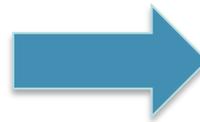


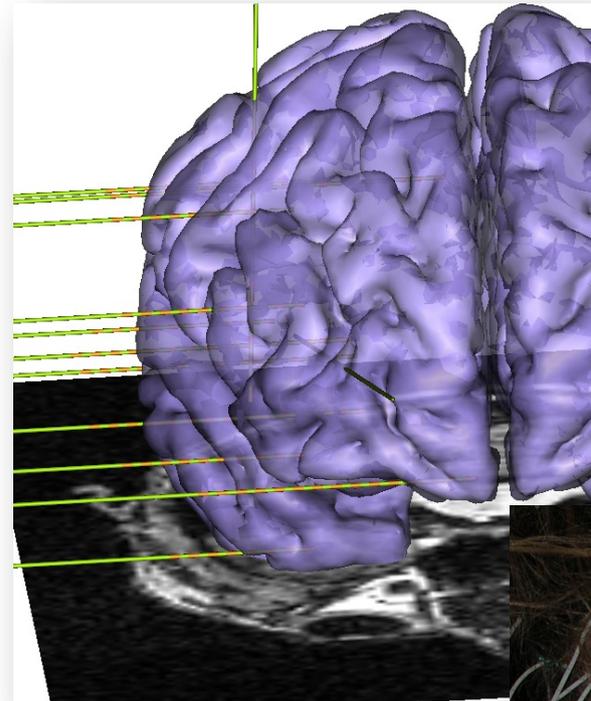
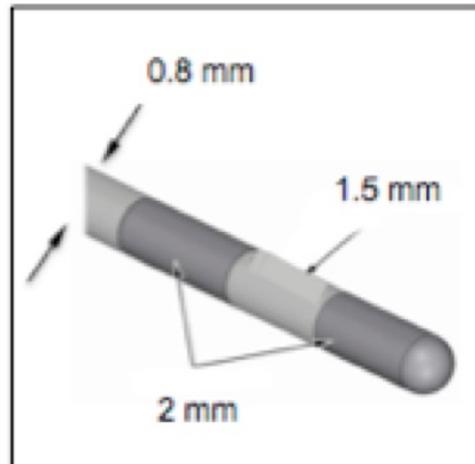
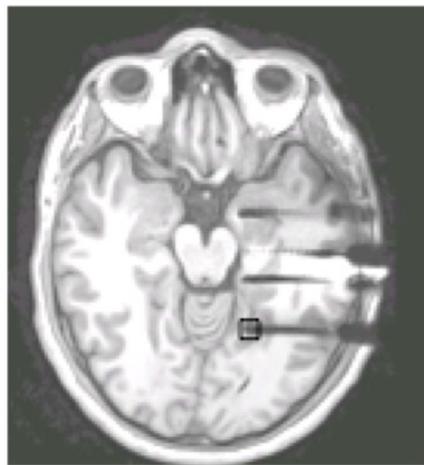
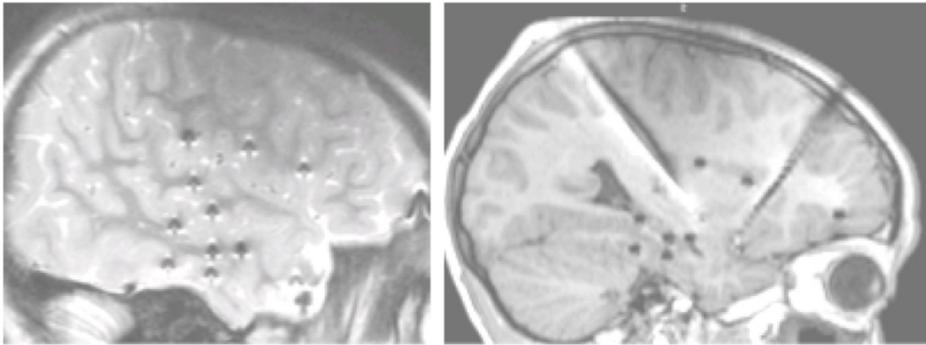
Direct cortical stimulation: a window to the brain and behaviour



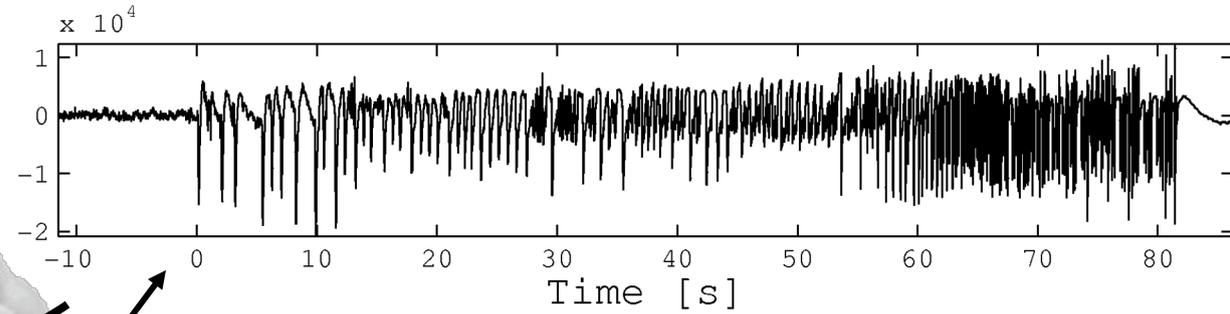
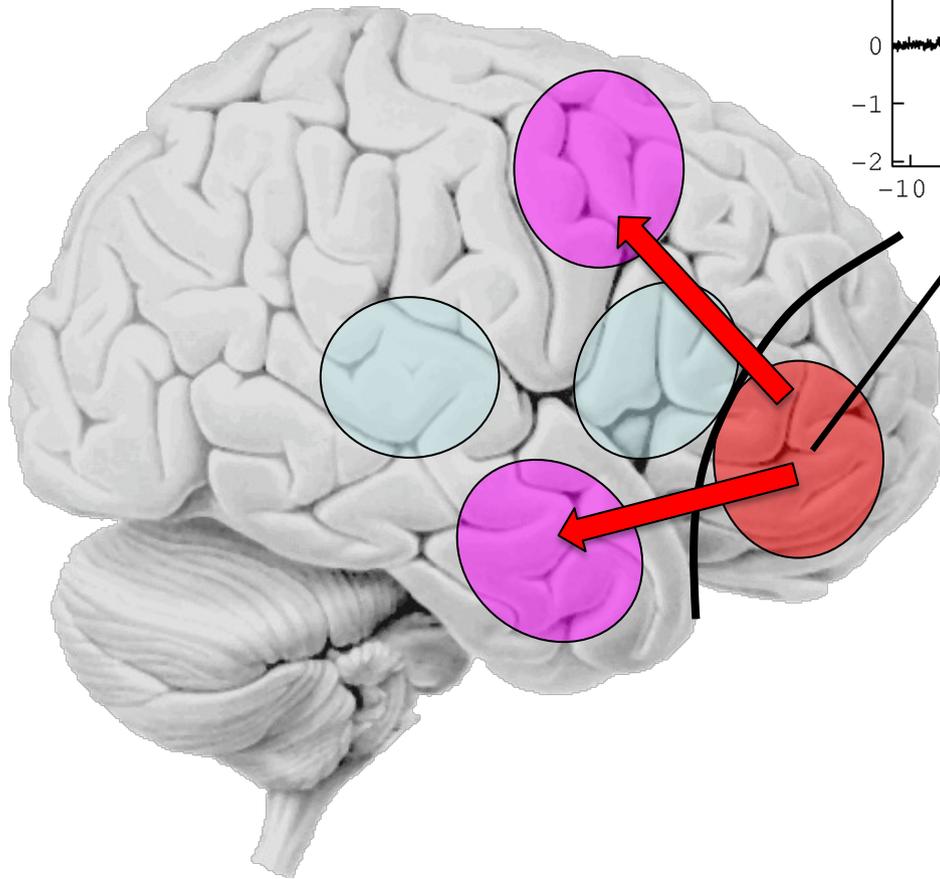
Olivier David, PhD
Olivier.David@inserm.fr

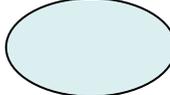
Epilepsy surgery Stereoelectroencephalography (SEEG)

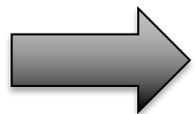
- Electrodes implanted during 2 weeks
- Invasive recordings of local field potentials (LFP)
- Grenoble setup: up to 256 channels, sampled at 2048 Hz



Functional mapping in epilepsy

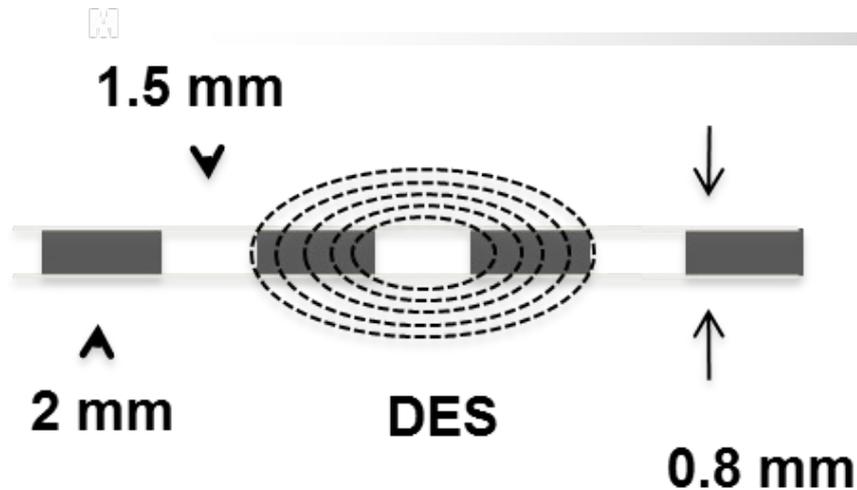


-  Eloquent cortex
-  Epileptic focus
-  Epileptic regions of propagation



Essential to predict deficits after surgery

Stimulation protocols in SEEG



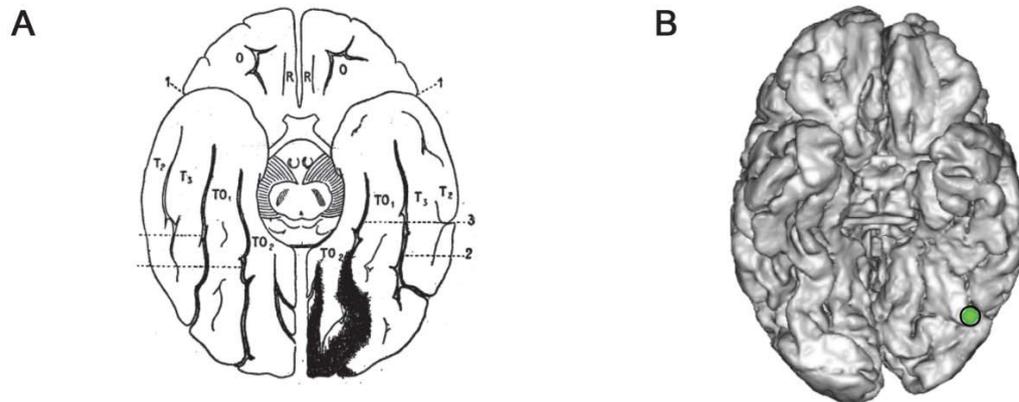
- **Two types of direct cortical stimulation**
 - Epilepsy and connectivity mapping
 - 1 Hz, from 3 to 40 seconds
 - Induce seizures similar to spontaneous seizures
 - Connectivity
 - Epilepsy & functional mapping
 - 50 Hz, from 1 to 5 seconds
 - Induce seizures similar to spontaneous seizures
 - “Local” inhibition of function

**Jean-Philippe Lachaux, Julien Bastin, Marcela Perrone-
Bertolotti, Lorella Minotti, Philippe Kahane**

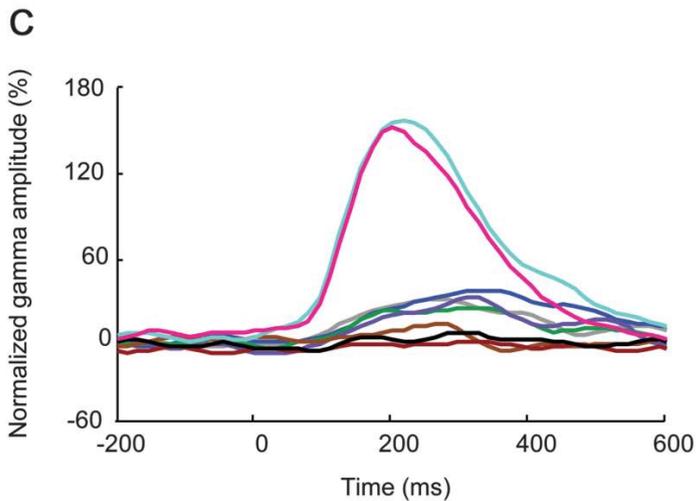
FUNCTIONAL MAPPING IN SEEG

Visual word form area

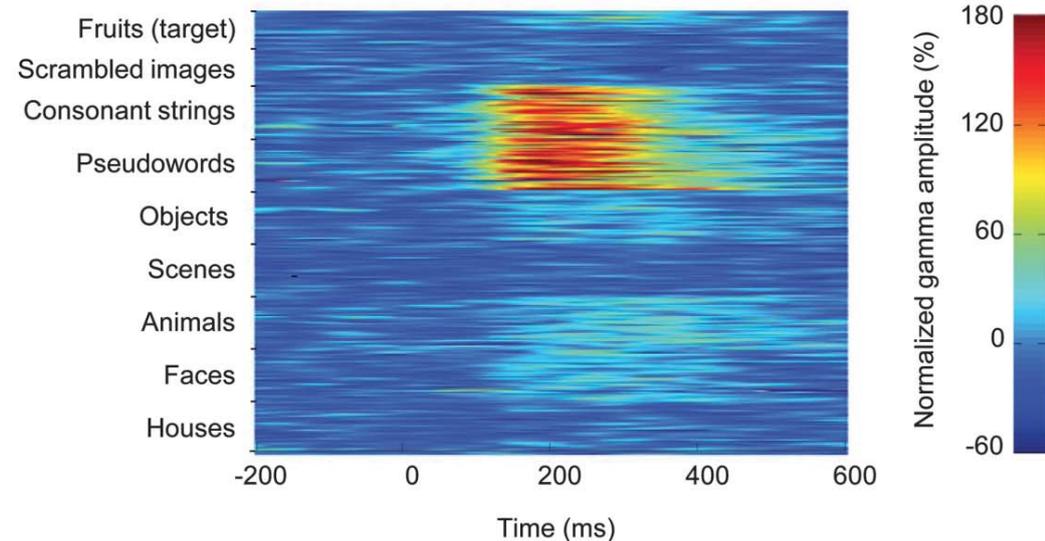
Dejerine's drawing (1891) of the lesion in a patient "who suddenly observed that he could not read a single word, while he could write and speak quite well."



- Response selective to letter strings
- Ventral occipitotemporal cortex
- Gamma band activity (GBA): 70-150 Hz

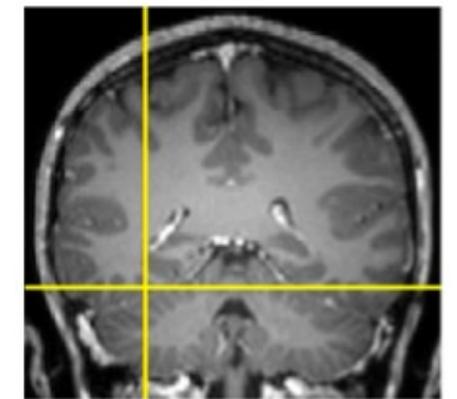
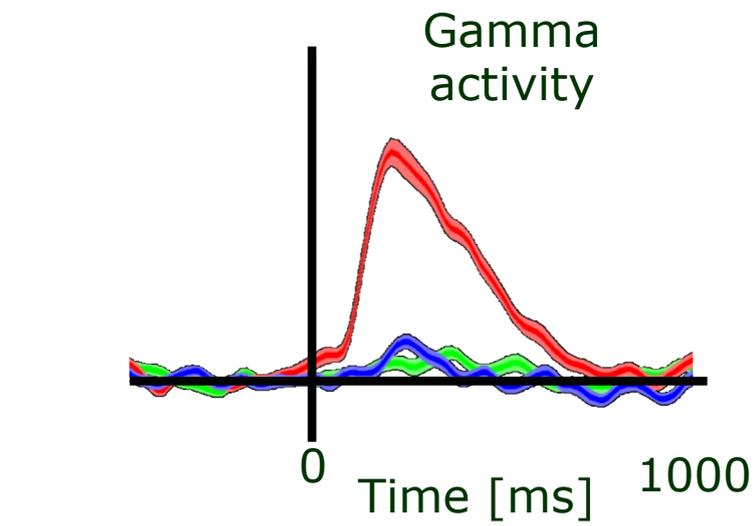
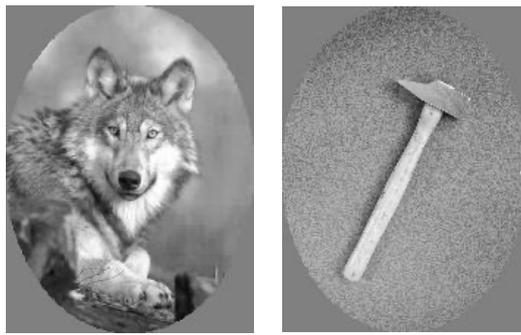


Fruits (target)
Scrambled images
Consonant strings (e.g. "qztlvcw")
Pseudowords (e.g. "boutale")
Objects
Scenes
Animals
Faces
Houses



