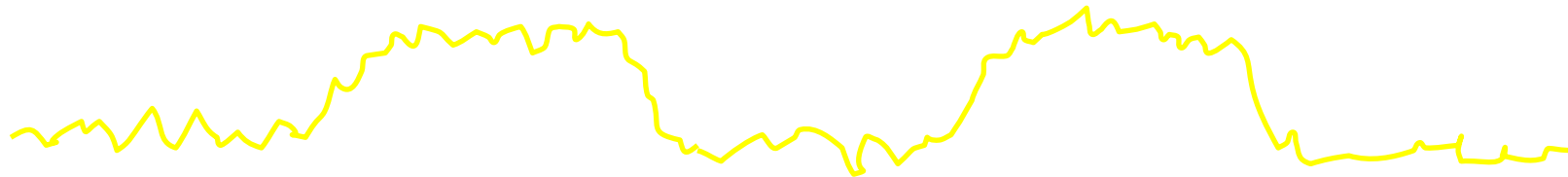
Experiments

- Classic neuroscience experiments
- Perform some type of task
- Compare brain activity during different states

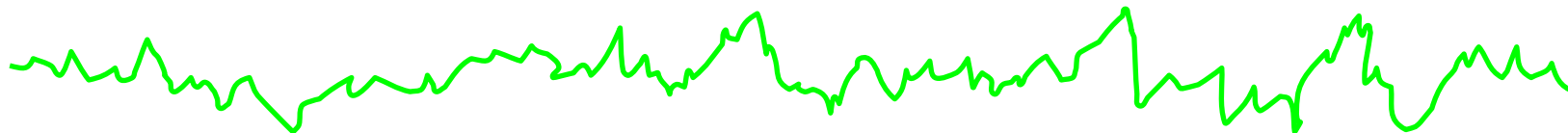
Tasks for neuroscience



Signal correlates with task: Active



Signal does not correlate with task: Inactive

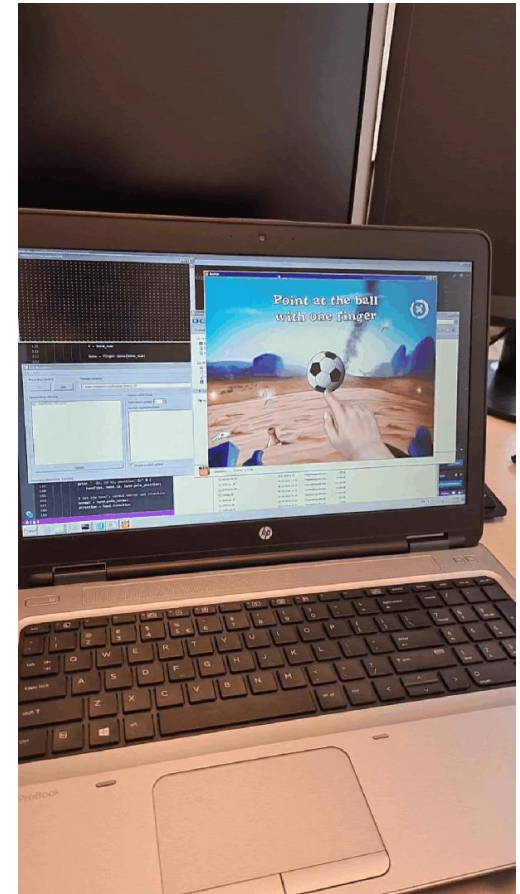
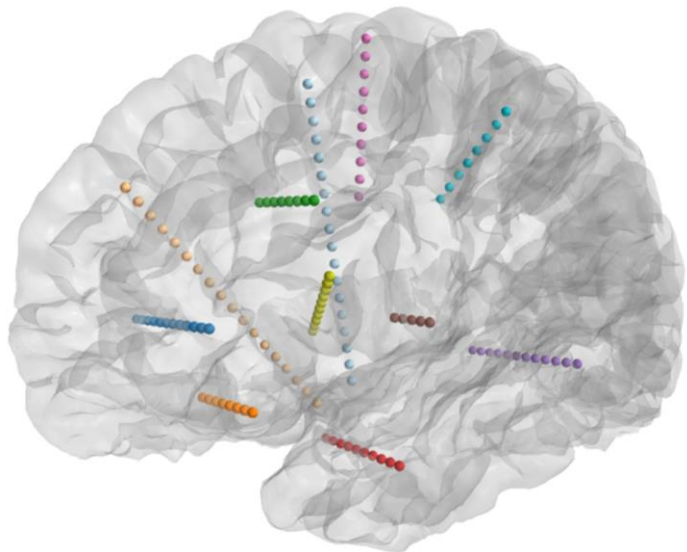


Motor decoding

- Decode motor intention with less invasive electrodes
- Involvement of deep structures
- Towards naturalistic movements

