Cortical stimulation and brain mapping in extra- and intra-operative epilepsy surgeries

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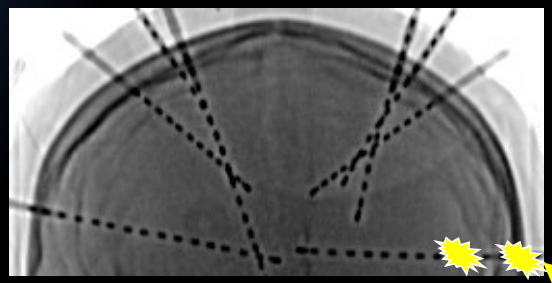
Stimulation can be delivered to stereo-EEG and subdural grid electrodes.



Electrical stimulator

↓

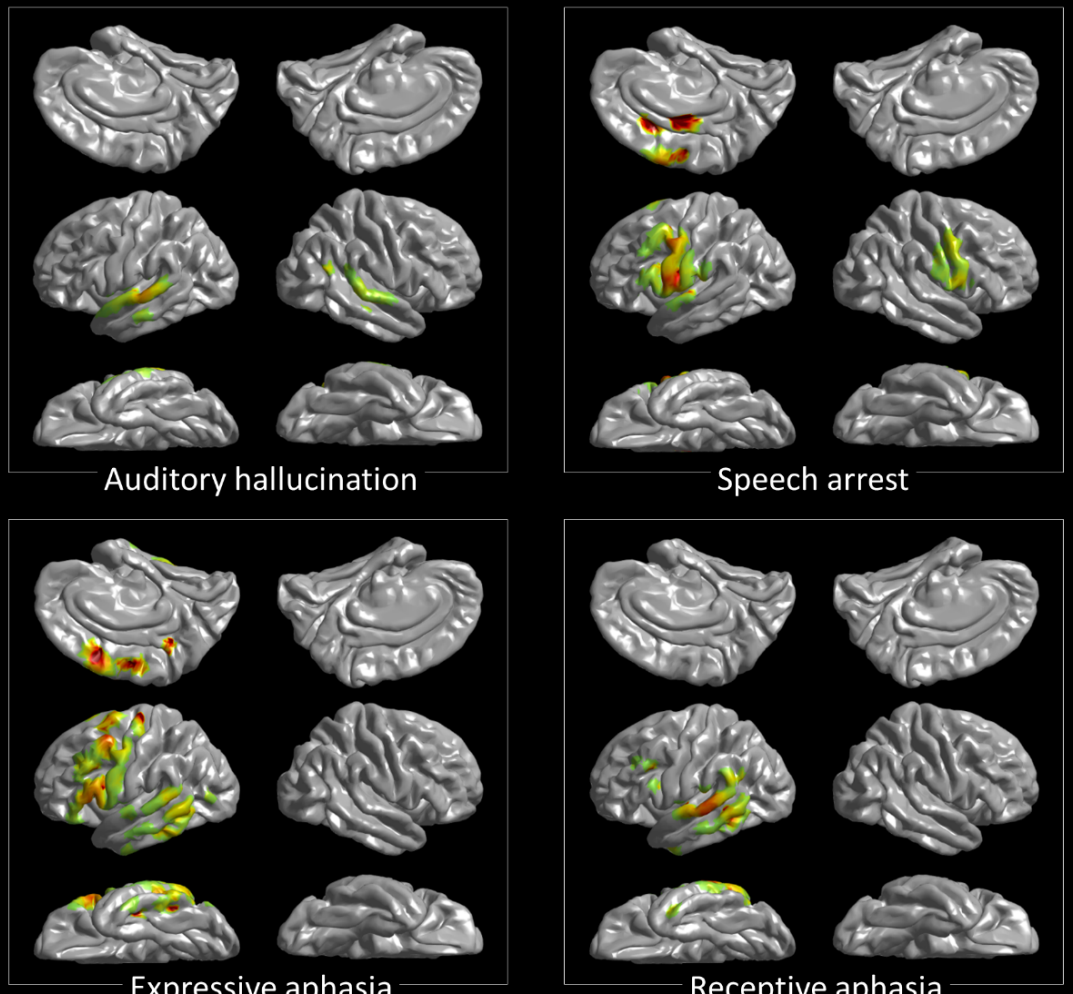
One can determine if stimulated sites are essential to perform the task,
based on the behavioral changes during stimulation.