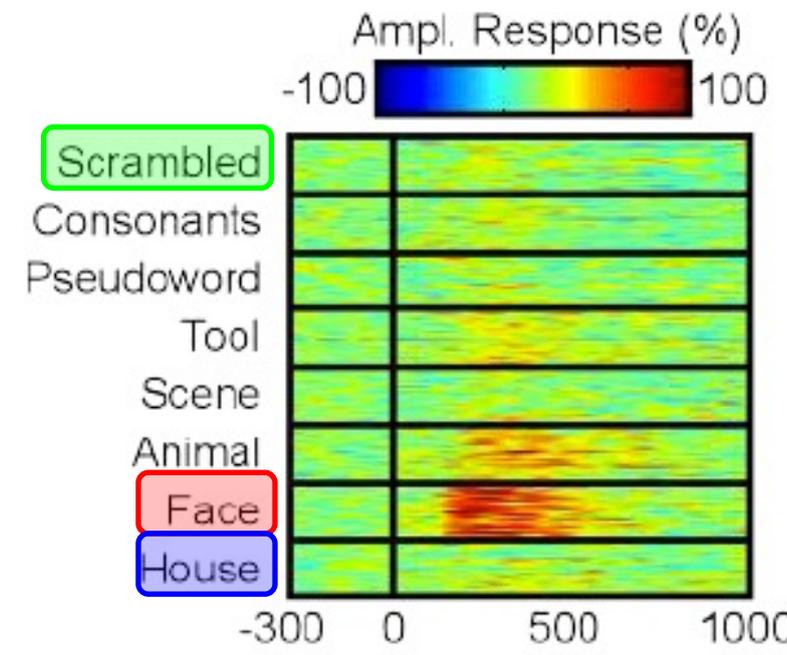
Hamamé et al, Neurology, 2013

Functional mapping by cognitive stimulation from intracranial recordings



Fusiform gyrus

Faces
Houses
No meaning



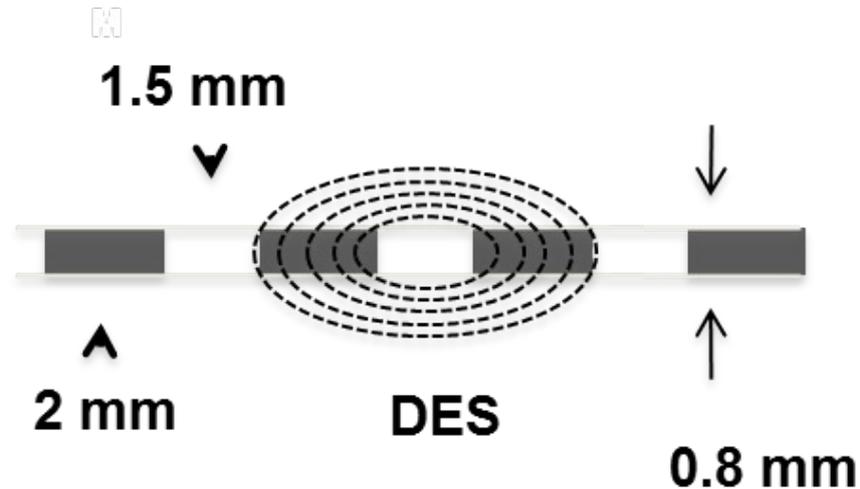
Selectivity of neuronal responses

Vidal et al, Front Hum Neurosci, 2010

Functional mapping by 50 Hz electrical stimulation

- **Stimulation parameters**

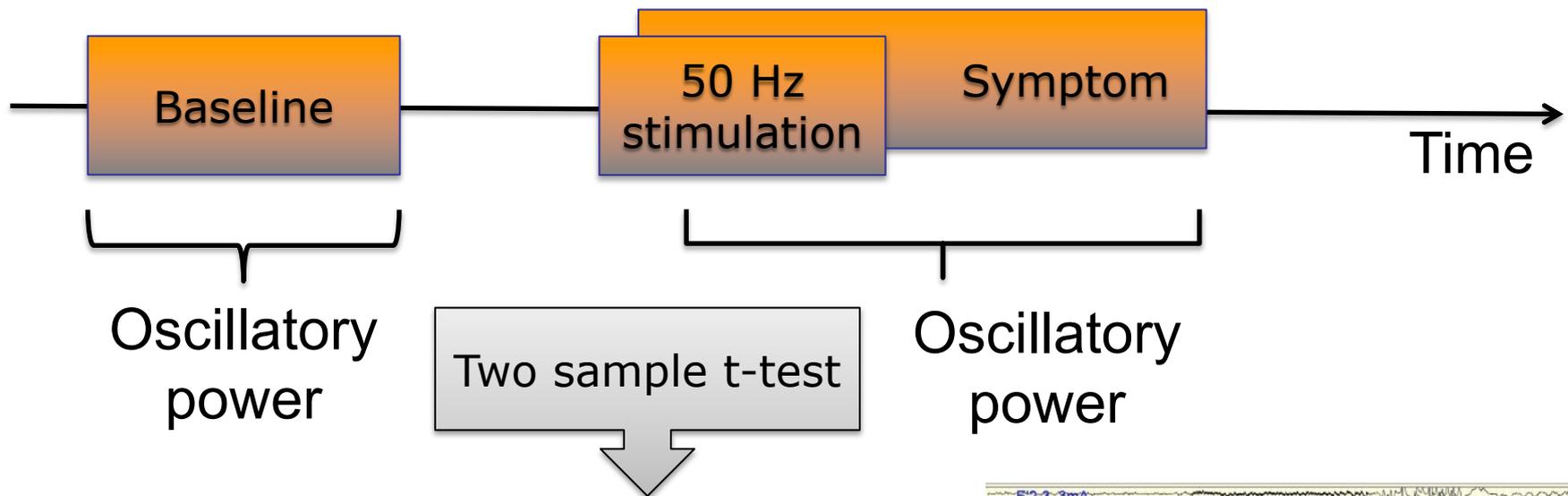
- 50 Hz, from 1 to 5 seconds
- “Local” inhibition of function
- Similar to peroperative functional mapping (epilepsy, tumors)



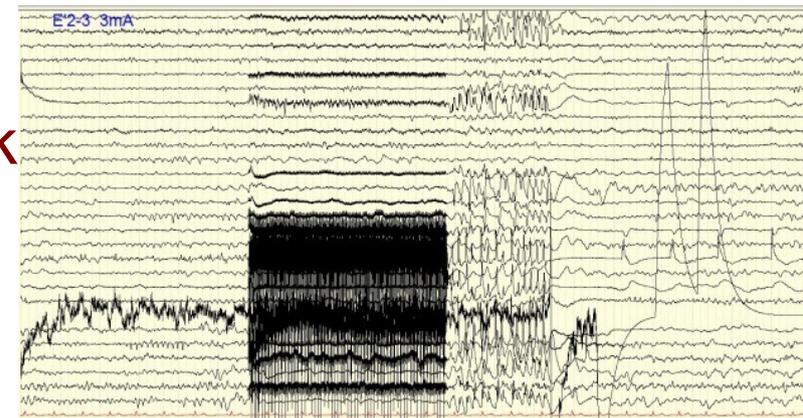
Statistical parametric mapping of oscillations induced by 50 Hz stimulation

- **Working hypothesis**

- 50 Hz stimulation alters “functional oscillations” (GBA), and thus induces clinical symptoms

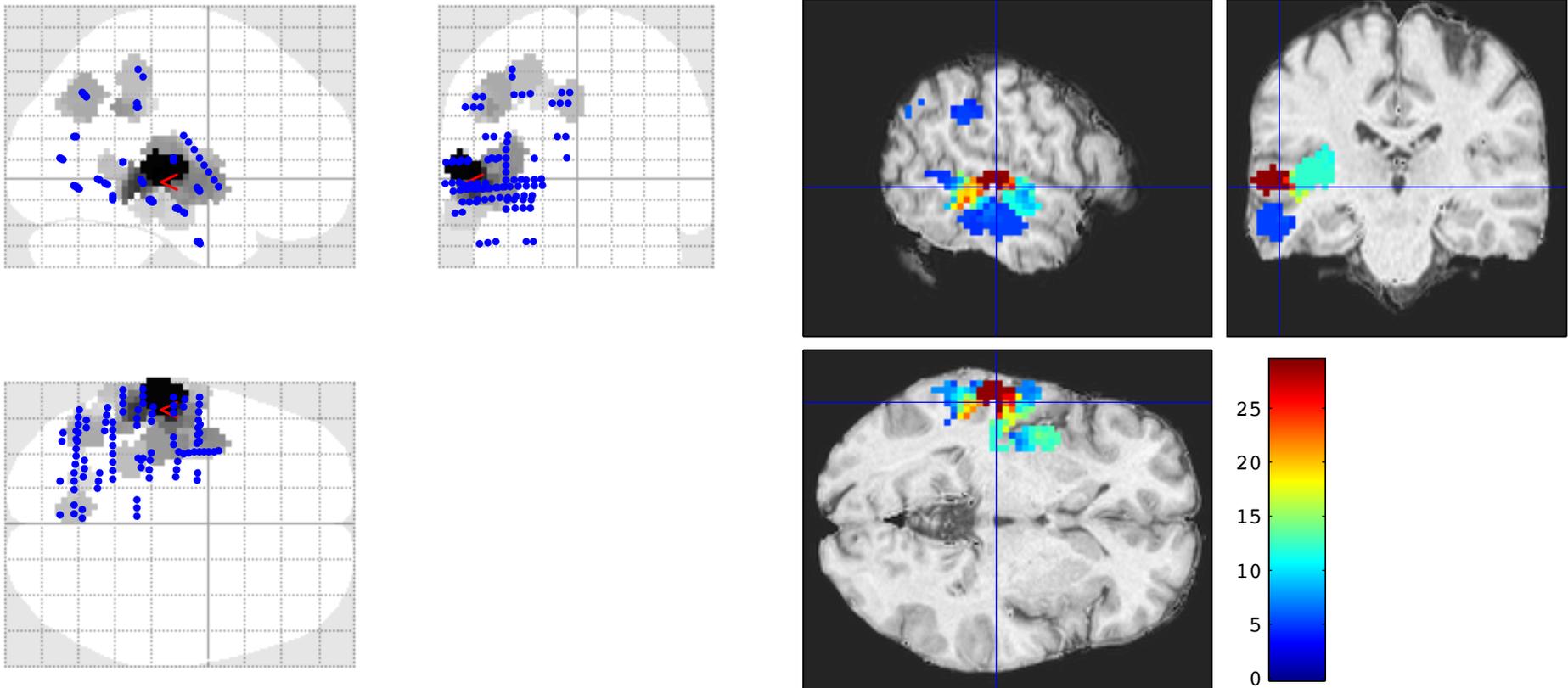


Statistical parametric map
of symptom-related network



High gamma oscillations induced by DES during auditory illusion

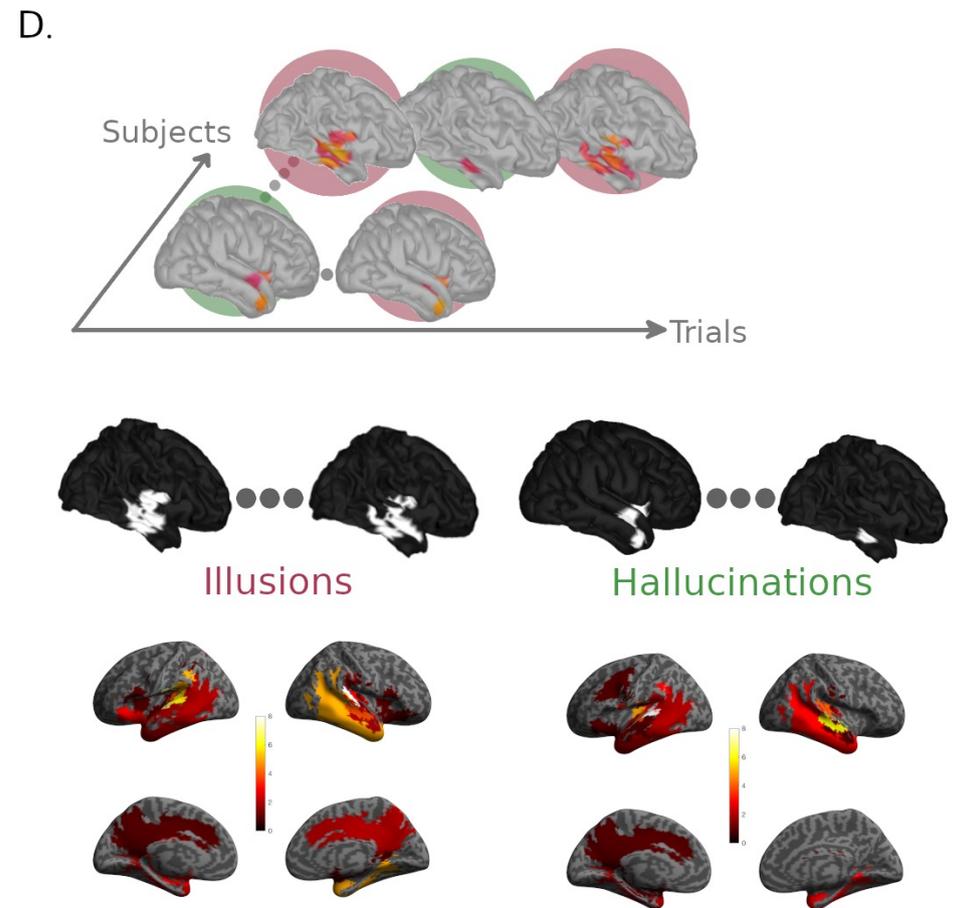
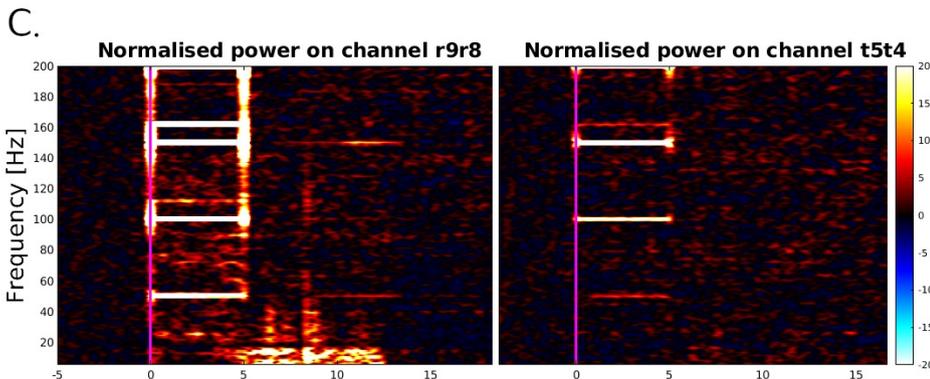
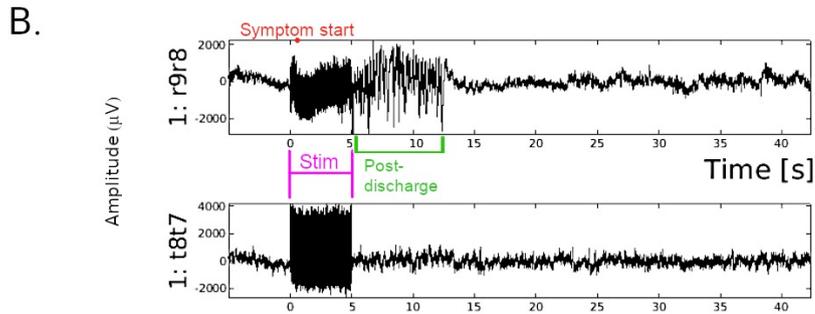
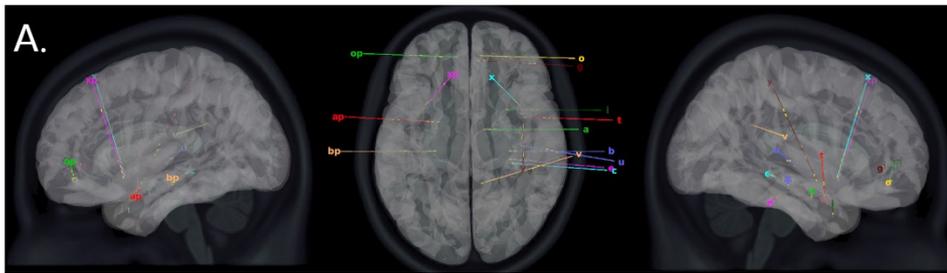
- [105 195] Hz
- [1 3] seconds post-stimulation onset



Group analysis of DES induced GBA Auditory illusions vs. hallucinations

- 109 reviewed patients
- 50 patients having auditory symptoms

Hallucinations - auditory experiences occurring in the absence of any corresponding sound input (elementary sounds such as clicking, whistling, ringing, buzzing or elaborate auditory phenomena such as music or voices).
Illusions - modulations of existing environmental sounds (change in loudness, pitch, distortion, echo ...).

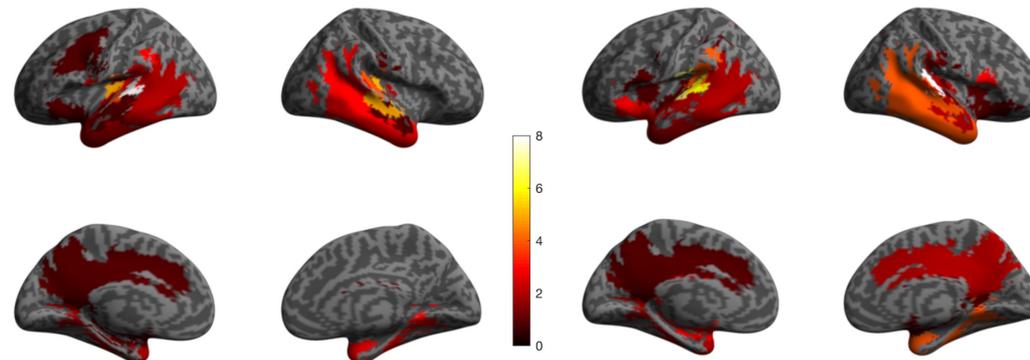


Group analysis of DES induced GBA Auditory illusions vs. hallucinations

- GBA is induced by DES in a large network around A1/A2
- Hallucinations involve more the mesio-temporal lobe and hallucination more opercular cortex and TPJ