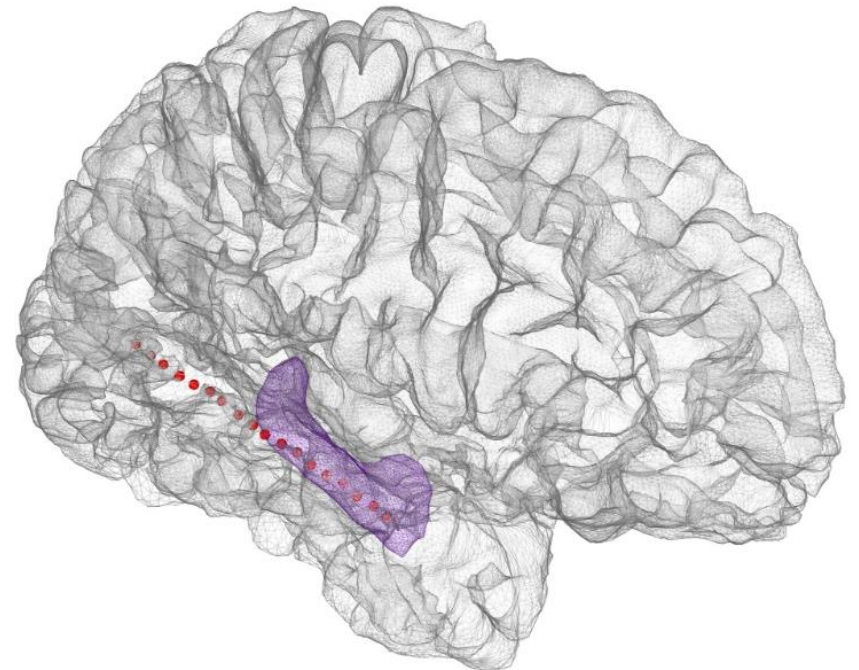
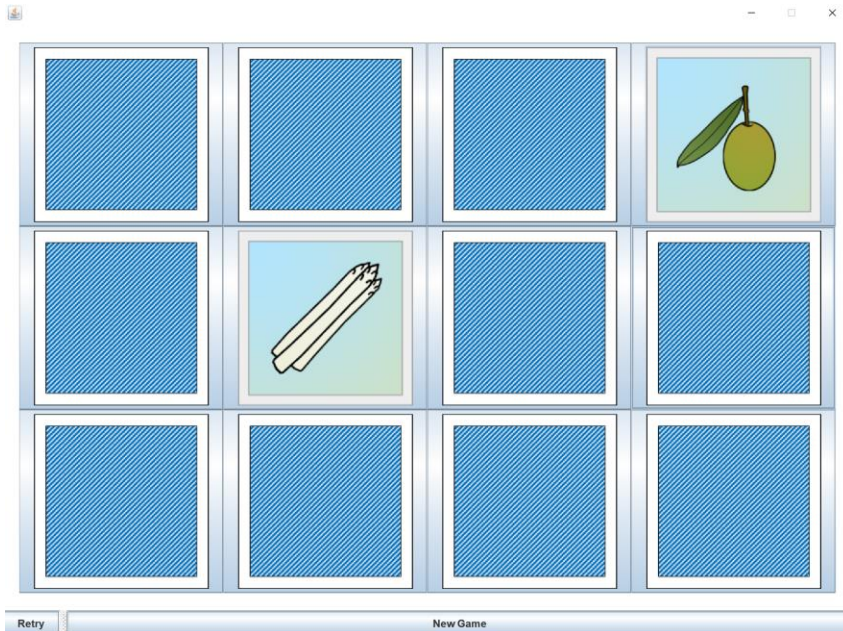


Maarten Ottenhoff
PhD student



Memory Decoding

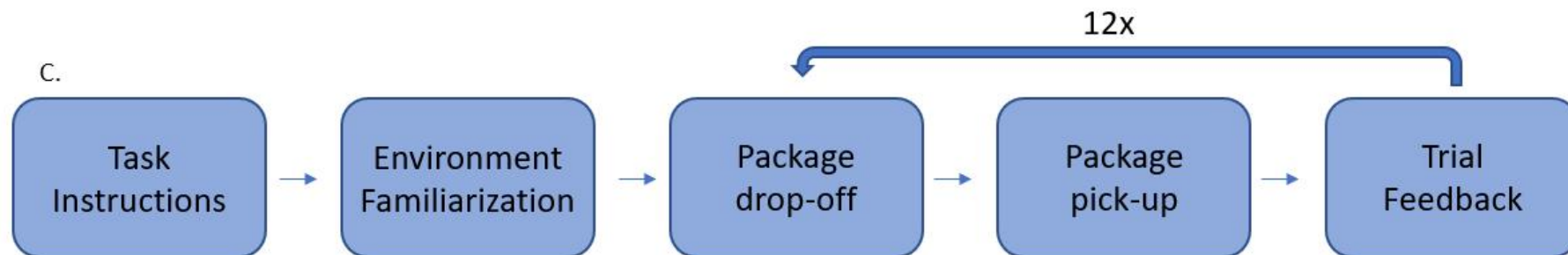
- Successful vs unsuccessful encoding
- Adapt Interface
- Stimulate?