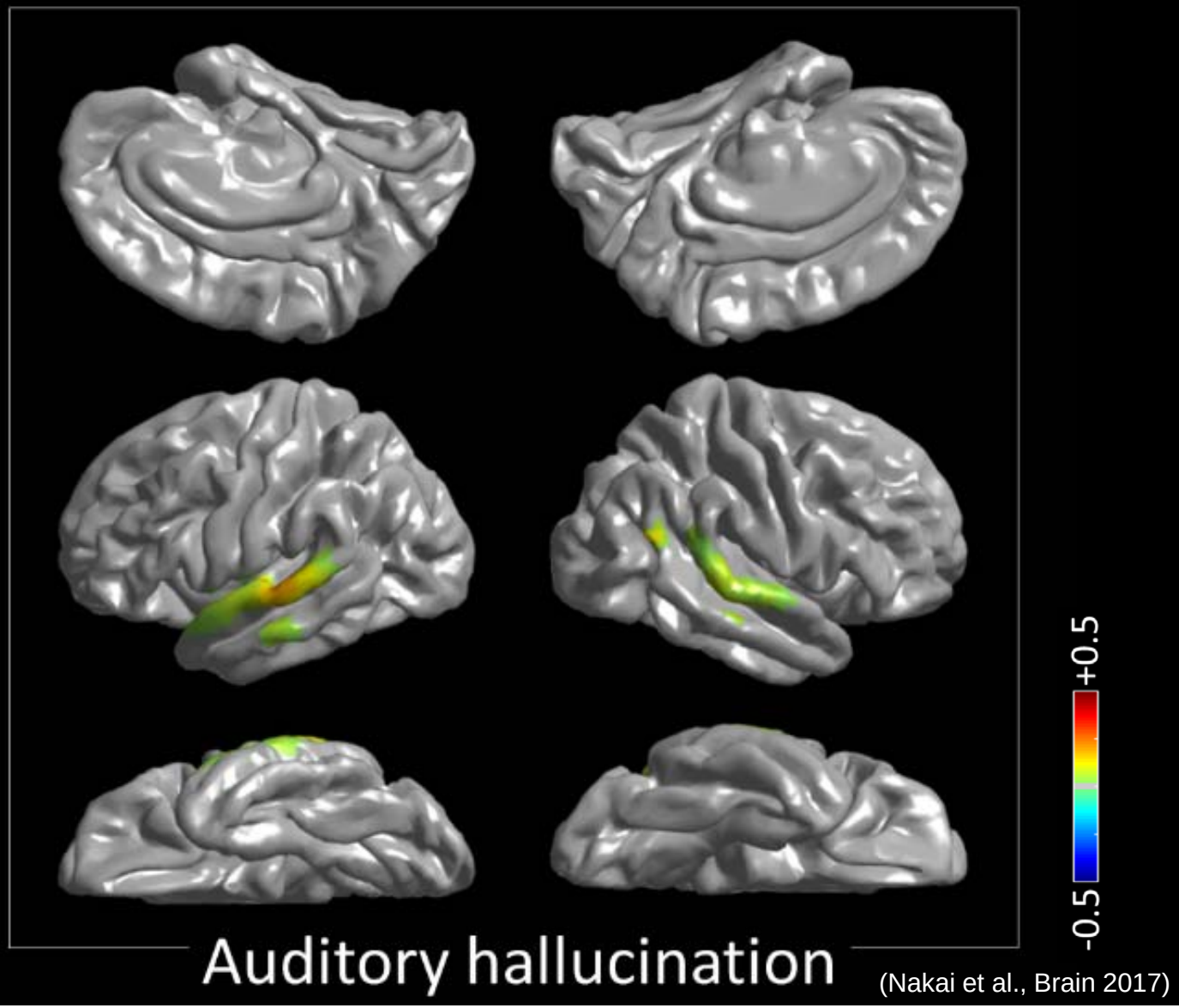
Stimulus intensity necessary to induce a motor response:

Stereo-EEG: 3.4 mA on average
Arya et al. Clin Neurophysiol 2020

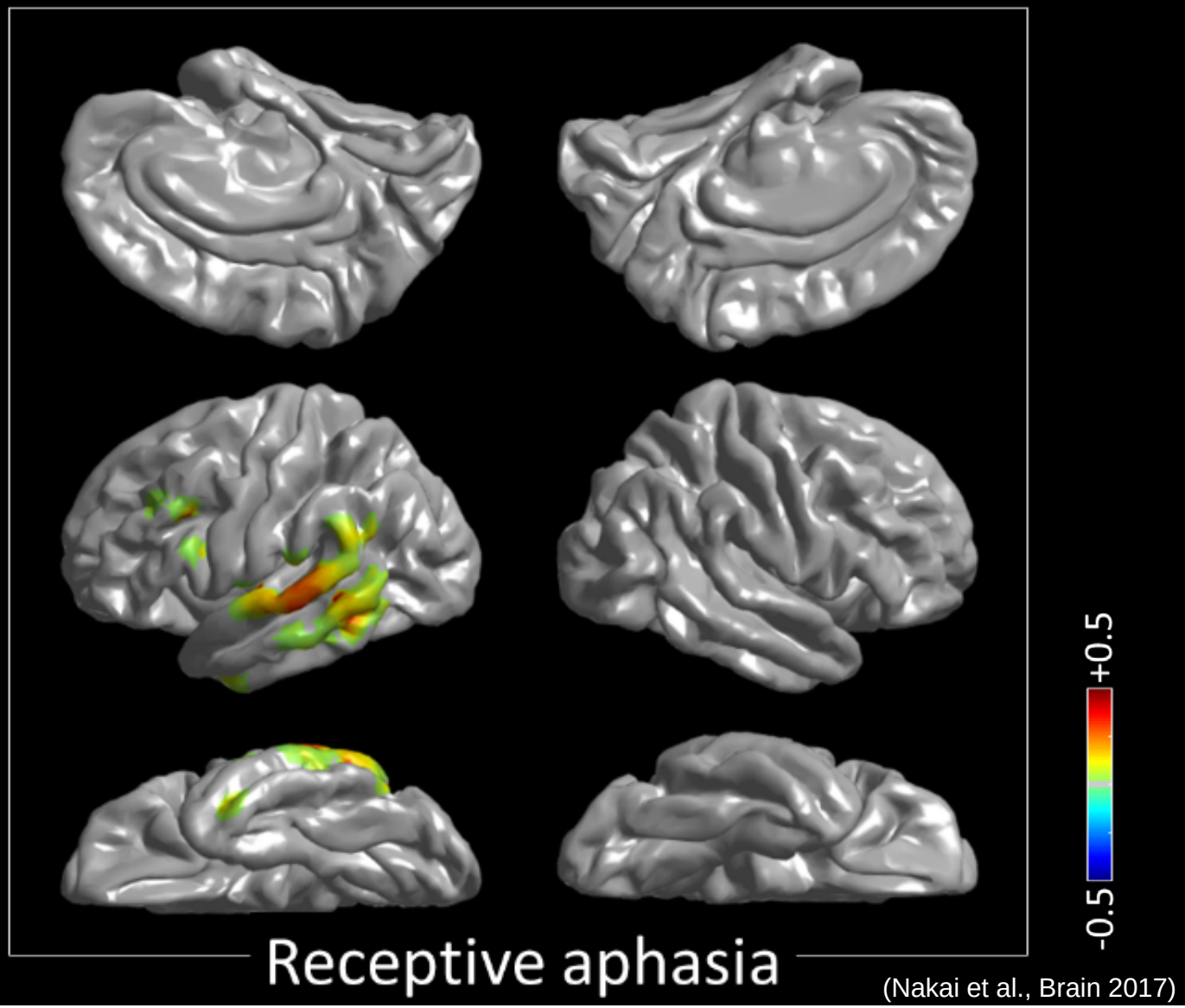
Subdural: 5.4 mA on average
Zea Vera et al. Clin Neurophysiol 2017