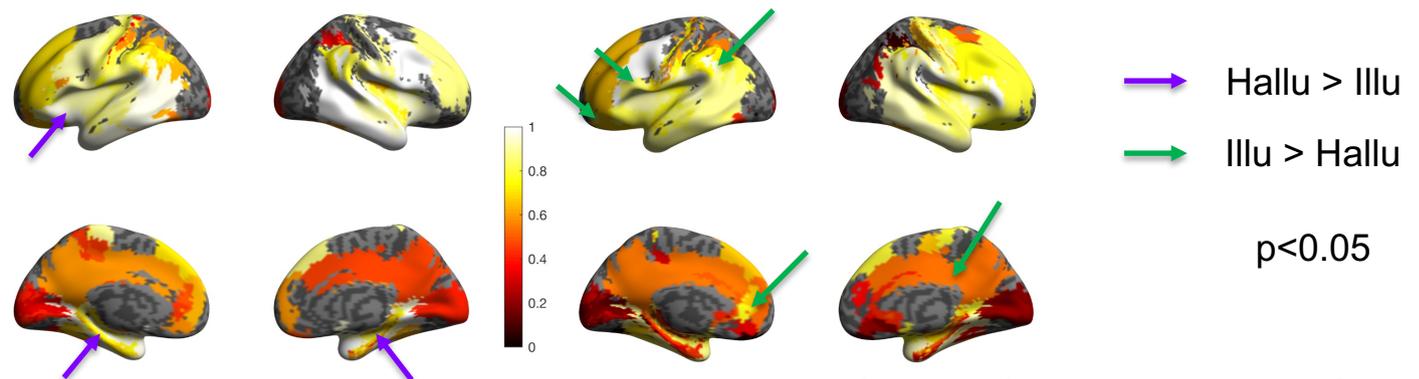
Hallucinations Illusions
ROI analysis

Stimulation sites



HFA analysis

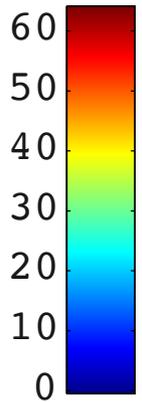
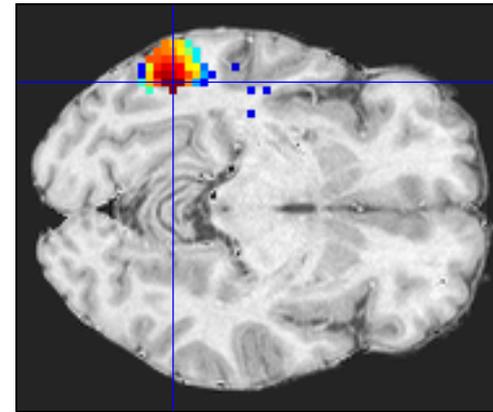
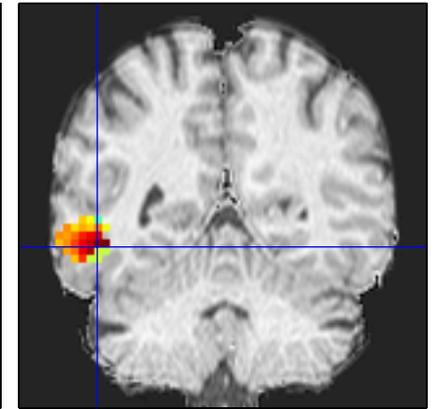
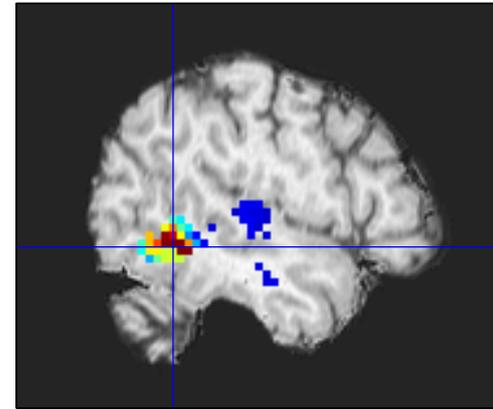
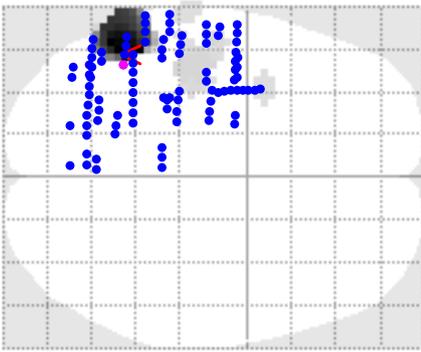
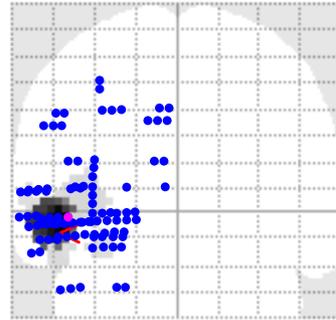
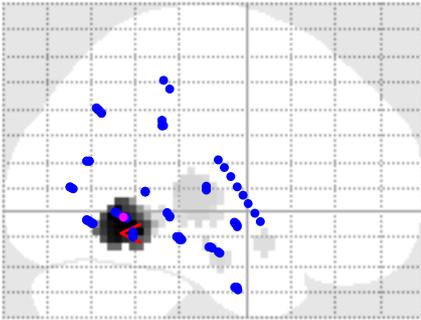
GBA-DES
response probability



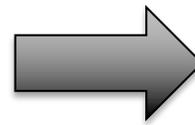
Jaroszynski et al., Brain Stimul, 2022

Mapping of symptom-related HFO 100-200 Hz during DES

SPMnip
[-48.3985, -52, -8.45455]



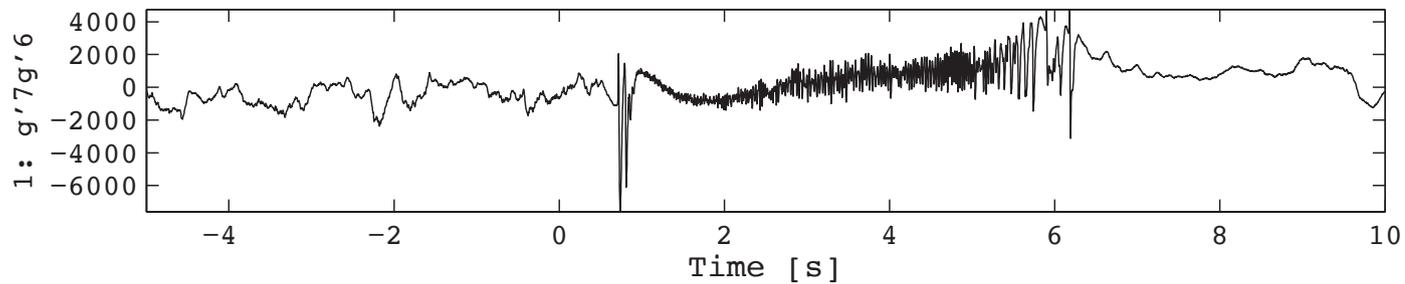
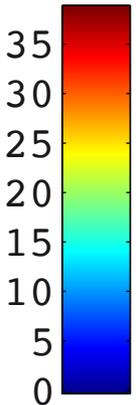
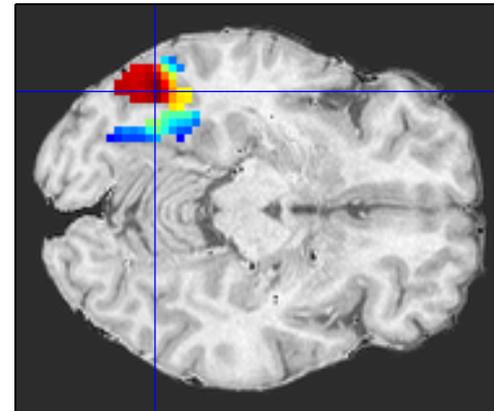
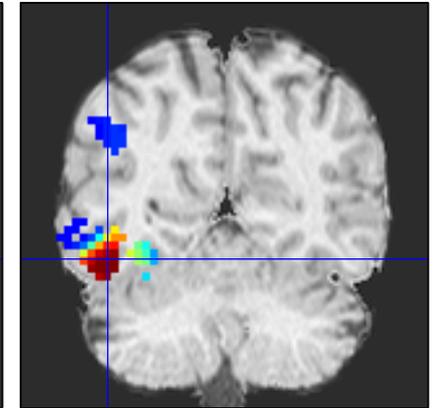
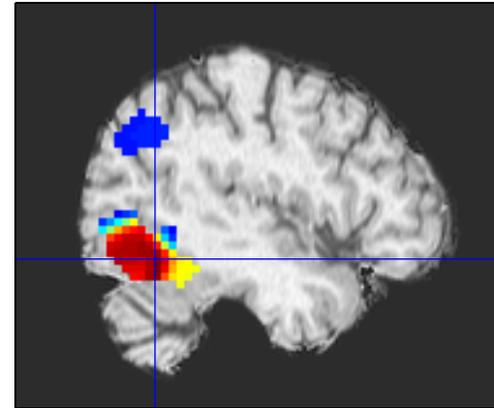
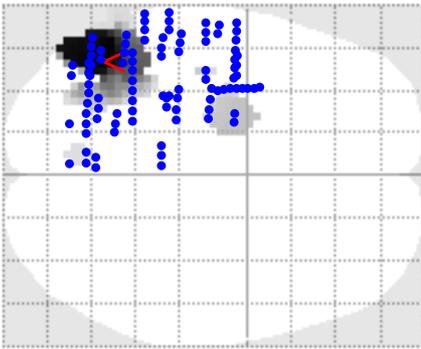
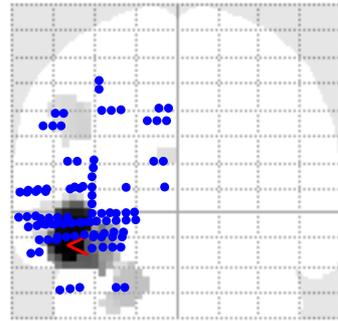
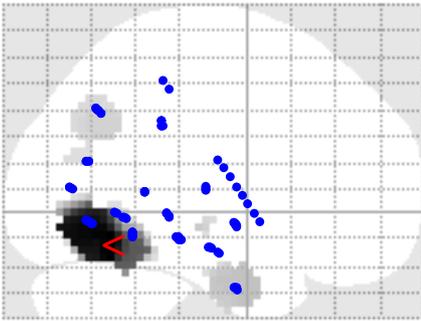
HFOs induced in
visual word form
area



Reading
impairment

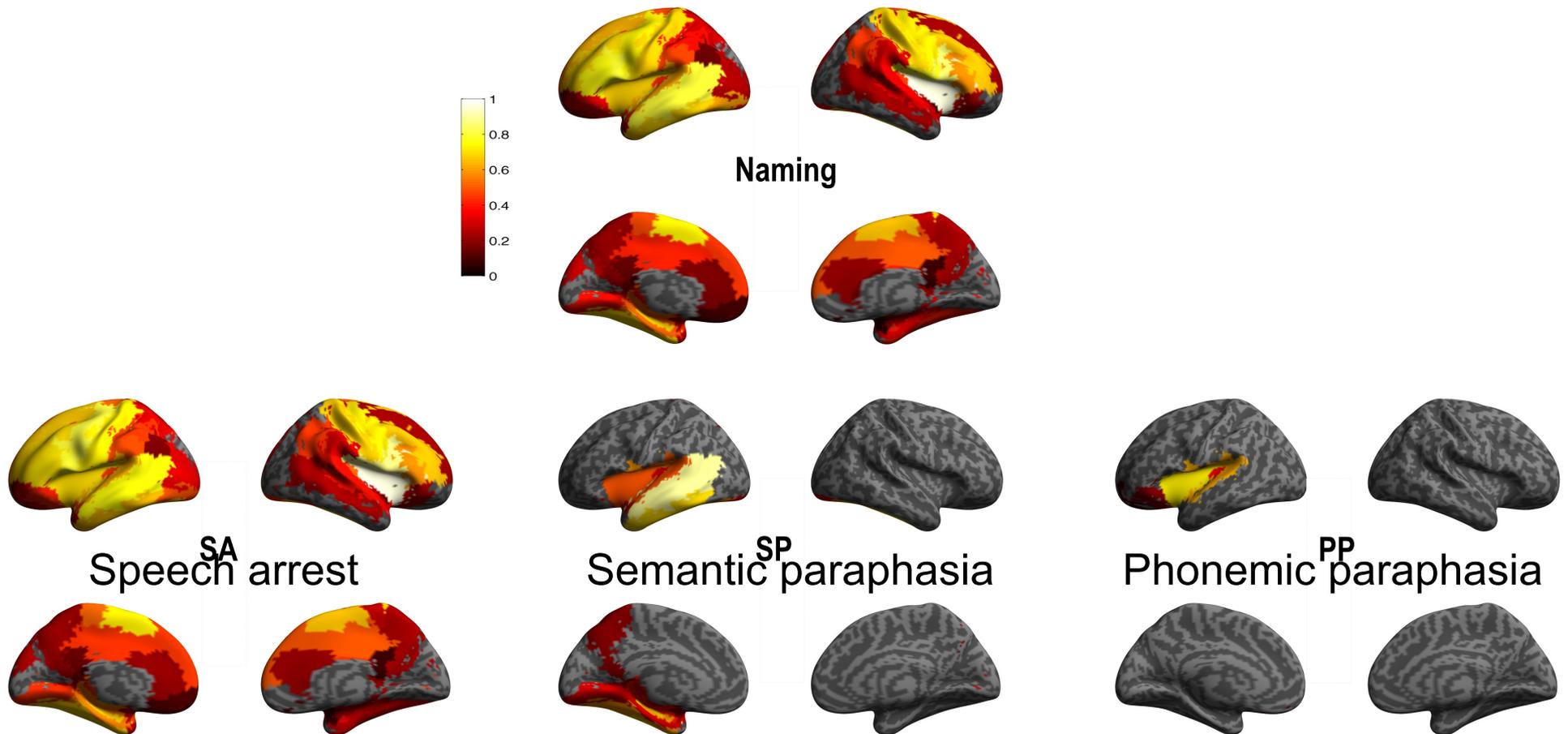
Mapping of ictal HFO

SPMnip
[-44.8571, -58.7531, -13.1818]



Group analysis of DES induced GBA Naming symptoms

- 29 patients



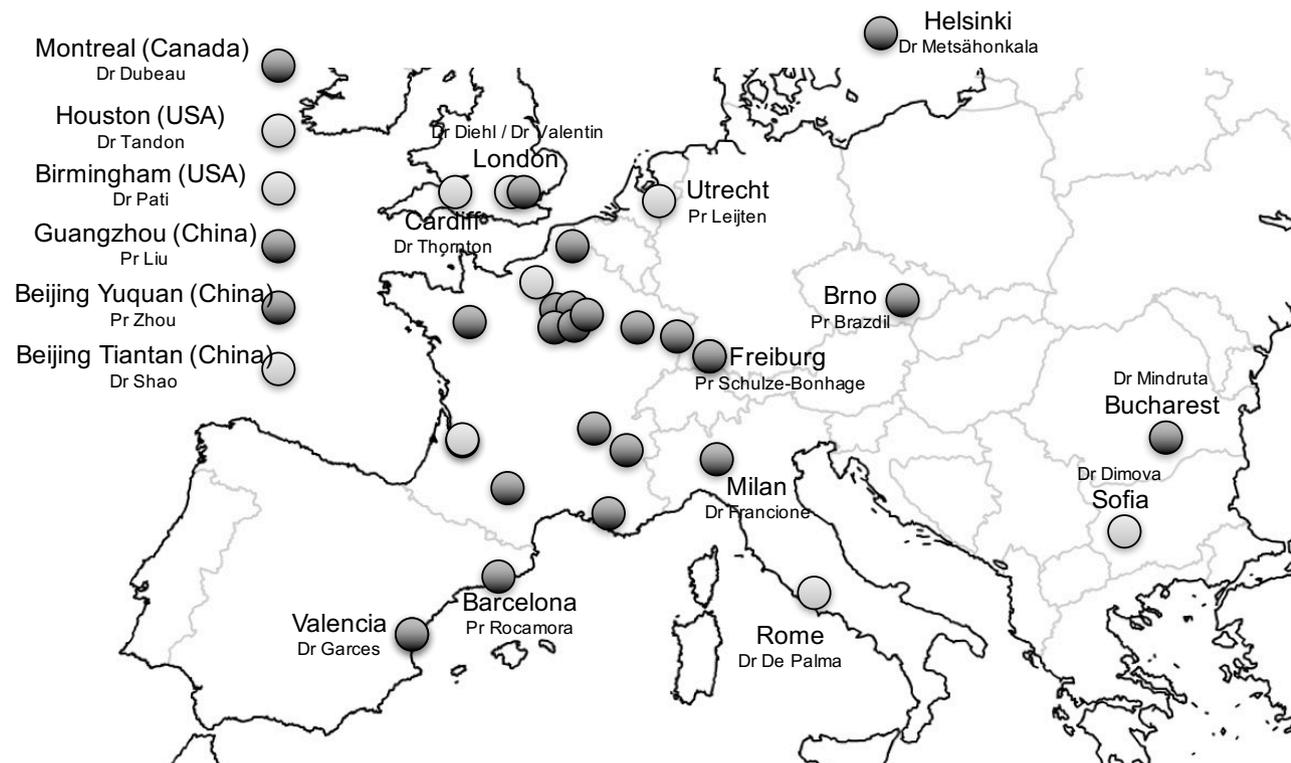
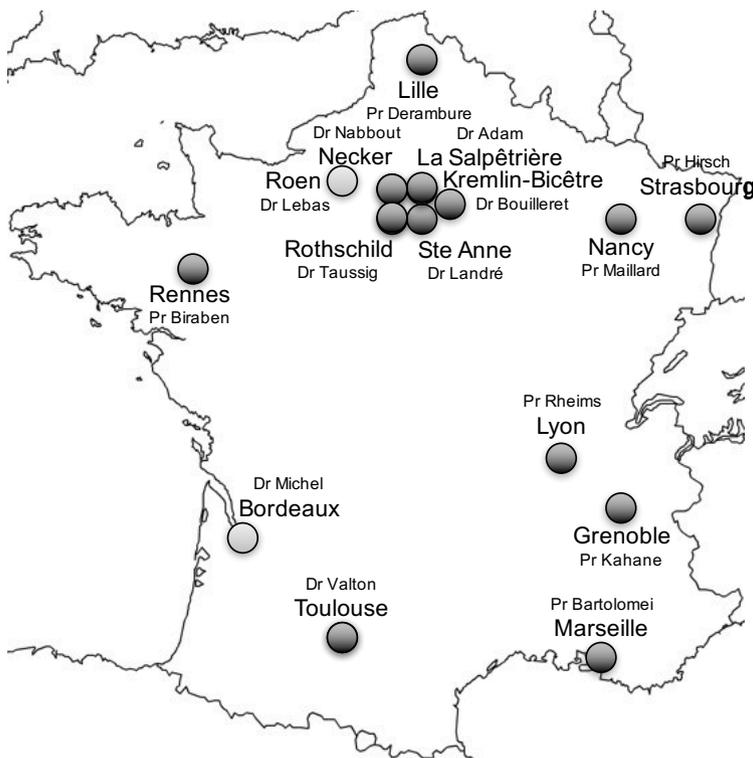
F-TRACT consortium

**NEUROANATOMICAL
MAPPING IN SEEG USING
1HZ STIMULATION
F-TRACT PROJECT**

- **Collaborating clinical centres**

- 14 French centres of epilepsy surgery
- Other European centres: Brno, Bucharest, Milan, London, Barcelona, Helsinki, Freiburg, Valencia, Florence, Budapest, King's College
- Non European centres: Montreal, Canton, Beijing