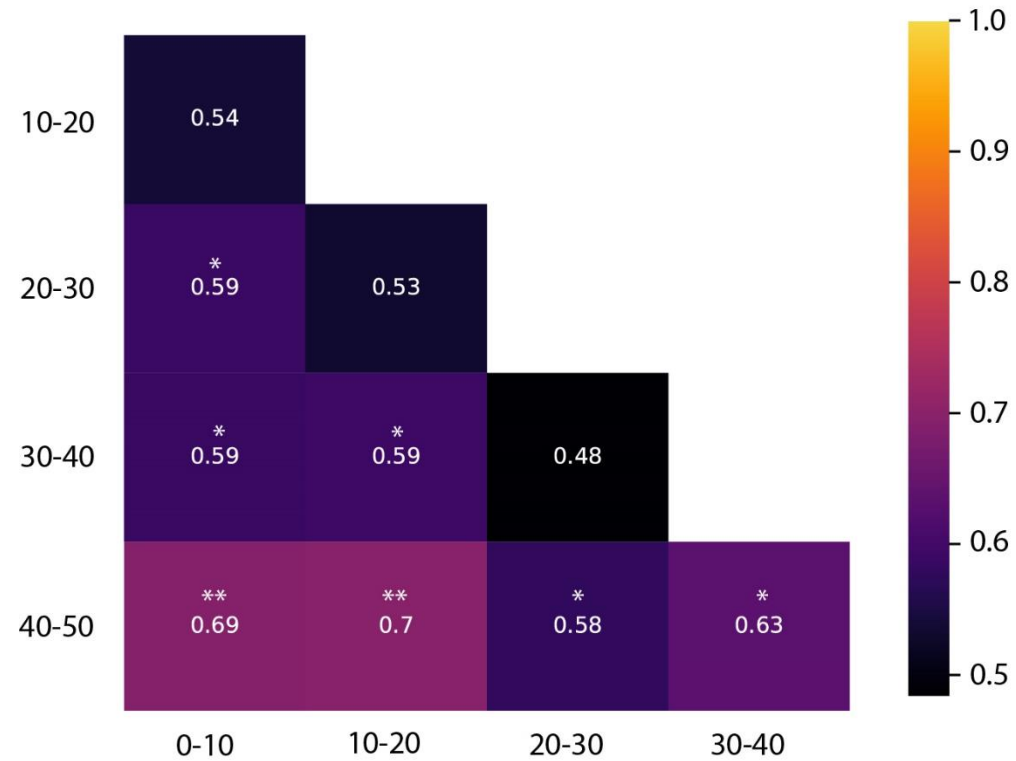
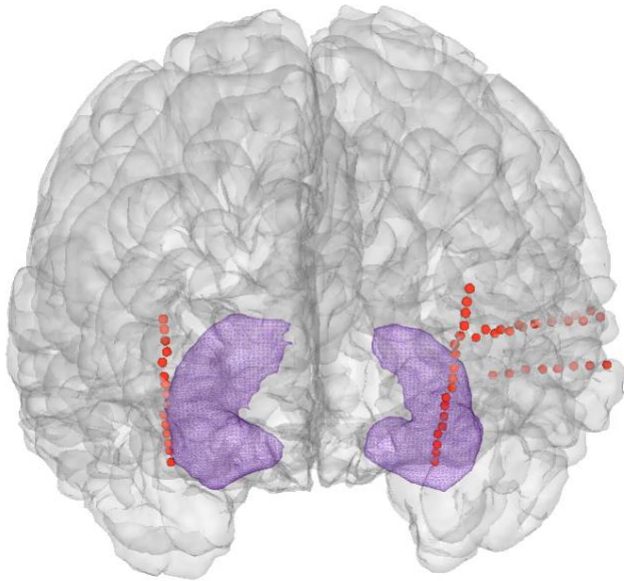
Human Navigation