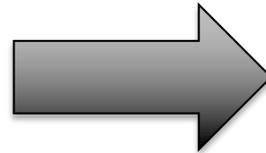
- Inclusions: > 1400 patients



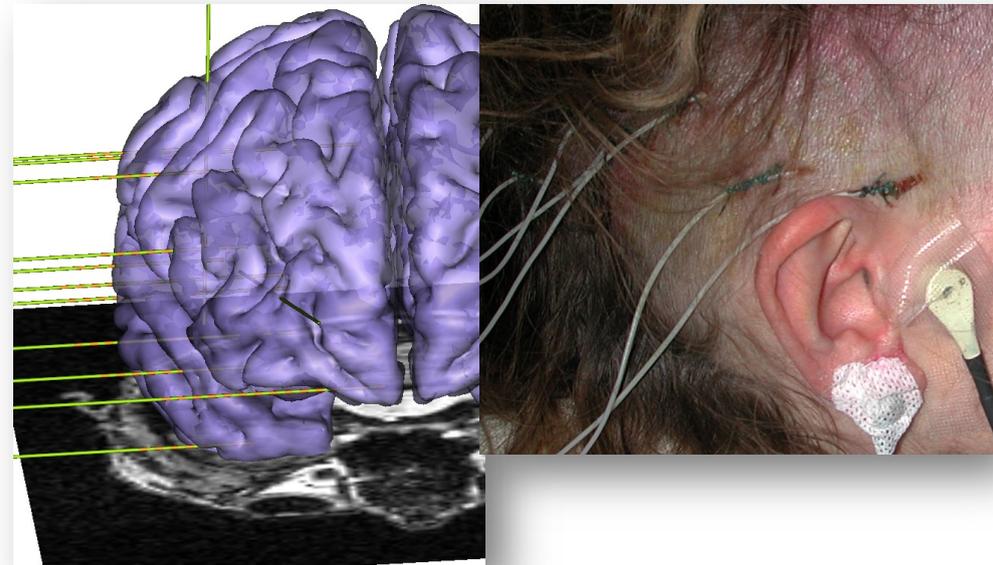
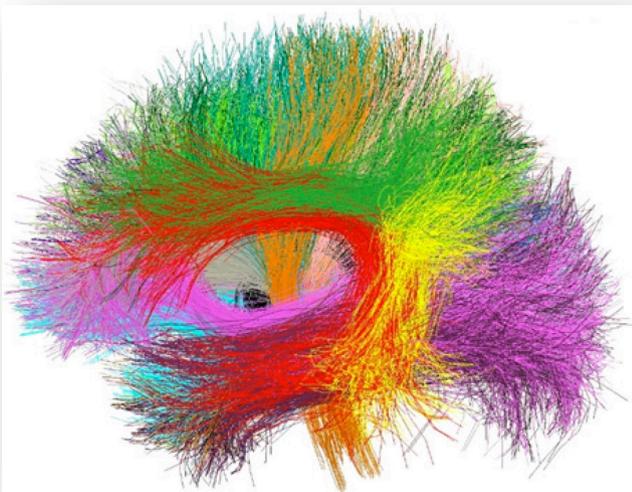
Main scientific goal of F-TRACT

- **To estimate dynamical properties of cortico-cortical connectivity in human *in vivo***
 - Directionnality
 - Propagation latency

DIFFUSION
MRI



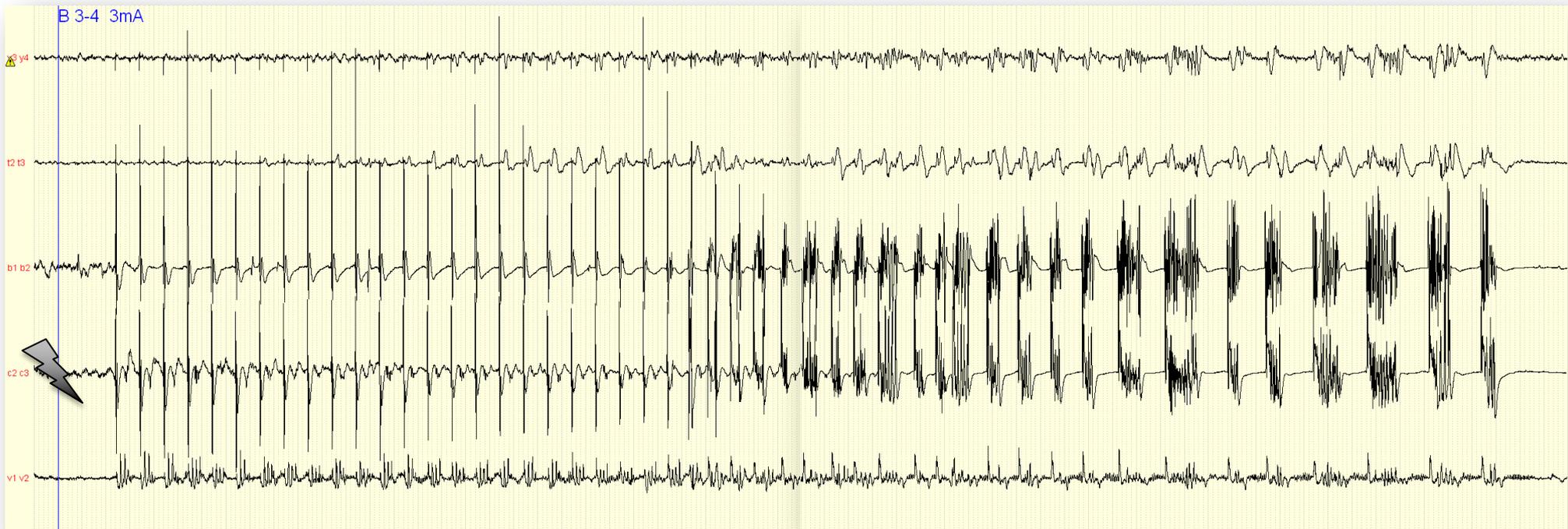
DIRECT ELECTRICAL
STIMULATION



Epilepsy mapping by 1 Hz direct electrical stimulation

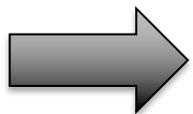
- Stimulation at low frequency to induce seizures

Anterior hippocampus



Stimulation

Seizure



Mesio-temporal epilepsy

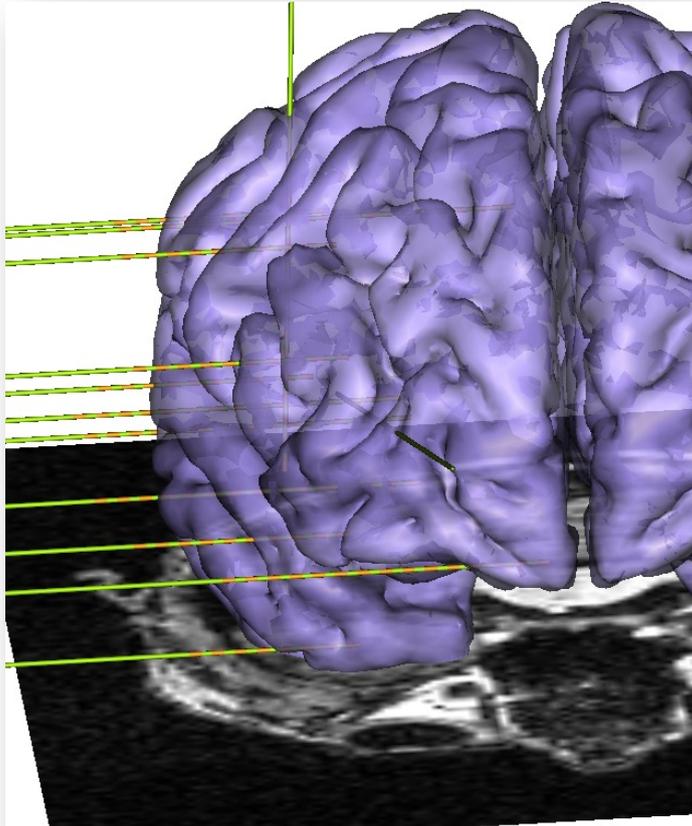
Epilepsy mapping by 1 Hz direct electrical stimulation

- Stimulation at low frequency with no induced seizure (most common case)

Temporal neocortex

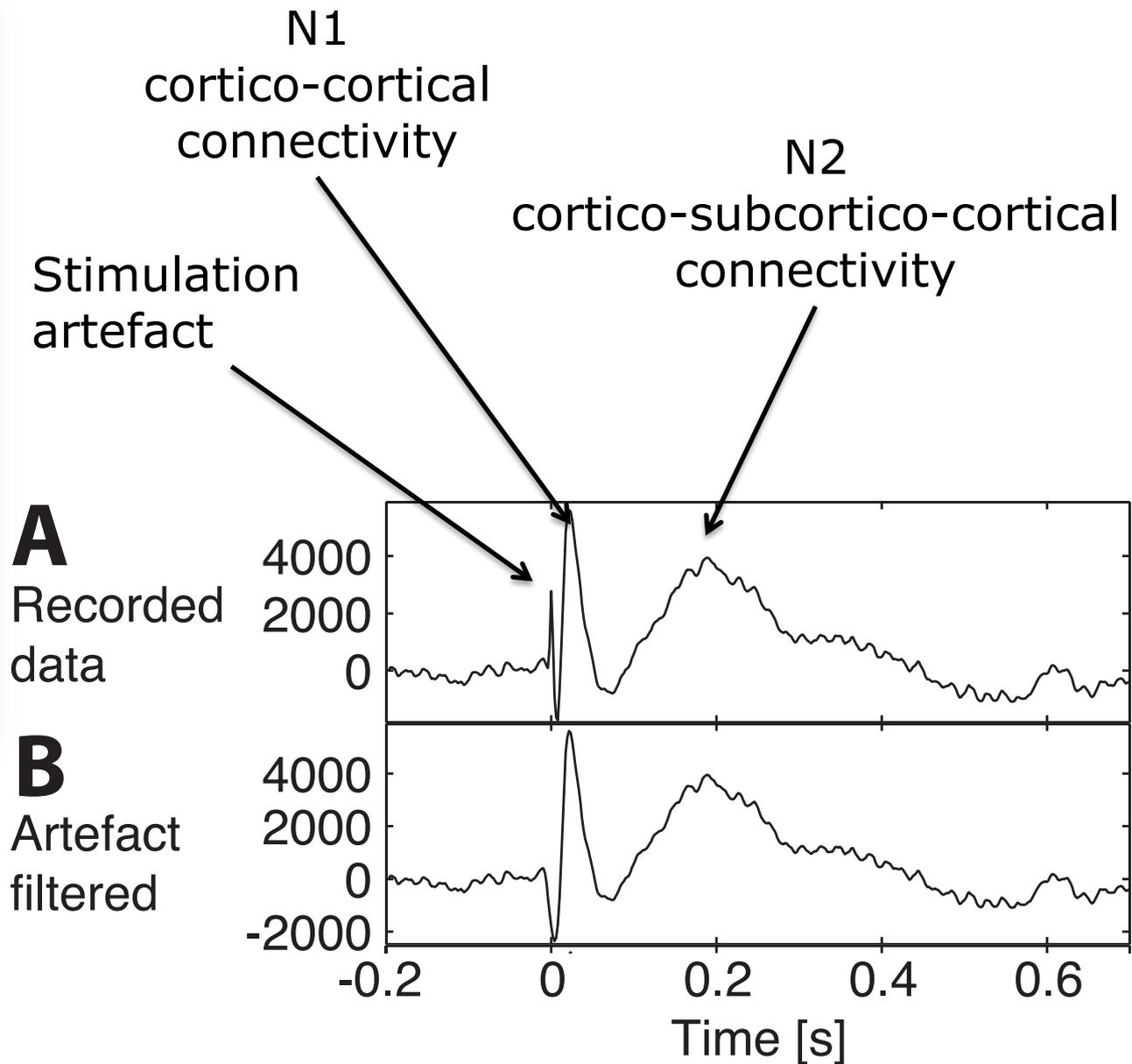


Cortico-cortical evoked potentials (CCEPs)

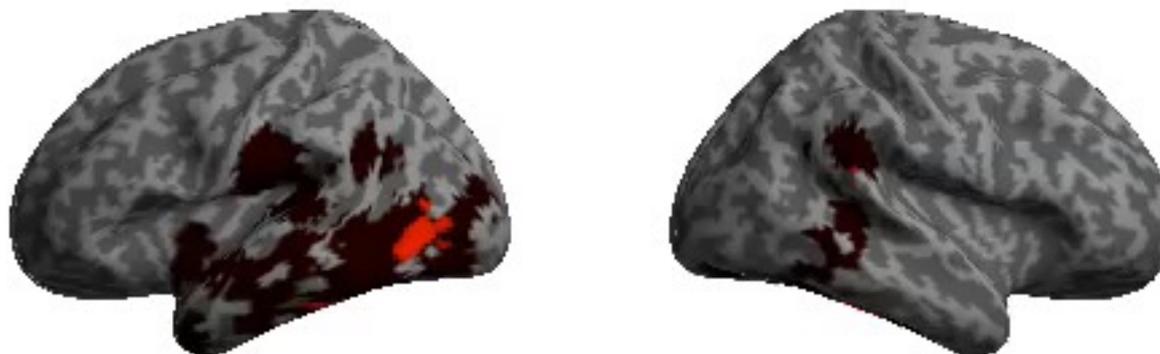


- Bipolar short (1 ms, 3 mA) stimulation pulse
- Recordings on all other electrodes

David et al., NeuroImage, 2013



- **Stimulation of left occipital cortex**



Time = 0 ms

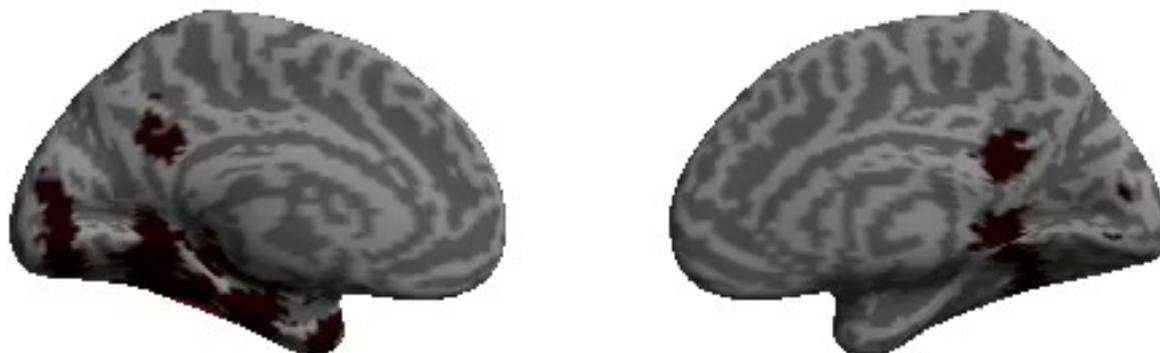
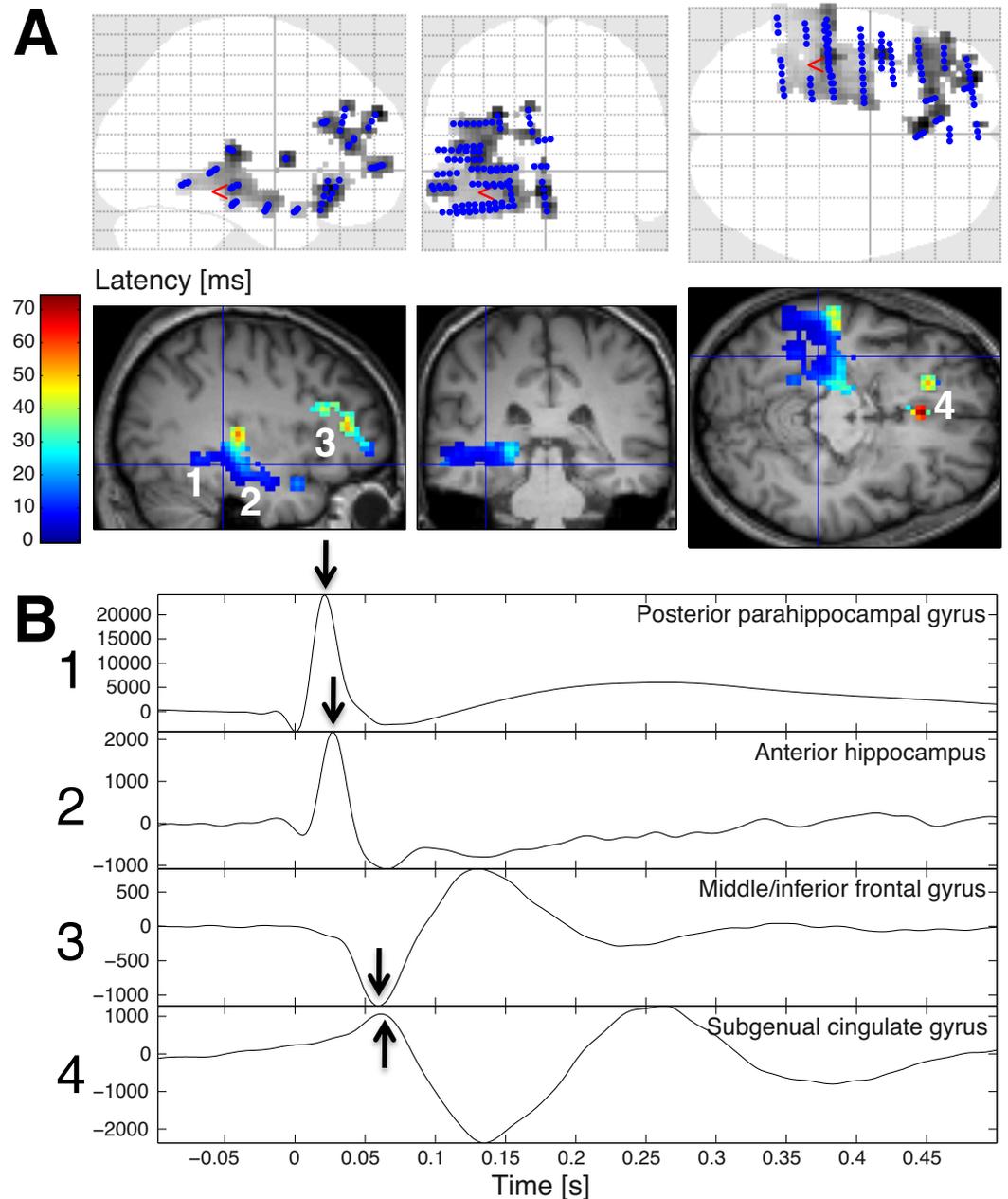


Image of CCEP peak latency

- Stimulation of left posterior parahippocampal gyrus



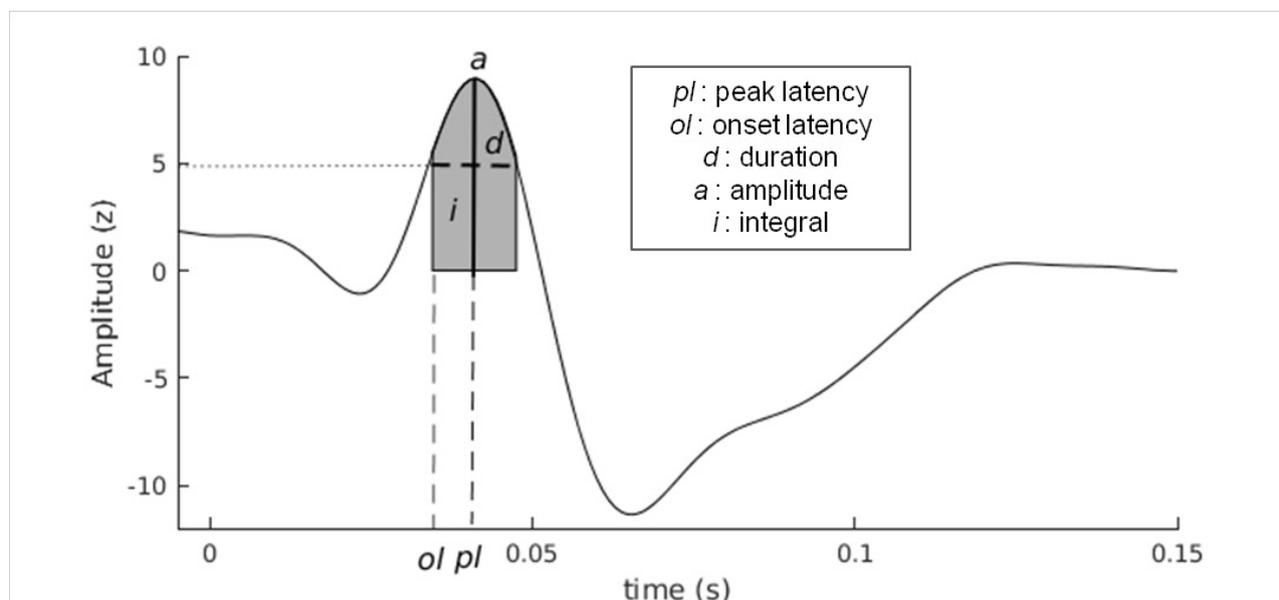
sEEG processing

Averaging over a run

Normalisation (z-score)

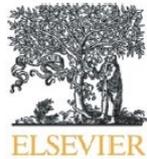
Extraction of response
significance and features

CCEP features



Methods for functional tractography

NeuroImage 80 (2013) 307–317



Contents lists available at SciVerse ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

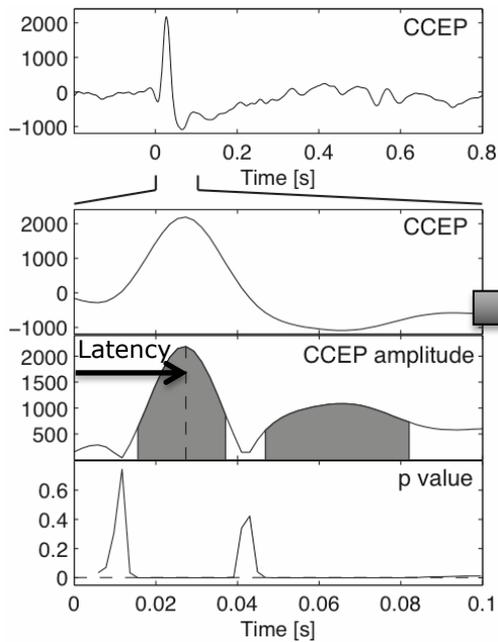


Probabilistic functional tractography of the human cortex

Olivier David ^{a,b,*}, Anne-Sophie Job ^{b,c}, Luca De Palma ^c, Dominique Hoffmann ^d,
 Lorella Minotti ^{b,c}, Philippe Kahane ^{b,c}

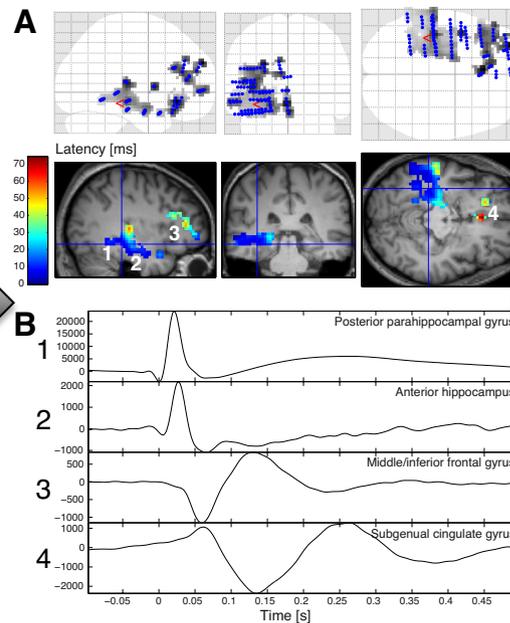
Step 1

Estimate response features



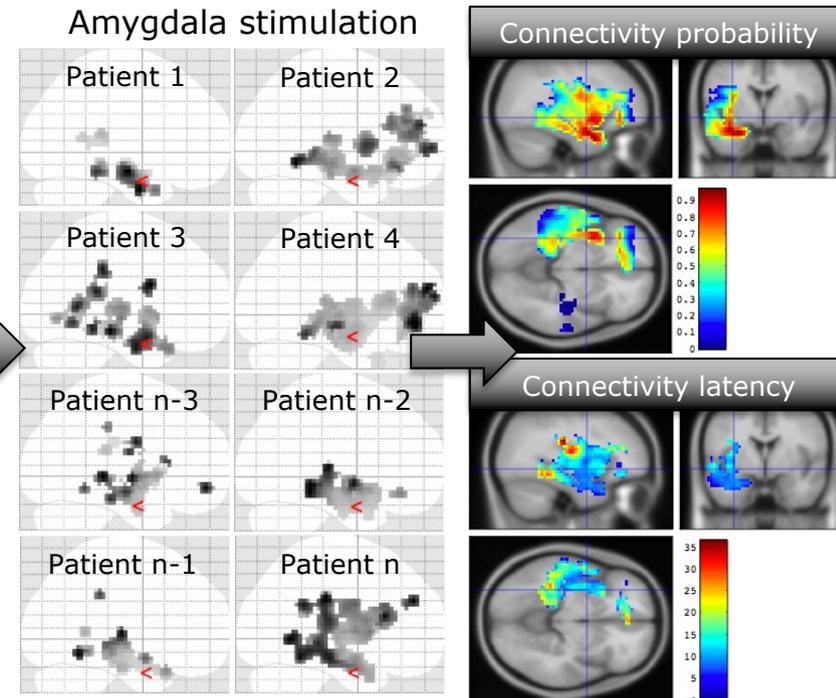
Step 2

Image response features



Step 3

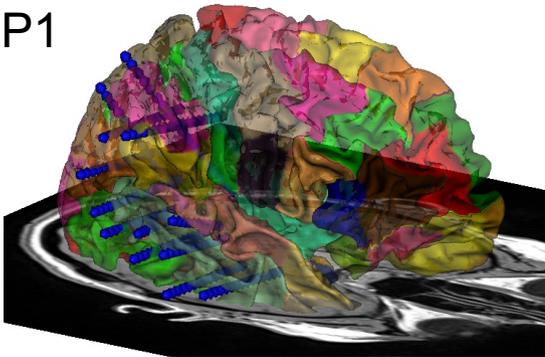
Probabilistic group maps



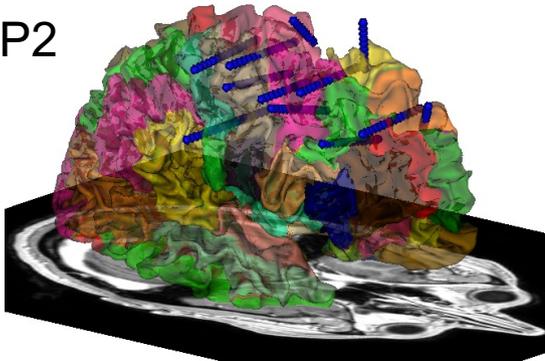
Parcellation for single-case and group studies

Patients' anatomy

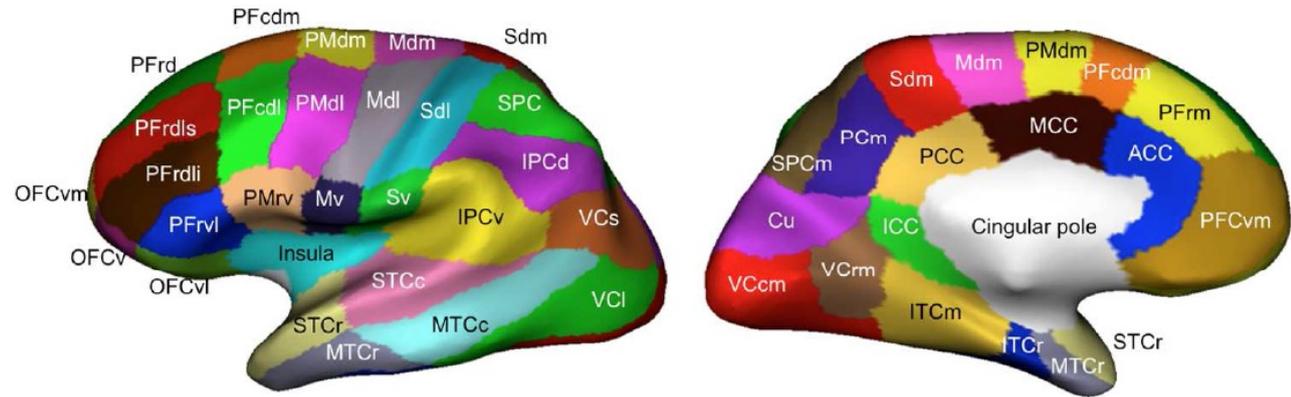
P1



P2

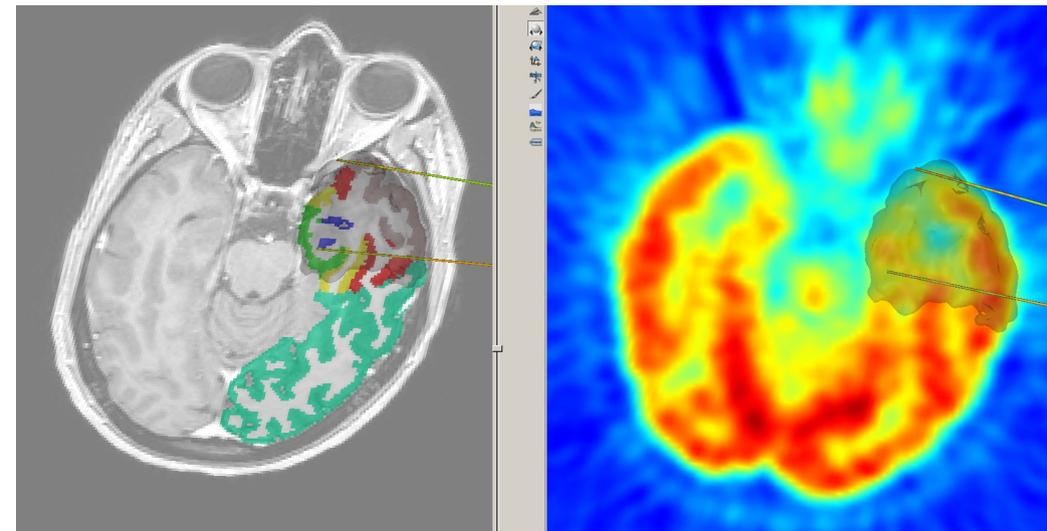


- Each contact is labelled according to:
 - Parcels in different atlases (MarsAtlas, AAL, MaxProbMap, Brodmann, Aicha, Destrieux, HCP, multiscale Lausanne atlas, **cytoarchitectonic Juelich atlas**)
 - Grey/White matter
 - Bad channel



MarsAtlas: Auzias et al., Human Brain Mapp, 2016

Fusion of SEEG, PET and post-operative MRI



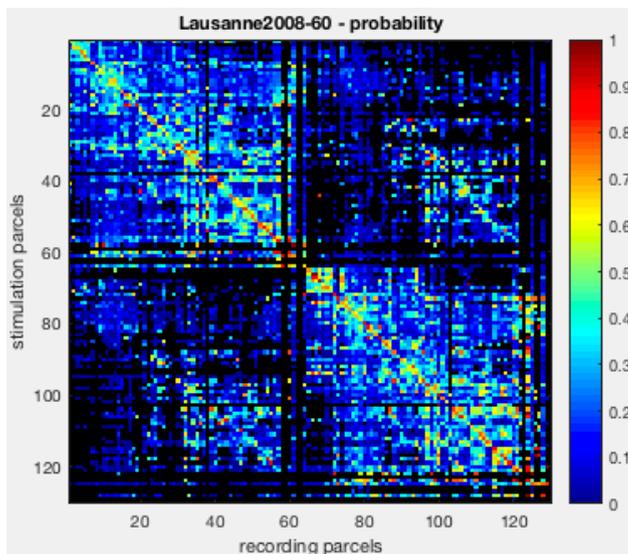
Deman et al., Frontiers Neuroinformatics, 2018

Multiscale spatial resolution approach

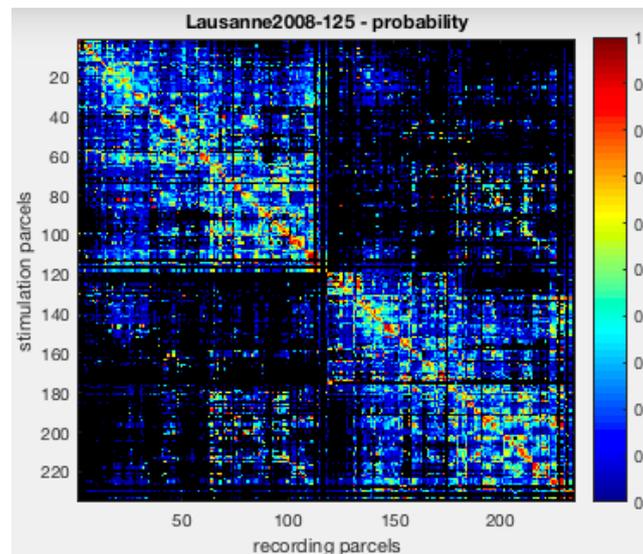
- **Spatial resolution of the F-TRACT atlas depends on locally available data**
- **Collaboration with P Hagman on the Lausanne atlas**

Connectivity probability matrices (~300 patients)