Jeremy Saal
UCSF



Decoding Speed from Hippocampal Recordings



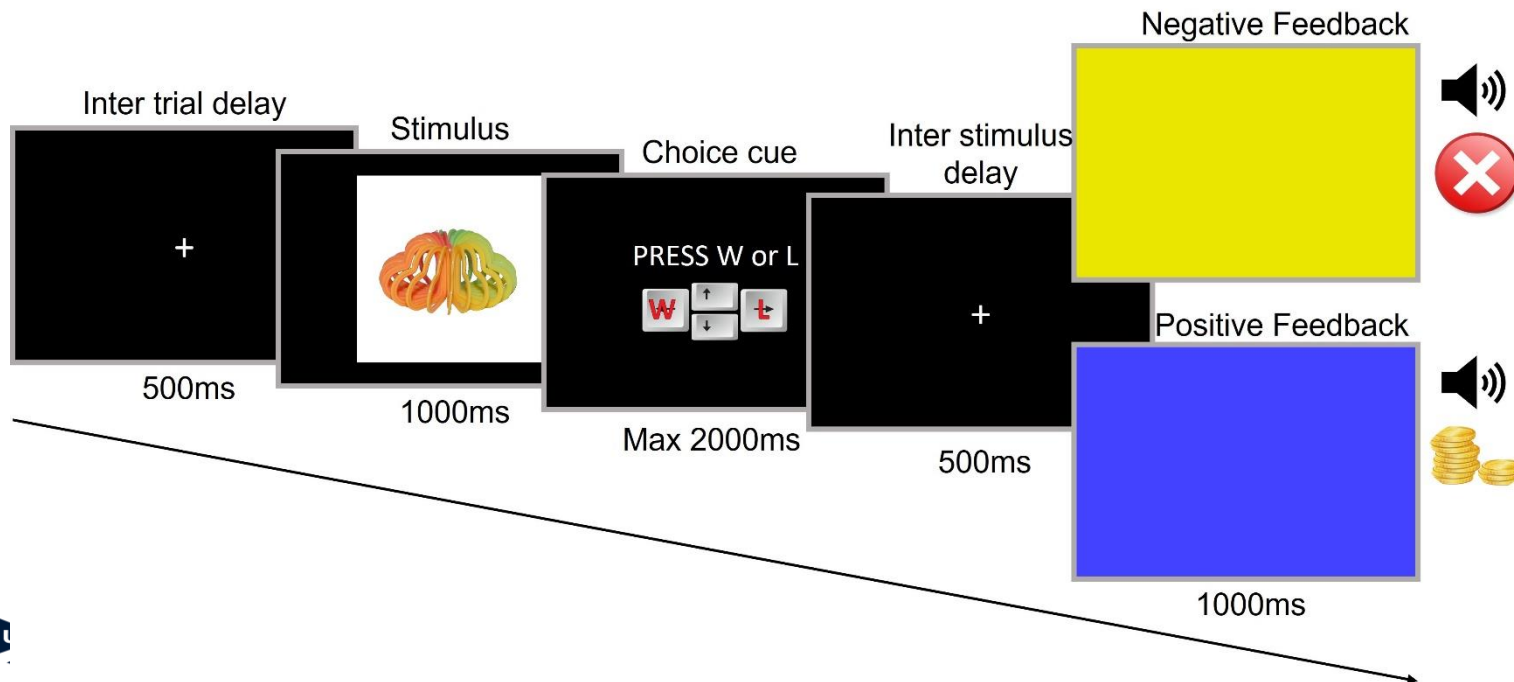
Feedback processing in decision making



Laura Marras
Research Assistant



- 30 symbols, each one presented 3 times in randomized order
- Goal: Categorize each symbol as “**Winning**” or “**Losing**”

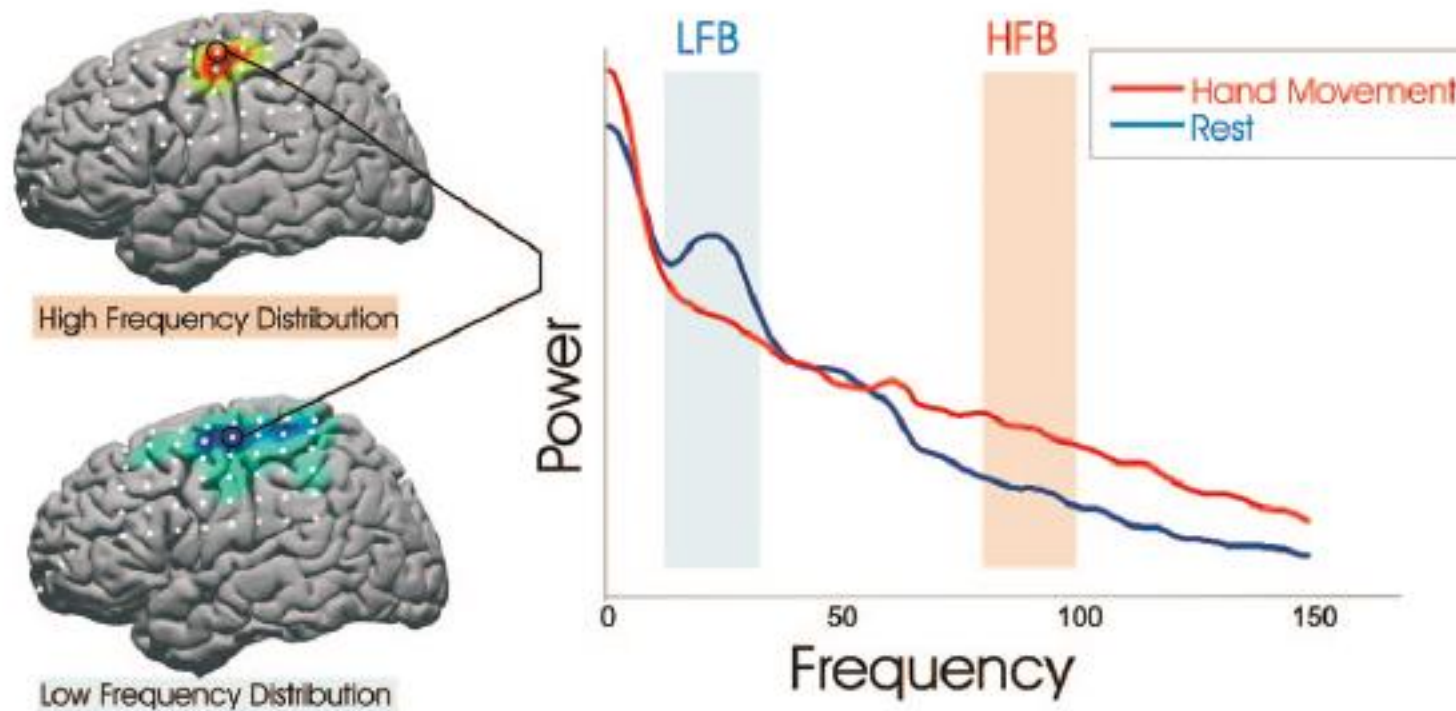


Total of 90 trials:

- 30 → 1st presentation
- 30 → 2nd presentation
- 30 → 3rd presentation

High-Gamma Band

- Very localized information
- Highly task correlated
- Reflects ensemble spiking