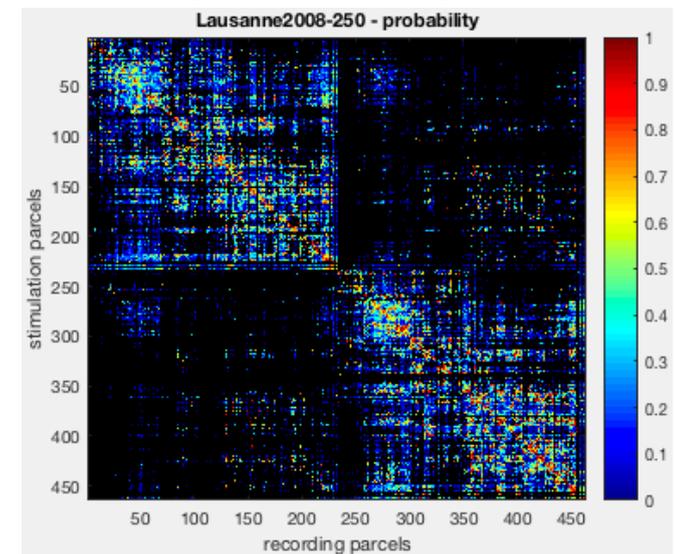
63 parcels / hemisphere



125 parcels / hemisphere



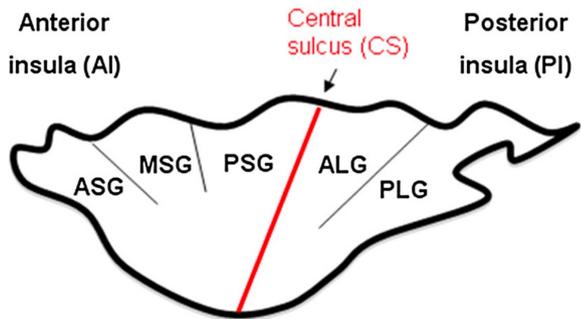
250 parcels / hemisphere



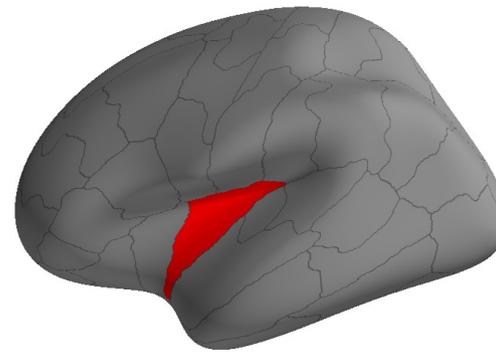
Multiresolution atlas

Example of connectivity of insula

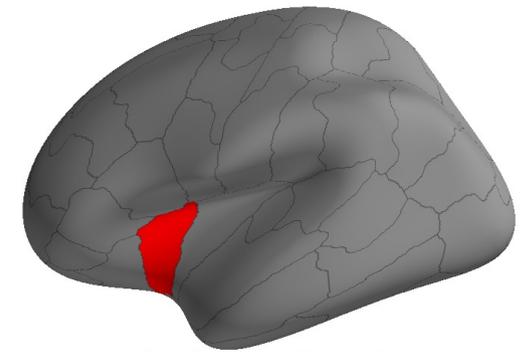
Lacuey et al., Brain Struct Func, 2016



Laussane2008-60

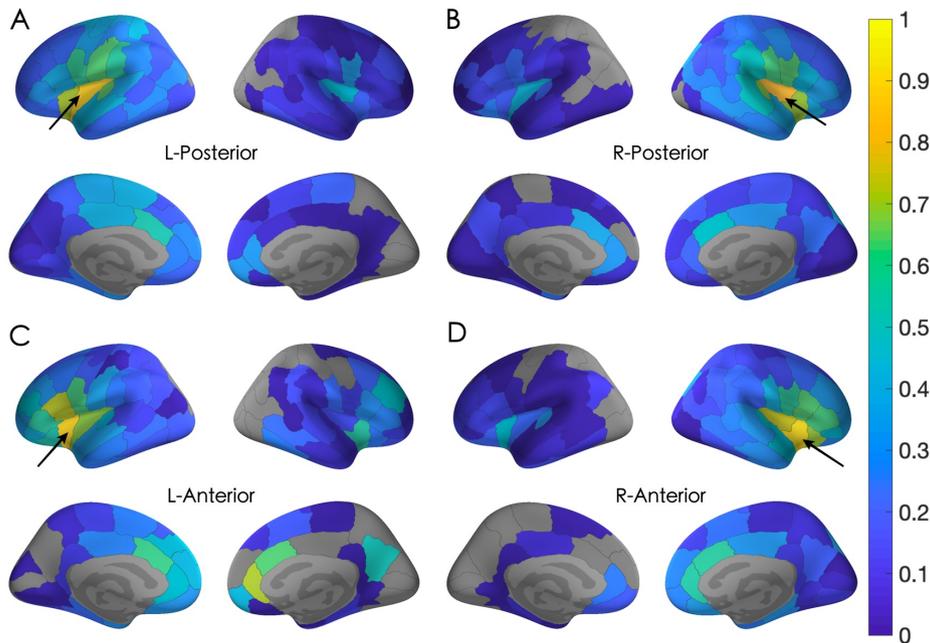


Posterior Insula

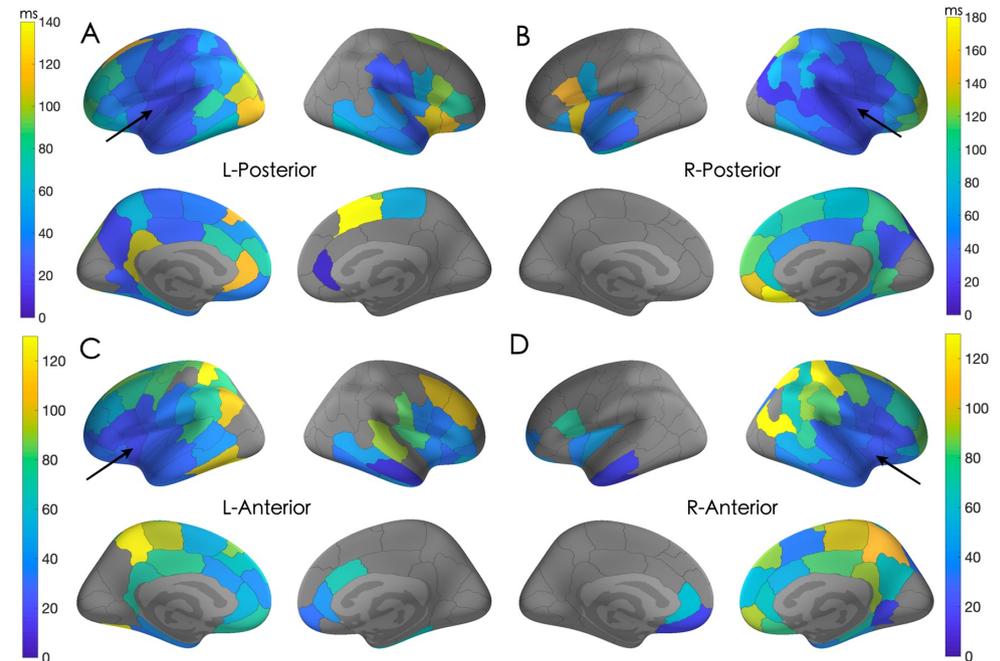


Anterior Insula

Connectivity probability



Median propagation latency

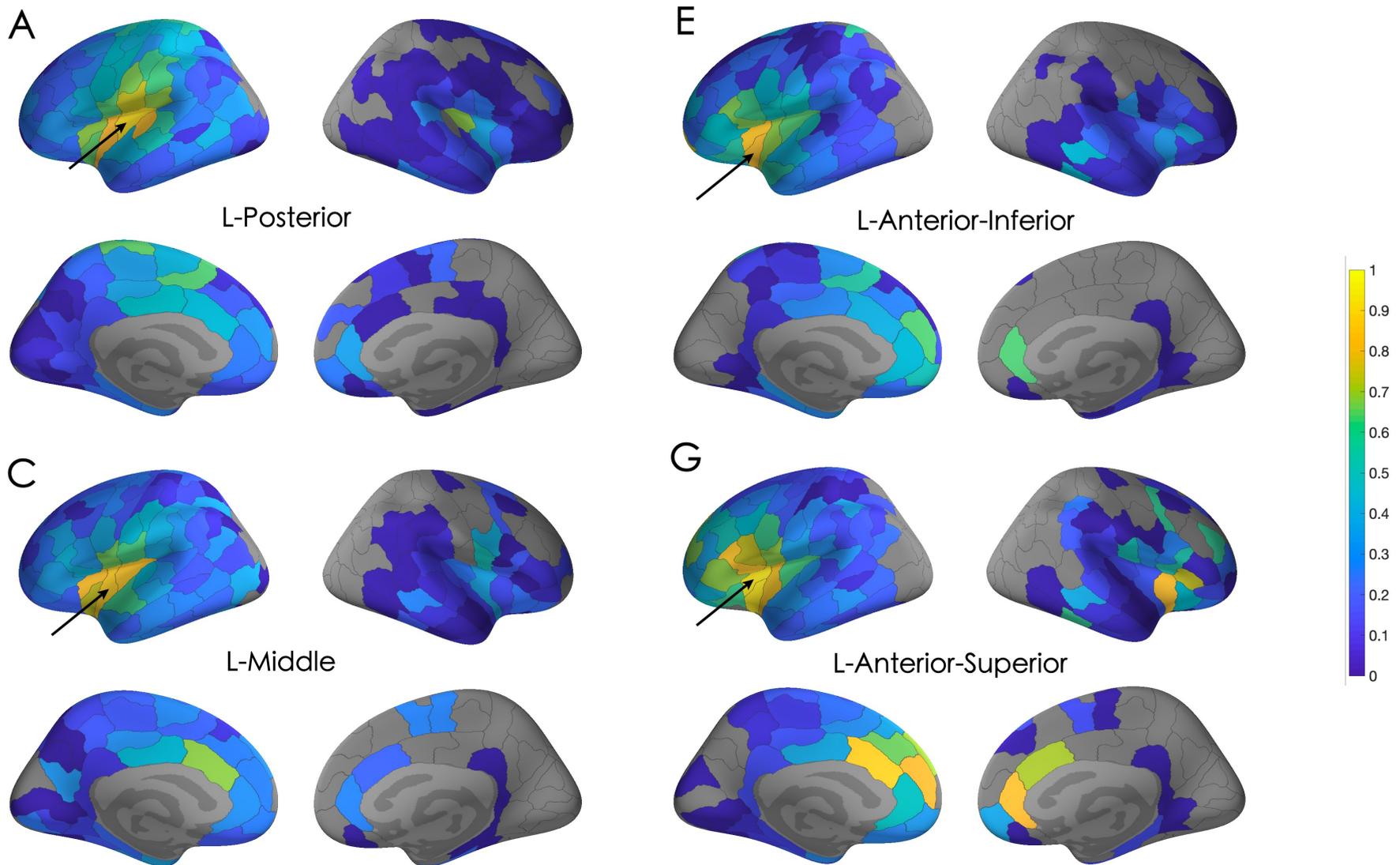


Ayoubian et al., Insula book, 2021

Multiresolution atlas

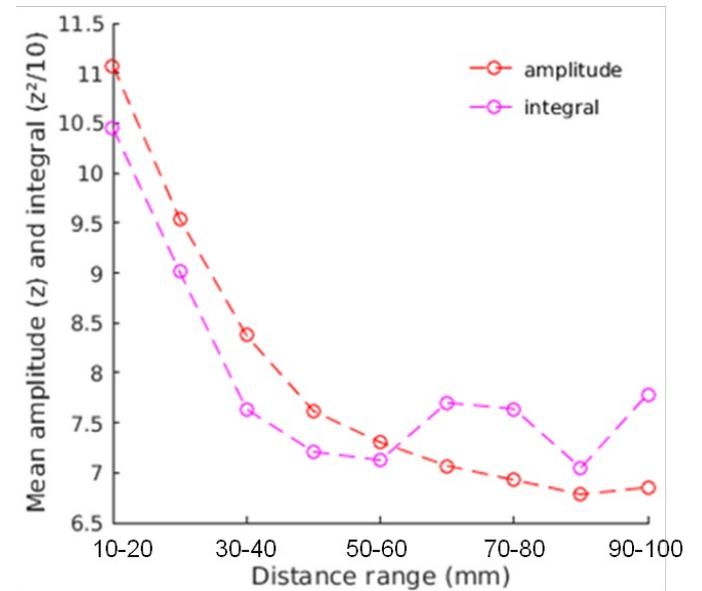
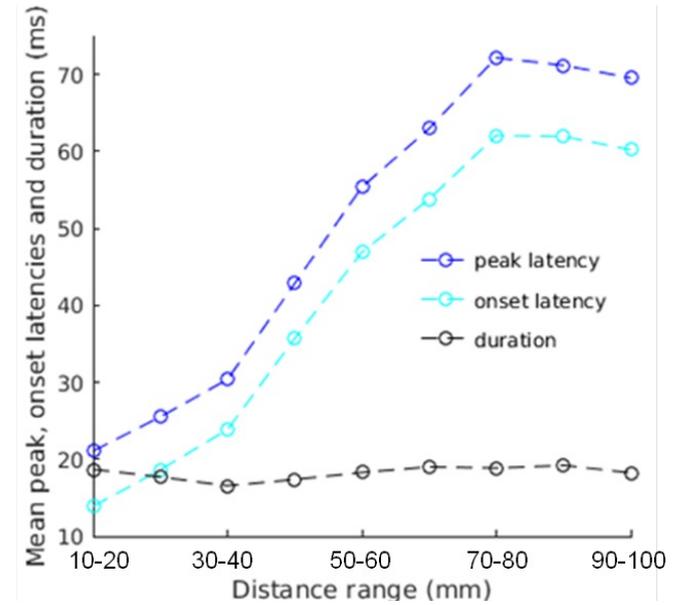
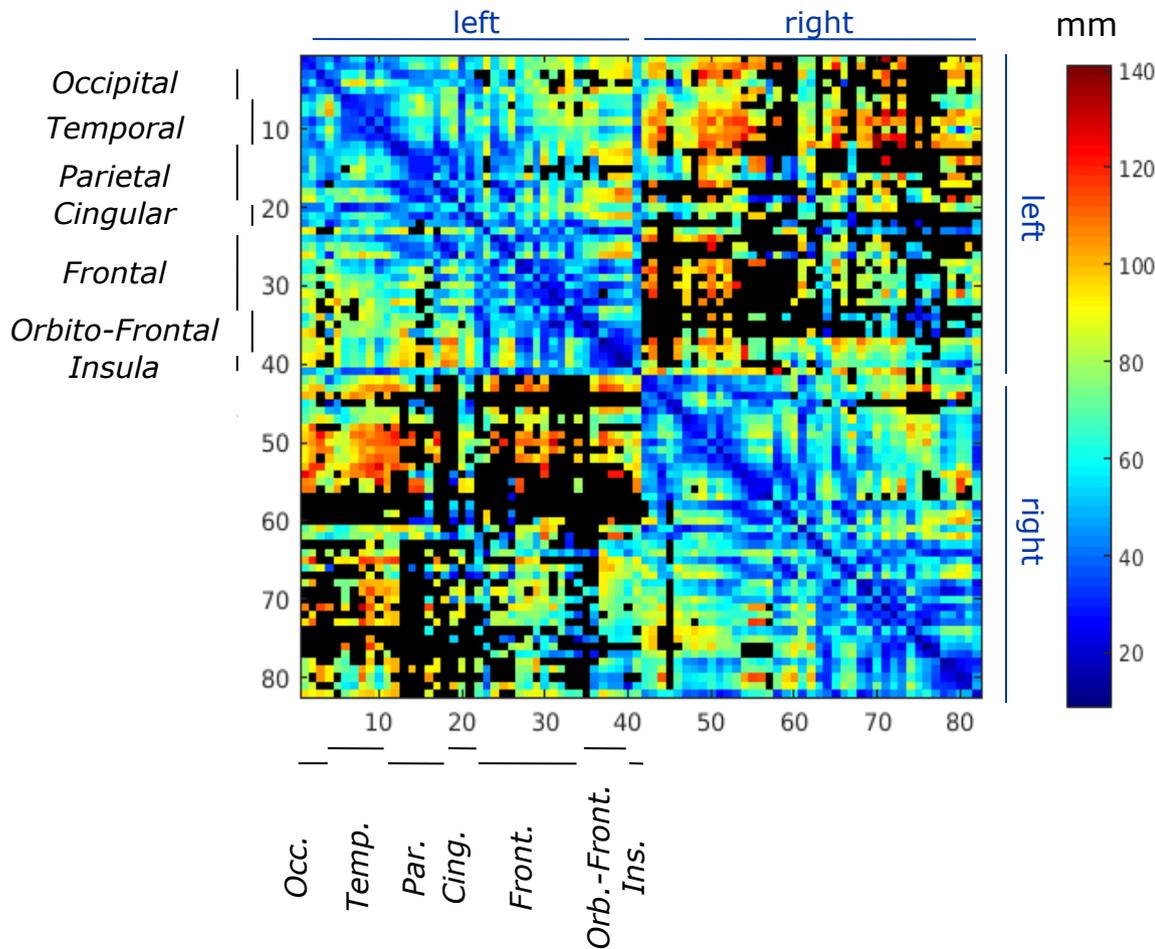
Example of connectivity of insula

Connectivity probability of Lausanne2008-125



Effect of distance on CCEP features

Distance matrix



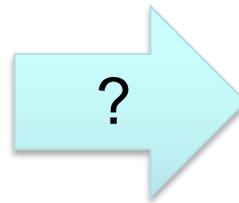
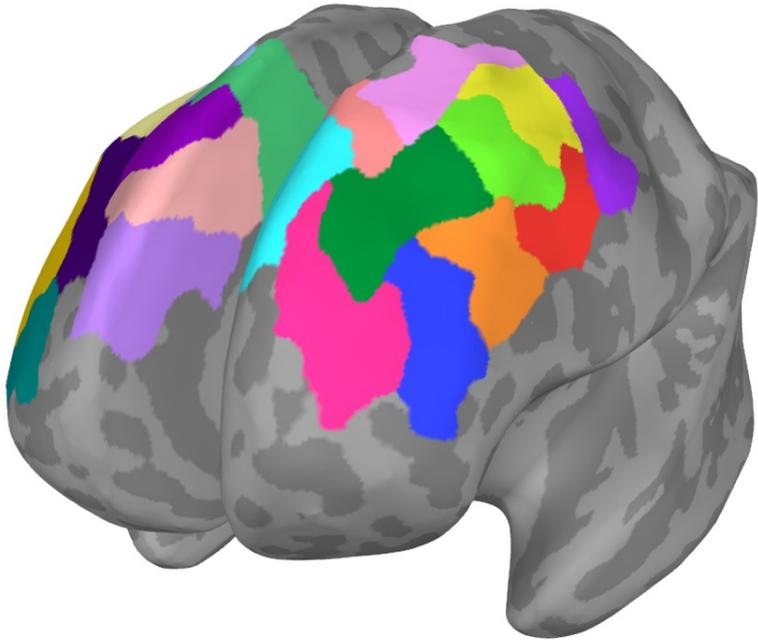
Trebaul et al., NeuroImage, 2018



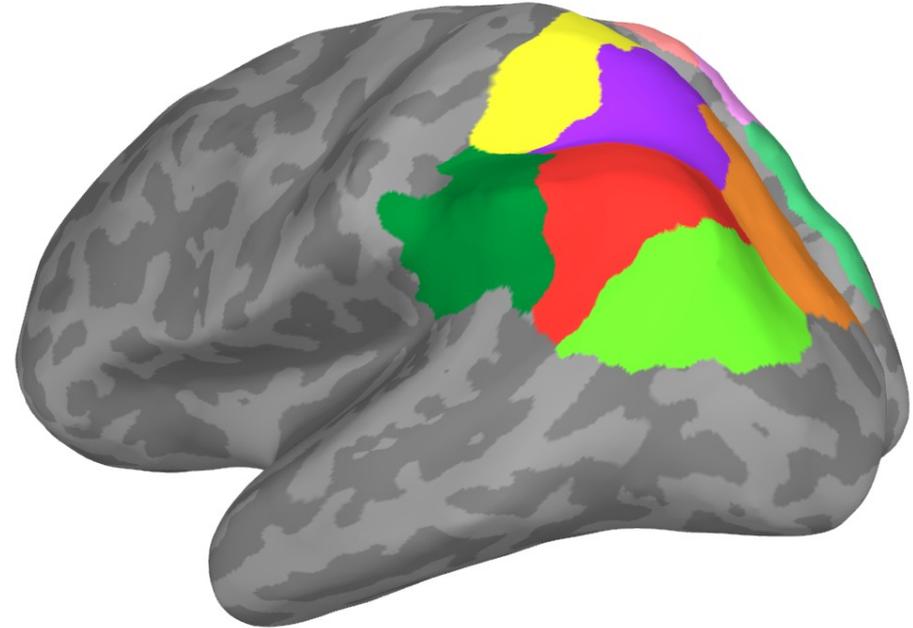
Connectivity of DLPFC and fronto-parietal network

- PhD project of Sofia Avalos Alais

Lausanne 125



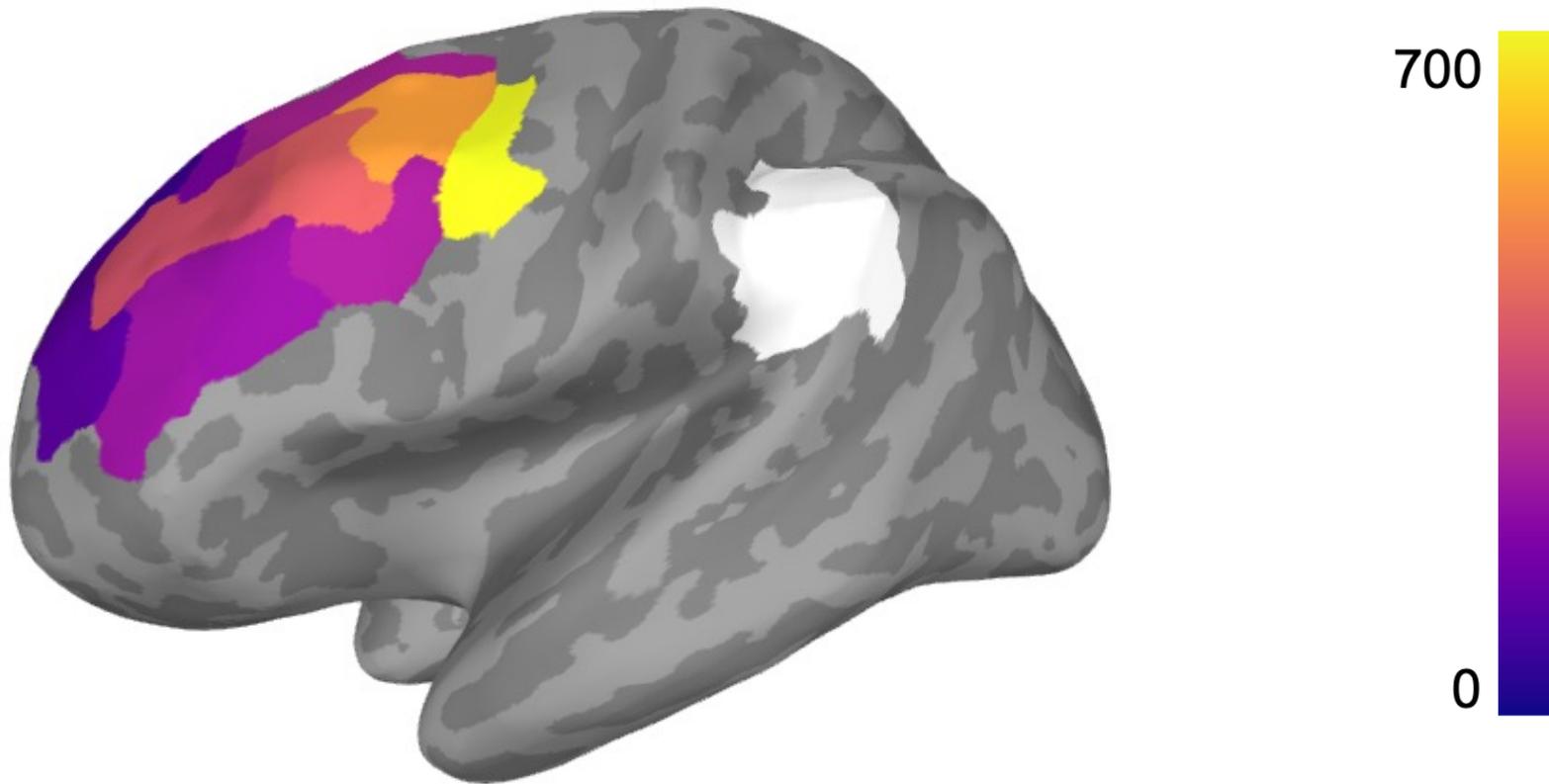
Lausanne 60





Connectivity of DLPFC and fronto-parietal network

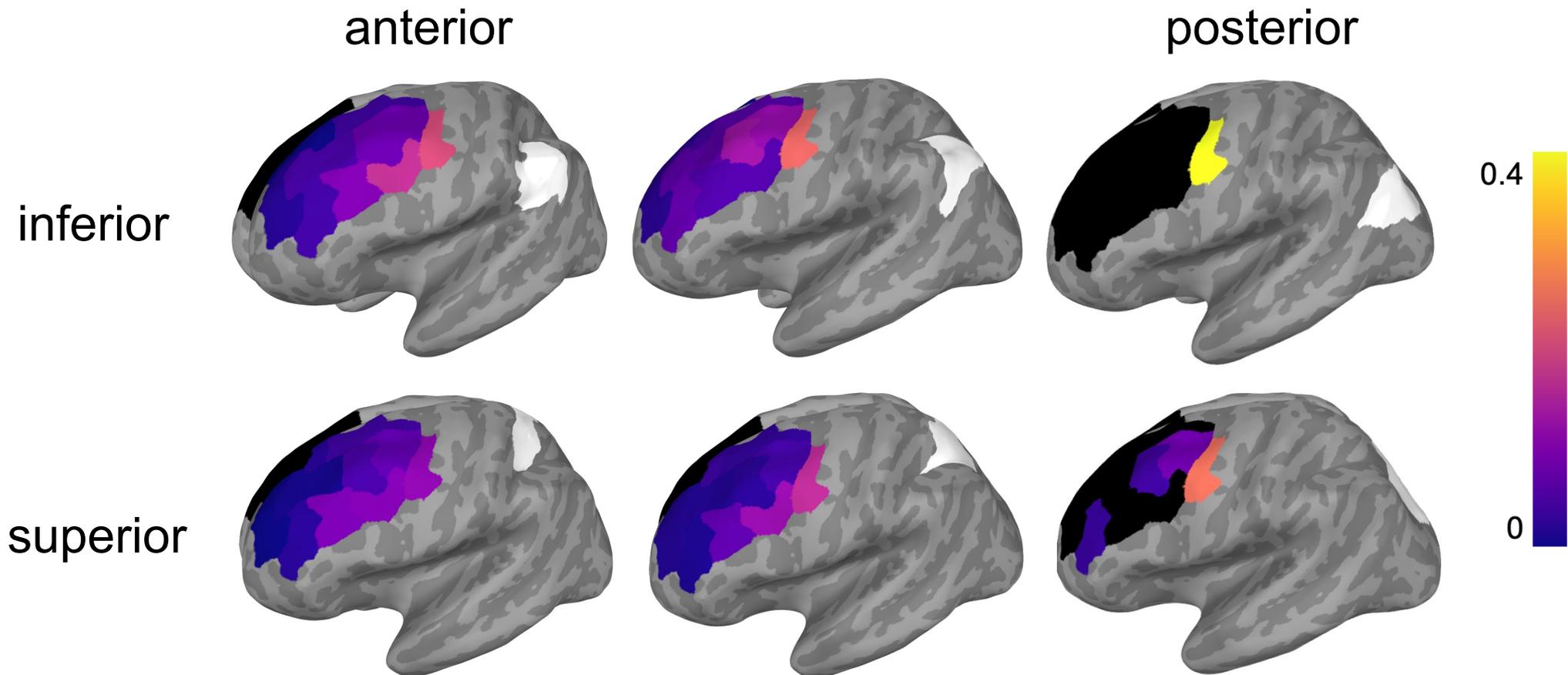
- **Number of stimulations used to map fronto-parietal connectivity**





Connectivity of DLPFC and fronto-parietal network

- **Direct fronto-parietal connectivity probability (responses before 50 ms, at least 50 stimulations per DLPFC ROI)**



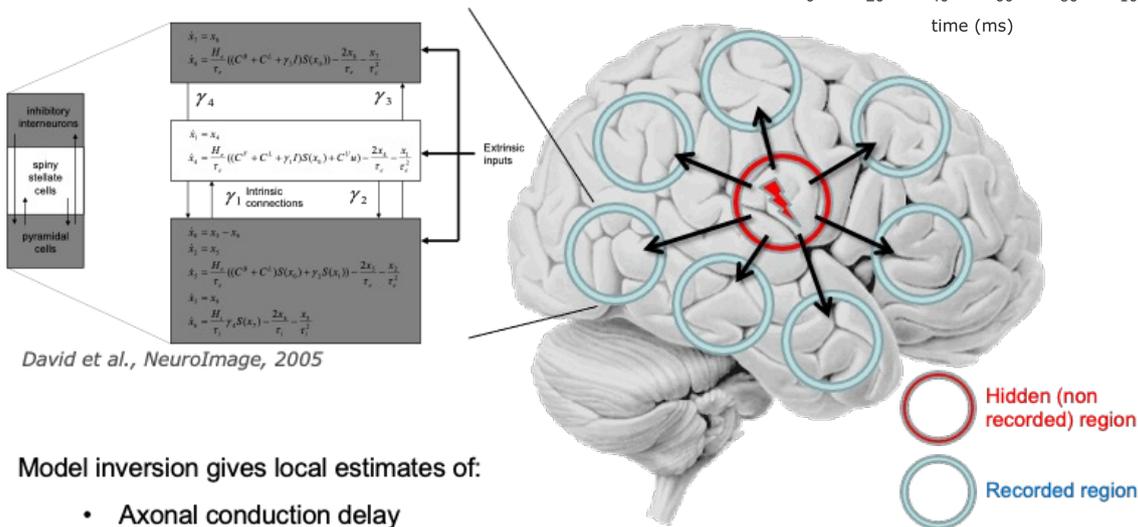
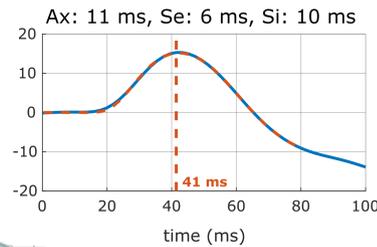
Cortical atlas of inhibitory and excitatory time constants

Materials

- 780 patients (F-TRACT database)
- 34354 bipolar stimulations (774445 CCEPs)

Methods

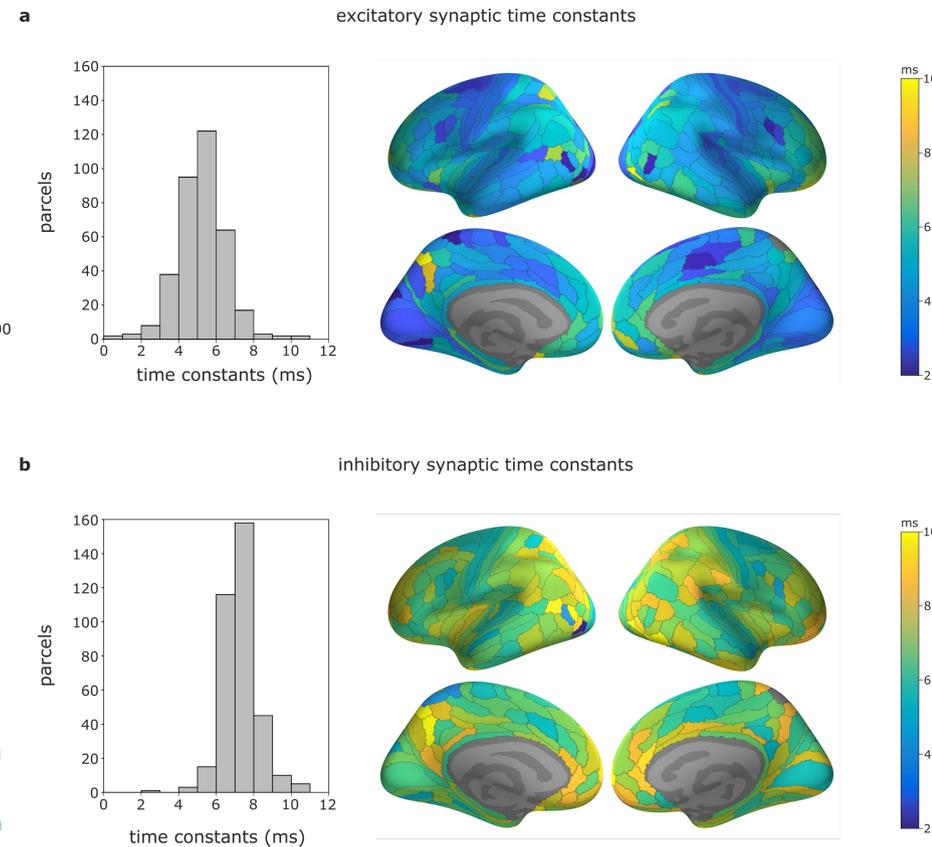
- N1 component with direct connection (peak < 80ms)
- Dynamic Causal Modeling (ERP neuronal model)



Model inversion gives local estimates of:

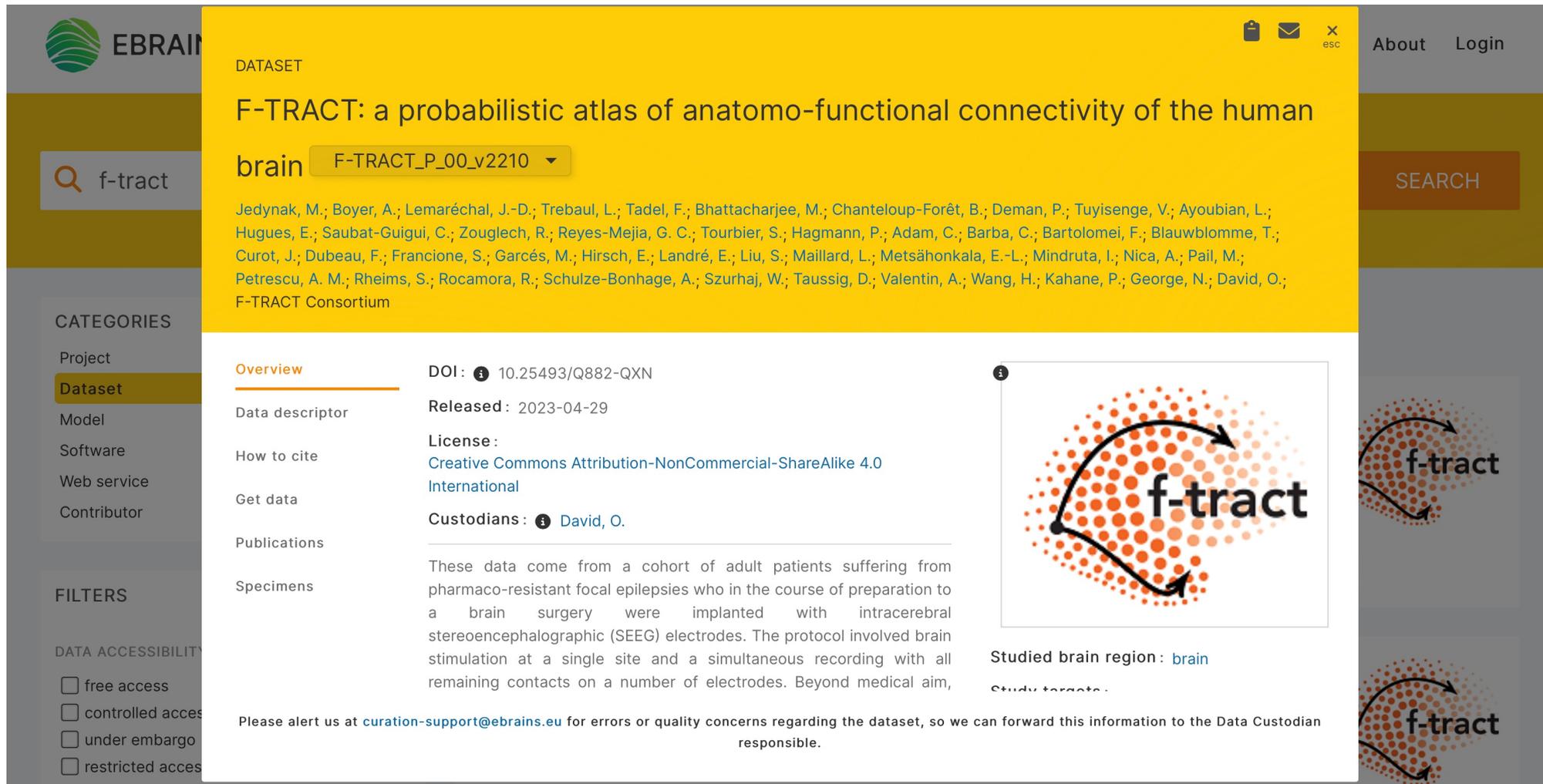
- Axonal conduction delay
- Excitatory time constant
- Inhibitory time constant

Mapping of synaptic properties



Primary cortices show faster synaptic properties

Lemaréchal et al., Brain, 2022



EBRAIN About Login

F-TRACT: a probabilistic atlas of anatomo-functional connectivity of the human brain SEARCH

F-TRACT_P_00_v2210

Jedynak, M.; Boyer, A.; Lemaréchal, J.-D.; Trebaul, L.; Tadel, F.; Bhattacharjee, M.; Chanteloup-Forêt, B.; Deman, P.; Tuyisenge, V.; Ayoubian, L.; Hugues, E.; Saubat-Guigui, C.; Zoglech, R.; Reyes-Mejia, G. C.; Tourbier, S.; Hagmann, P.; Adam, C.; Barba, C.; Bartolomei, F.; Blauwblomme, T.; Curot, J.; Dubeau, F.; Francione, S.; Garcés, M.; Hirsch, E.; Landré, E.; Liu, S.; Maillard, L.; Metsähonkala, E.-L.; Mindruta, I.; Nica, A.; Pail, M.; Petrescu, A. M.; Rheims, S.; Rocamora, R.; Schulze-Bonhage, A.; Szurhaj, W.; Taussig, D.; Valentin, A.; Wang, H.; Kahane, P.; George, N.; David, O.; F-TRACT Consortium

Overview

DOI: [10.25493/Q882-QXN](https://doi.org/10.25493/Q882-QXN)

Released: 2023-04-29

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Custodians: [David, O.](#)

These data come from a cohort of adult patients suffering from pharmaco-resistant focal epilepsies who in the course of preparation to a brain surgery were implanted with intracerebral stereoencephalographic (SEEG) electrodes. The protocol involved brain stimulation at a single site and a simultaneous recording with all remaining contacts on a number of electrodes. Beyond medical aim,

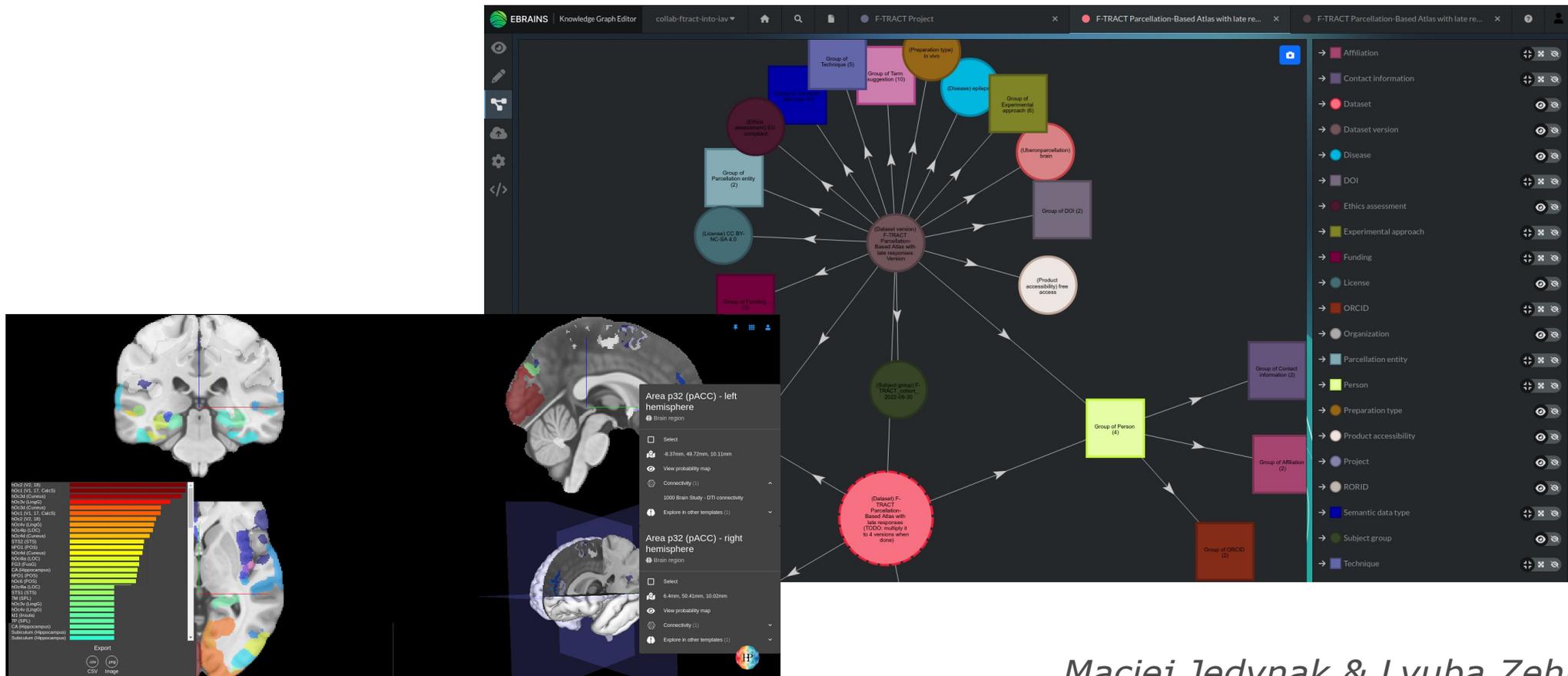
Please alert us at curation-support@ebrains.eu for errors or quality concerns regarding the dataset, so we can forward this information to the Data Custodian responsible.