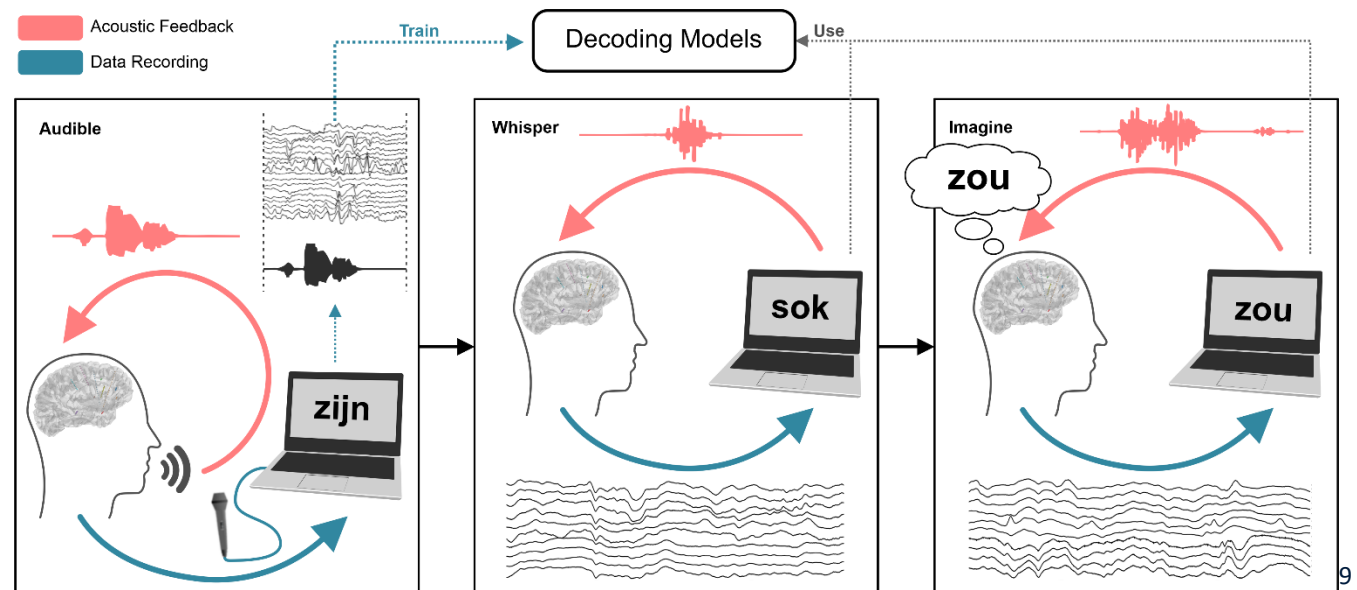


Imagined Speech

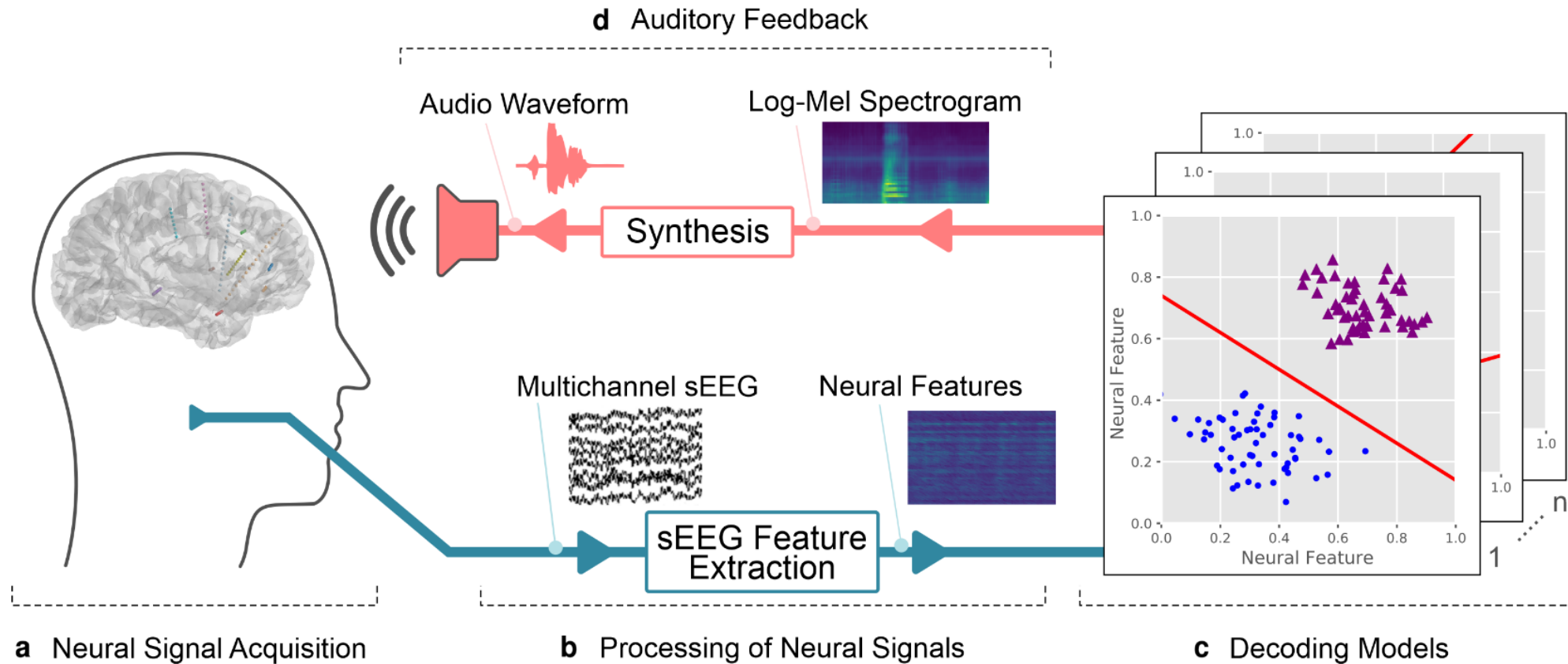
- Speech imagery is hard
- N=1 (20 y/o, female)
- Dutch
- Training data: 100 words of articulated speech
- Closed-Loop
 - Whisper
 - Imagine