Studied brain region: [brain](#)

Study targets:

Integration of F-TRACT data in the Big Brain atlas

- F-TRACT atlas integrated into EBRAINS via the Knowledge Graph, making it findable and linked to other elements of the platform.
- F-TRACT atlas browsable in the online Atlas Viewer

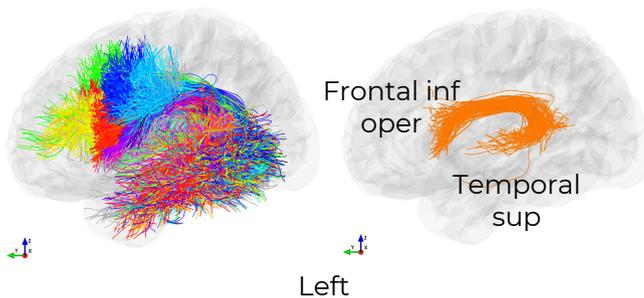


Maciej Jedynak & Lyuba Zehl

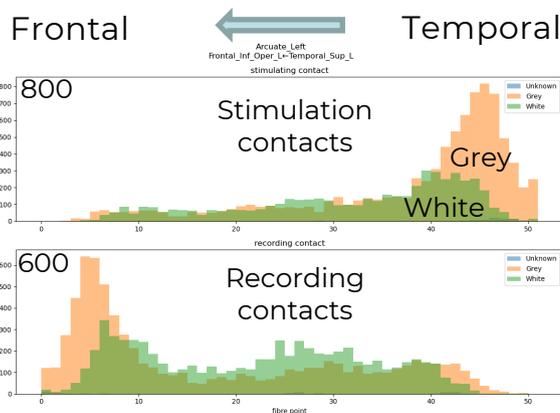
Atlas of fiber bundles dynamically informed from CCEPs

- Collaboration between CEA (JF Mangin) and UGA/AMU (O David). Post-doc project of Maciej Jedynak.
- Main objective: Map F-TRACT CCEP information on fiber pathways of the ARCHI database

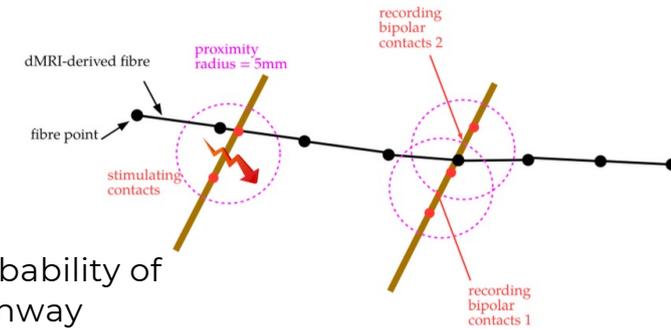
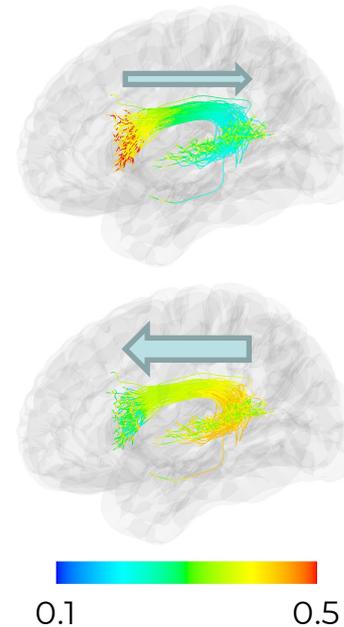
Pathway decomposition to match SEEG spatial resolution based on AAL parcellation



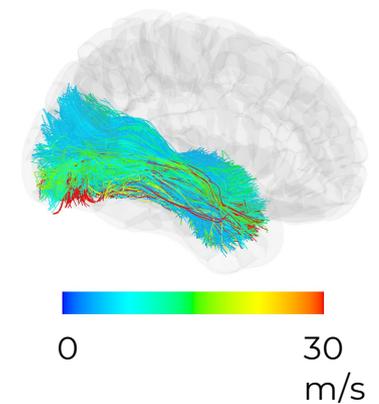
Arcuate fasciculus



Connectivity probability of arcuate pathway

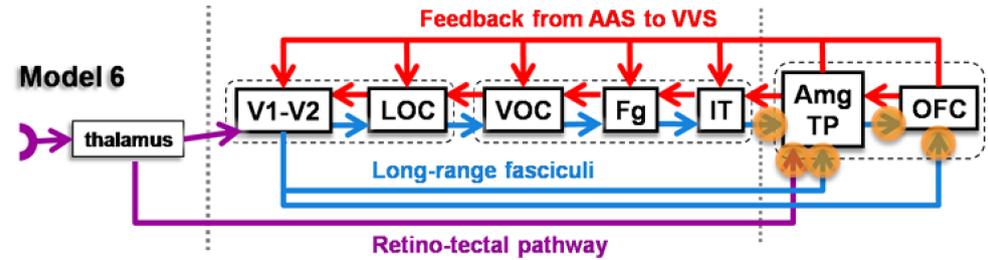


Pathway-based axonal speed

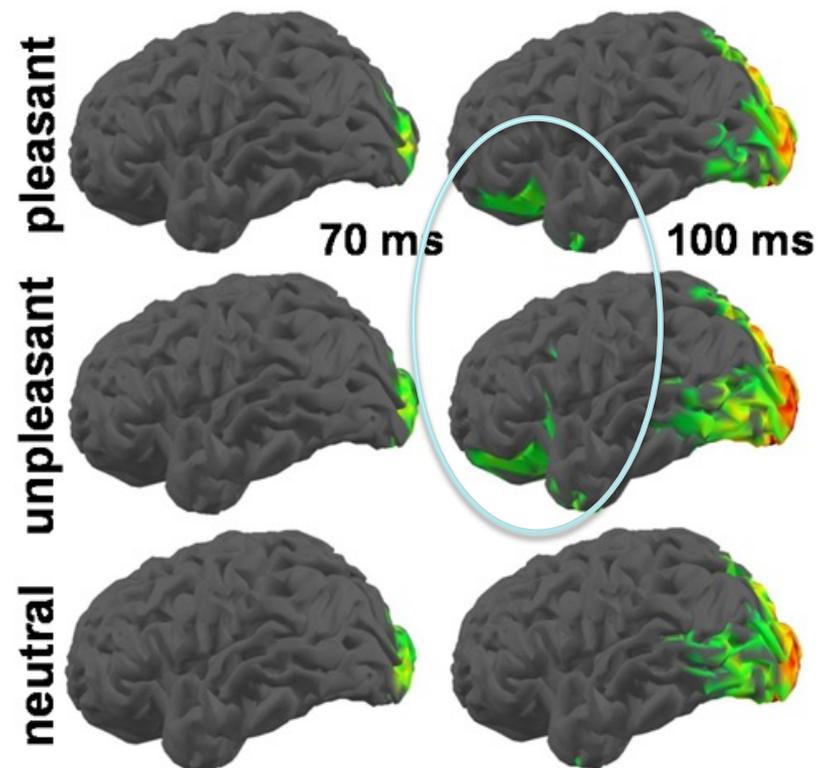
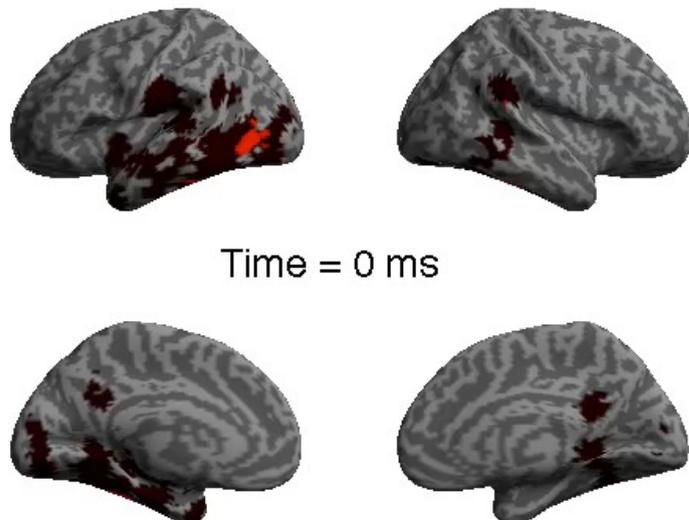


Example of fiber mapping of efferent early responses (<50 ms)

- Model of interactions of anterior affective system and the ventral visual system for processing of emotional stimuli

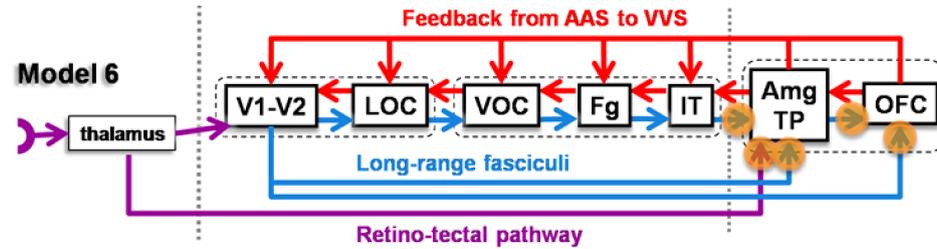


MEG responses



Rudrauf et al., J Neurosci, 2008

Example of fiber mapping of efferent early responses (<50 ms)

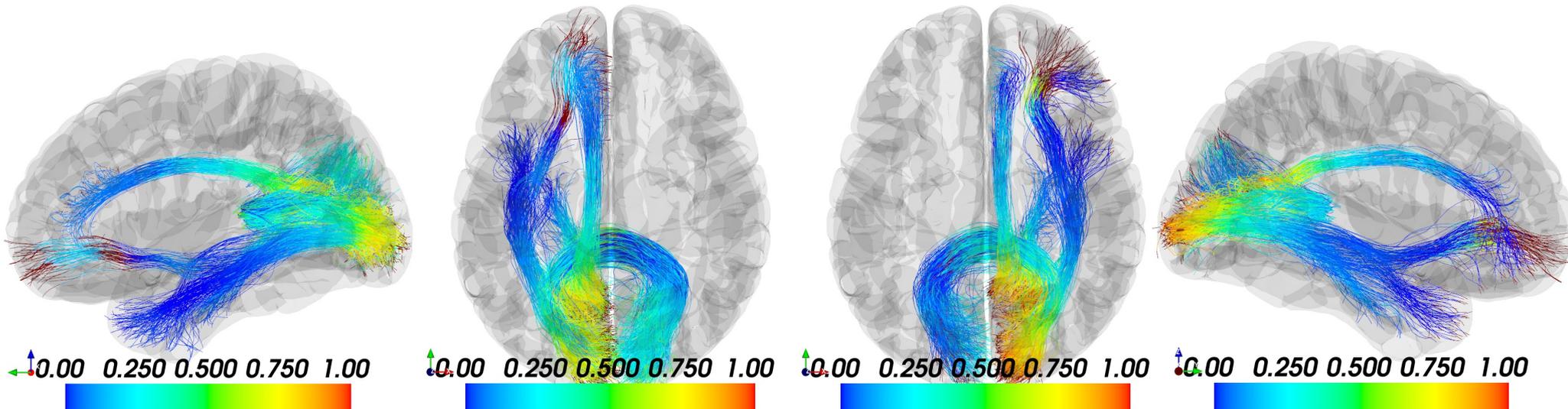


Bottom-up

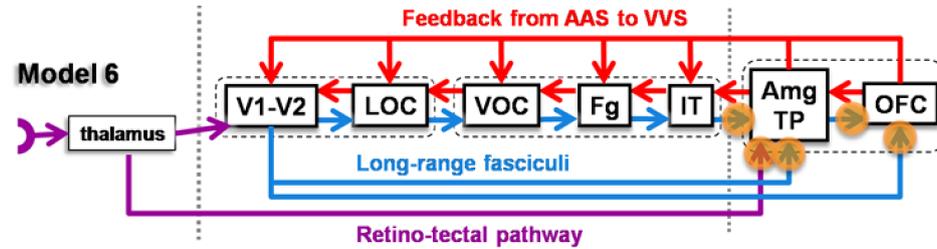
F-TRACT Fibre atlas

Calcarine left

Calcarine right



Example of fiber mapping of efferent early responses (<50 ms)

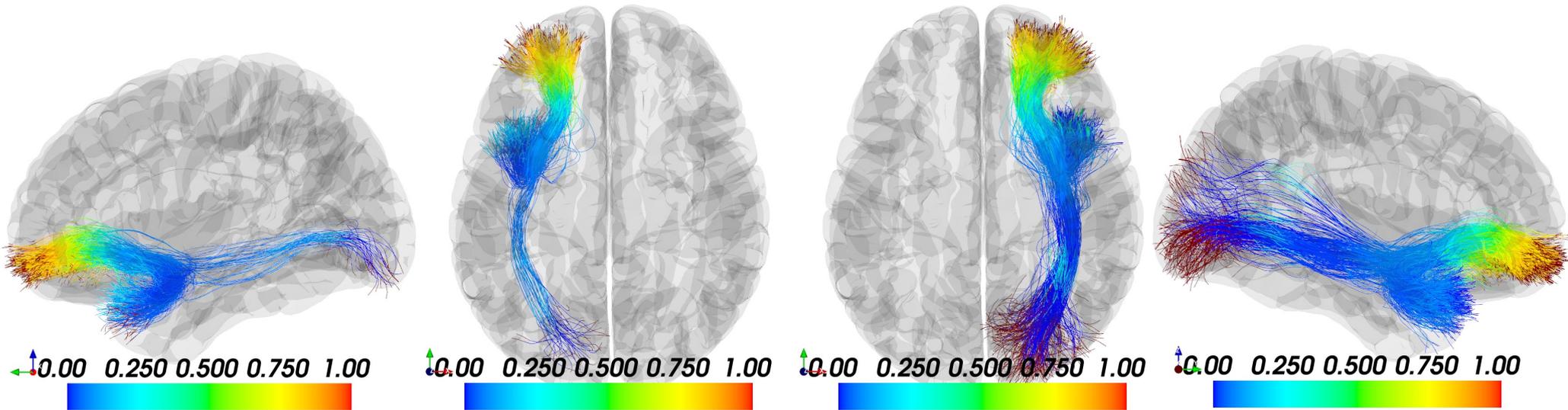


Top-down

F-TRACT Fibre atlas

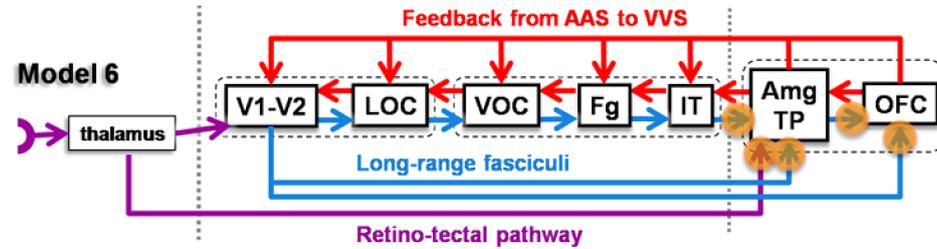
Frontal middle orbital left

Frontal middle orbital right



Jedynak et al., in preparation

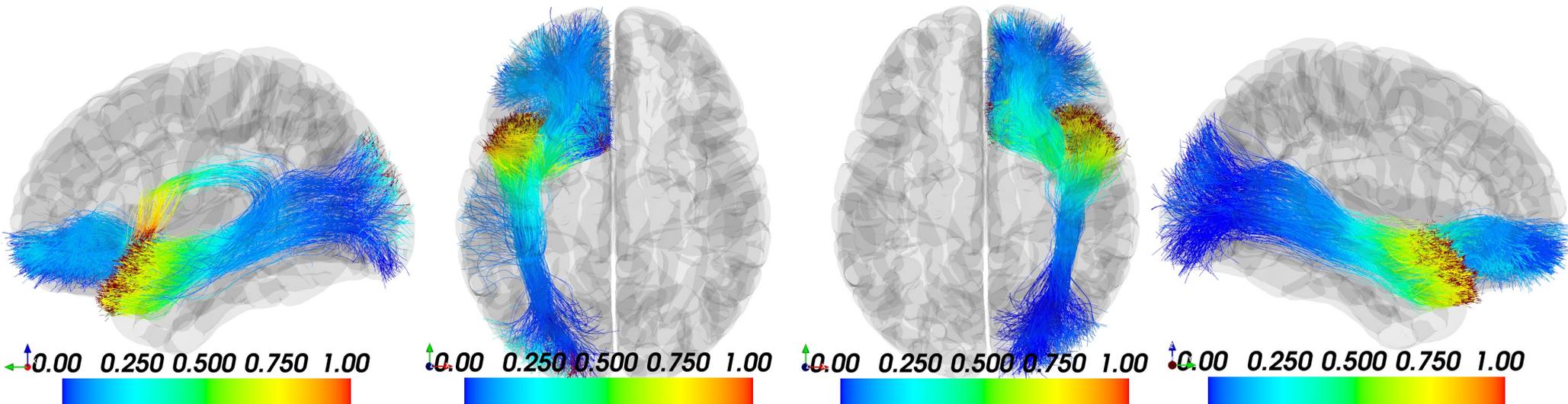
Example of fiber mapping of efferent early responses (<50 ms)



Top-down

Temporal pole superior left

Temporal pole superior right



- **How to correct efficiently for the distance confound?**
- **How to assess intersubject and intrasubject variability?**
 - In Jedynak et al., Brain Topogr, 2022, we found intrasubject variability is high.
- **How to minimise the effect of pathology (epilepsy and lesion)?**
- **Gender and age effects?**
- **Etc.**

- **INS NeuroStim team:** A Boyer, M Jedynak, S Avalos-Alais, M Bonnard, R Carron
- **F-TRACT research team:** A Boyer, M Jedynak, M Bhattacharjee, B Chanteloup-Forêt, C Saubat-Guigui, L Trebaul, P Deman, V Tuyisenge, E Hugues, F Tadel, GC Reyes-Mejia, L Ayoubian, D Rudrauf
- **F-TRACT clinical collaborators:** P Kahane, W Szurhaj, T Blauwblomme, C Adam, D Taussig, E Landré, A Nica, L Maillard, E Hirsch, S Rheims, A Trébuchon, L Valton, A Valentin, M Bradzil, I Mindruta, R Rocamora, S Francione, F Dubeau, S Liu, A Schulze-Bonhage, EL Metsähonkala, W Zhou, M Garces
- **HBP HIP team:** P Ryvlin, E Kavun, N Casati, M Spuehler, B Schaffhauser, S Tourbier, JP Lachaux, B Bontemps, F Sipp, V Jirsa, M Woodman, J Fousek
- **CIMENT computing facility:** B Bzeznik, R Cavagna
- **Funding sources:**



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Human Brain Project