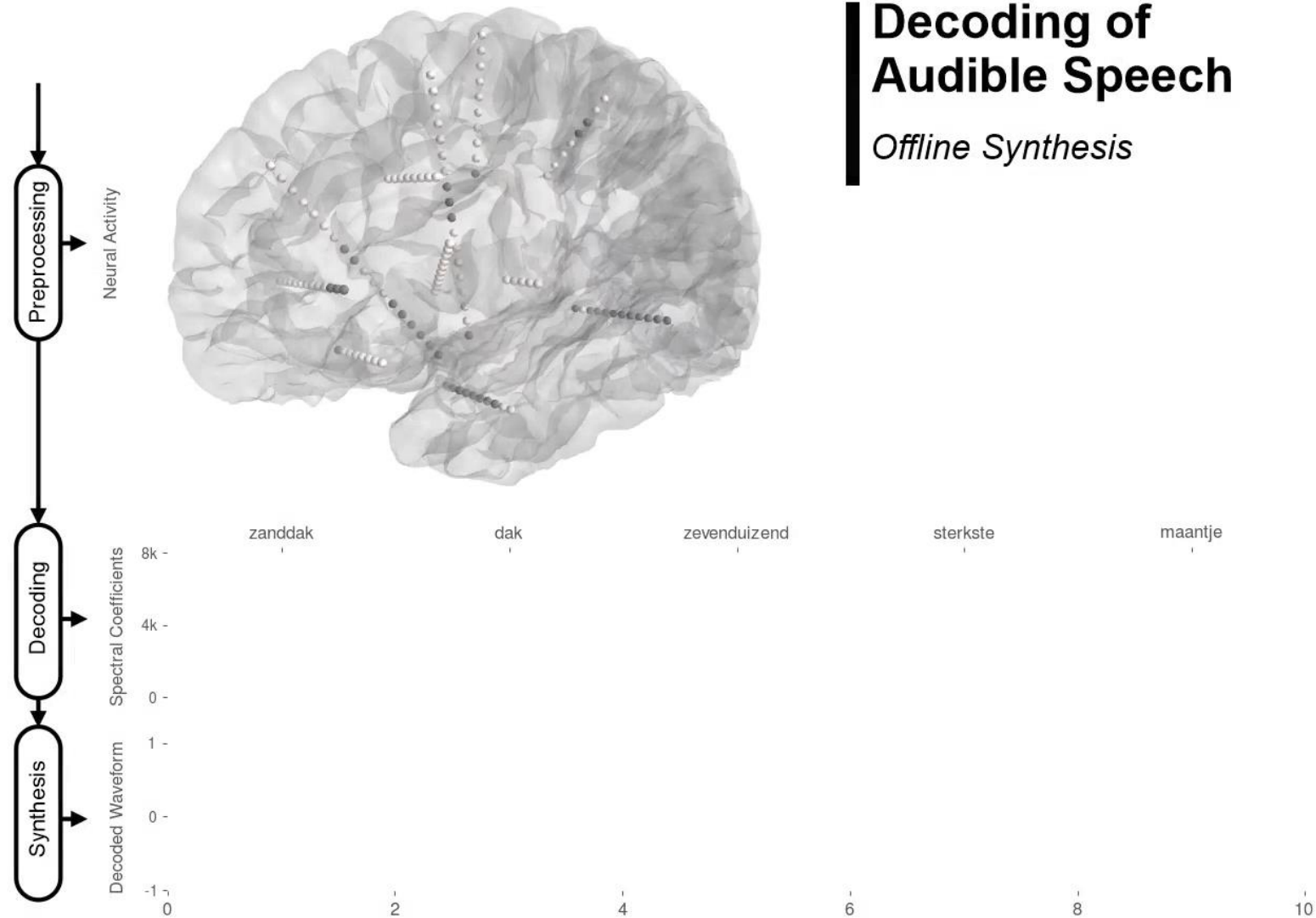
Miguel Angrick, MSc
CSL @Uni Bremen



Closed-loop Pipeline



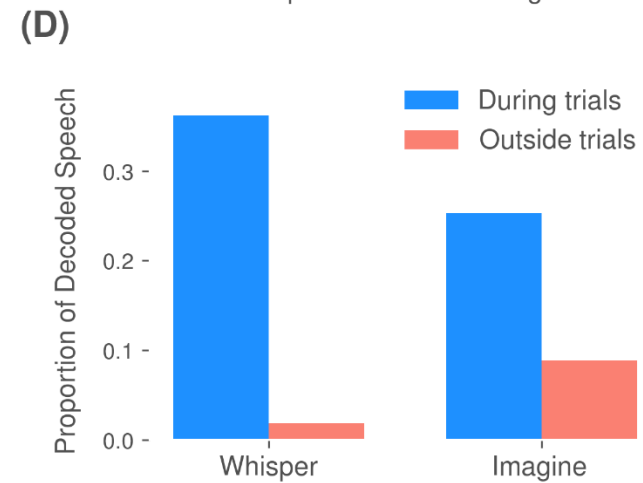
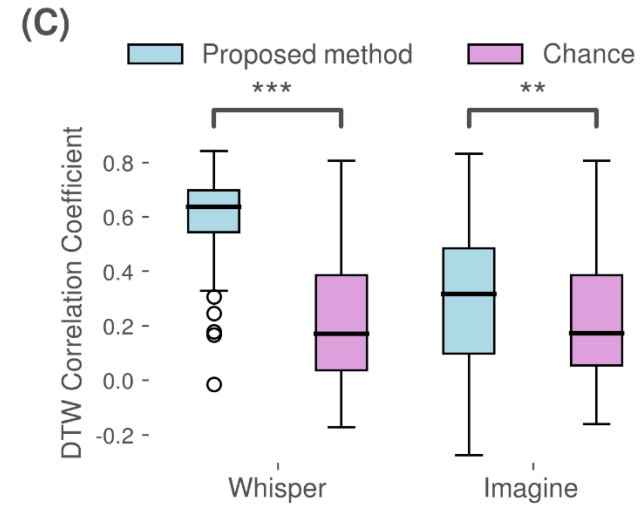
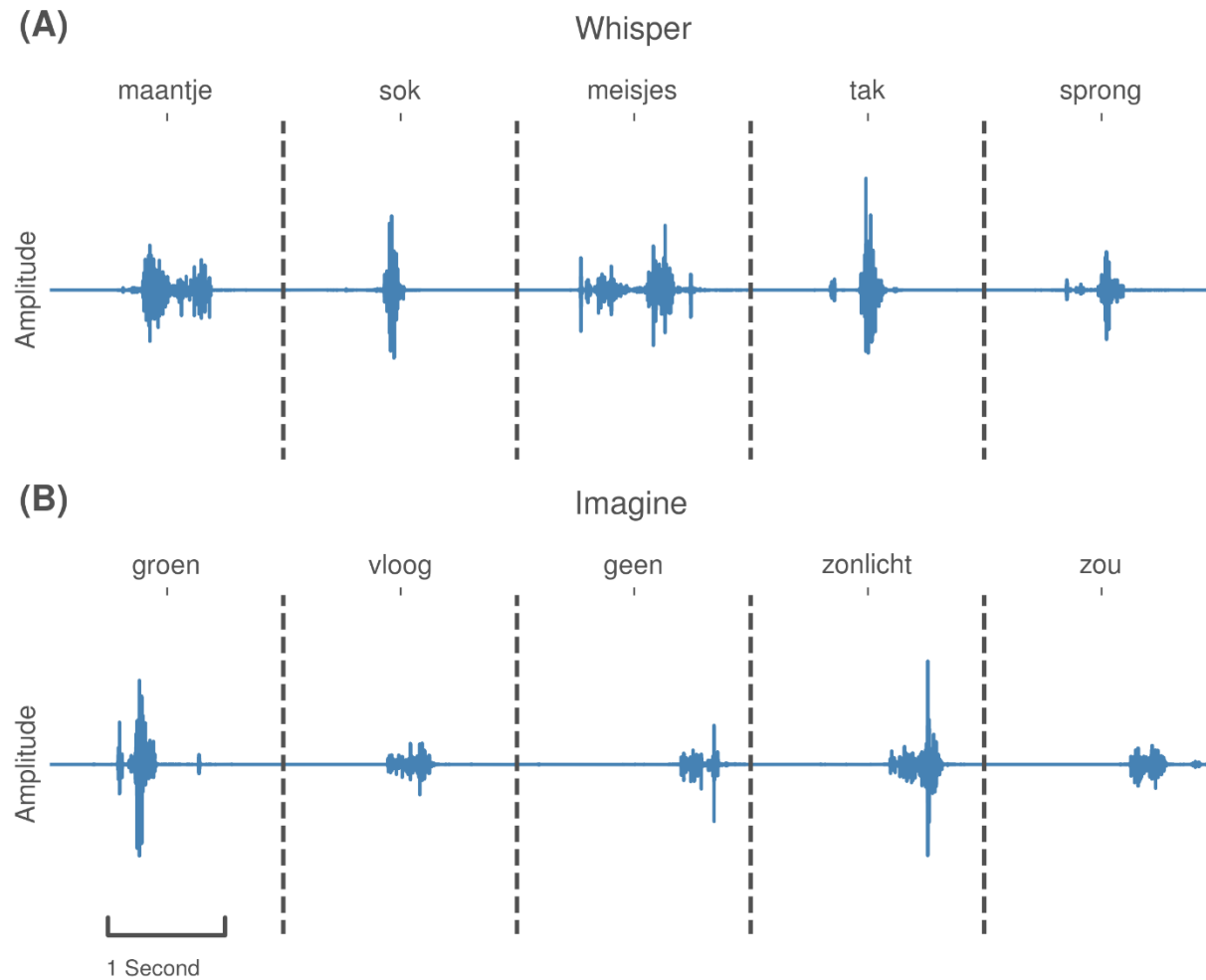
Demo



Decoding of Audible Speech

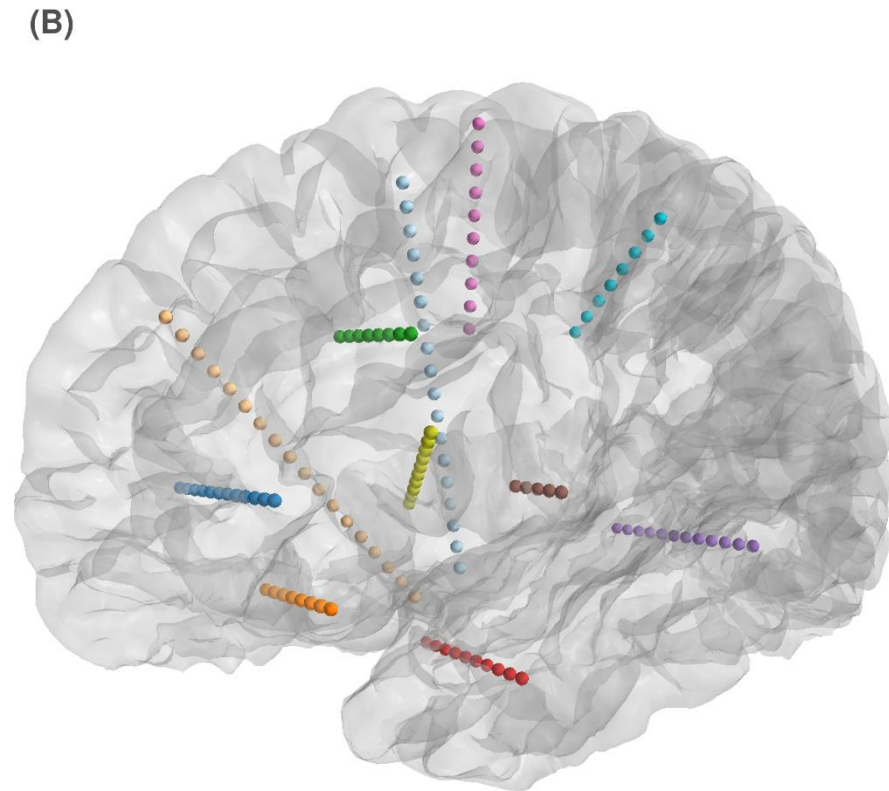
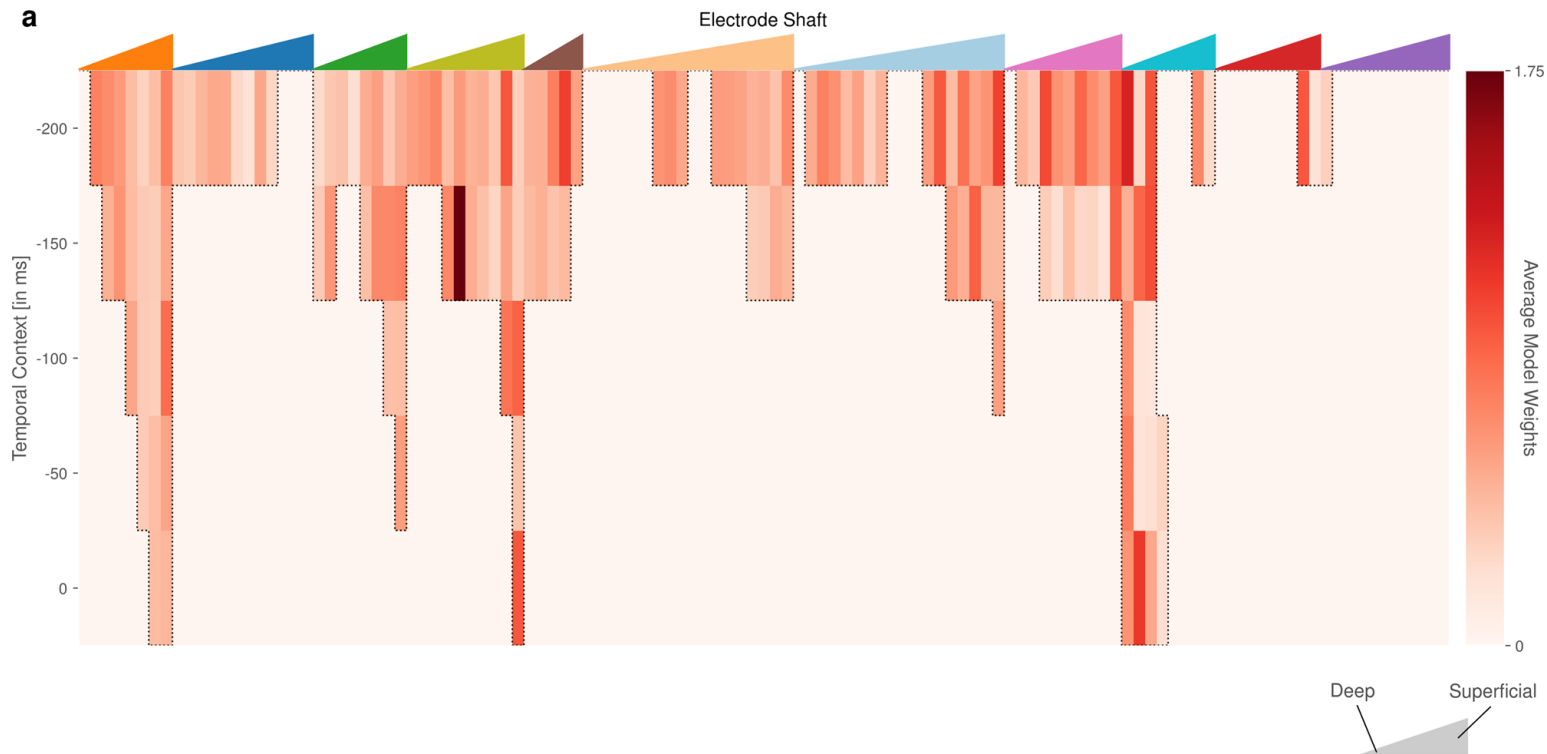
Offline Synthesis

Results



Interpretation

- Linear Classifiers predict Sigmoid-quantized spectrograms



Conclusion

- Piggybacking on necessary surgeries enables high-fidelity neuroscience without burden on patients
- High-temporal and high-spatial resolution in deep brain areas
- Sparse sampling from many brain areas