Whole-brain level 3D probability maps of speech/language based on extraoperative electrical stimulation in 100 patients (Nakai et al., Brain 2017)

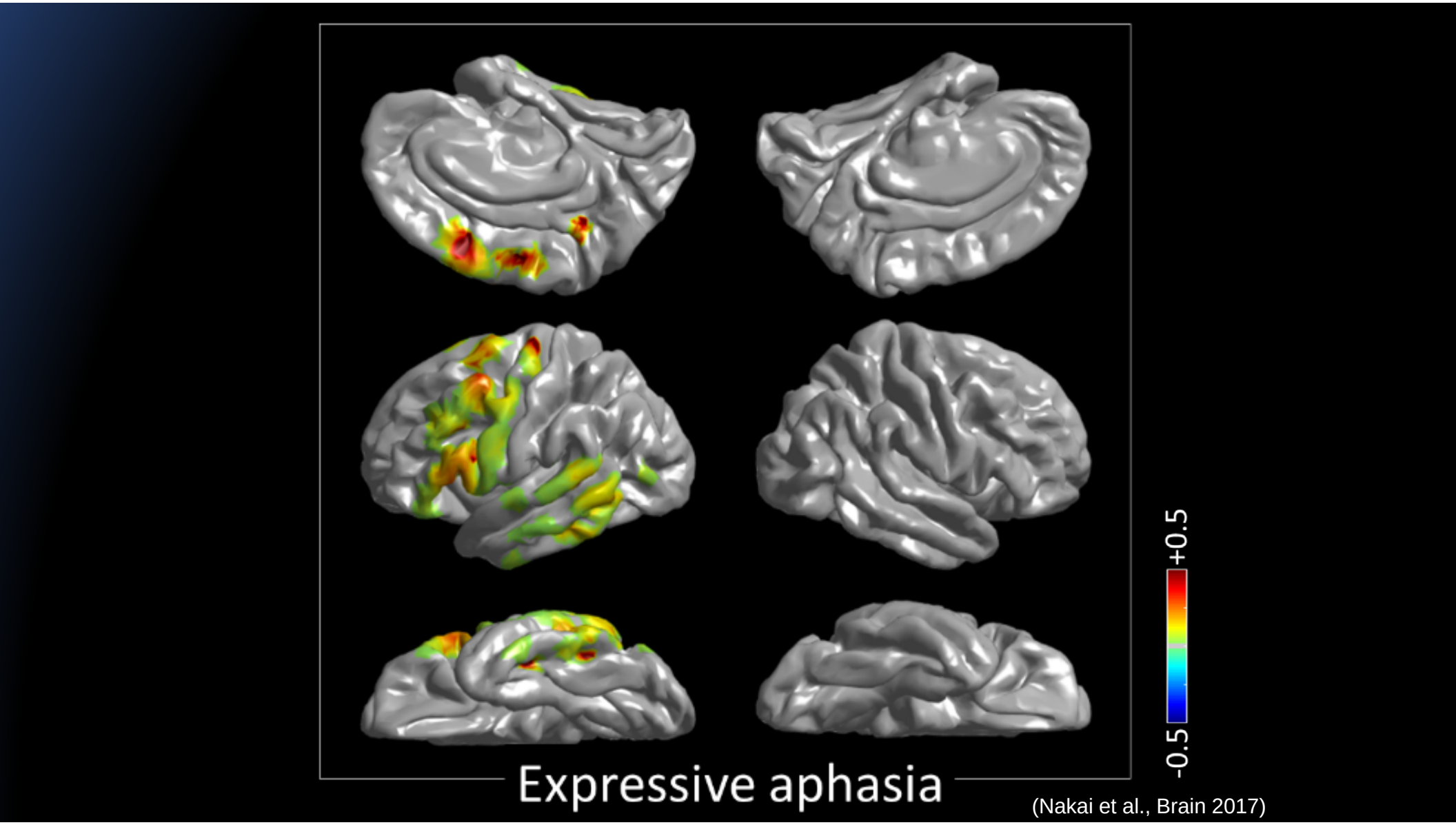




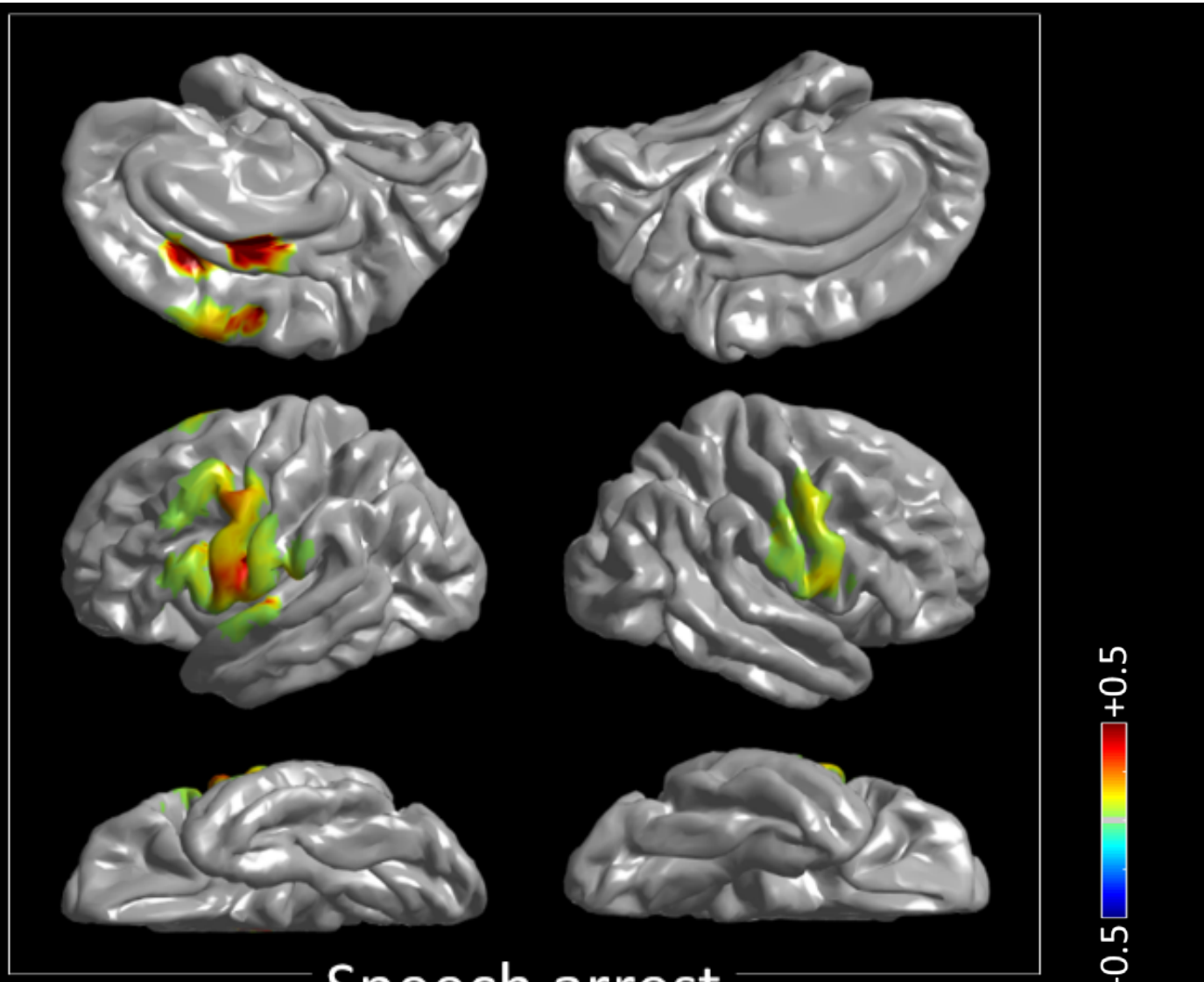
(Nakai et al., Brain 2017)



(Nakai et al., Brain 2017)

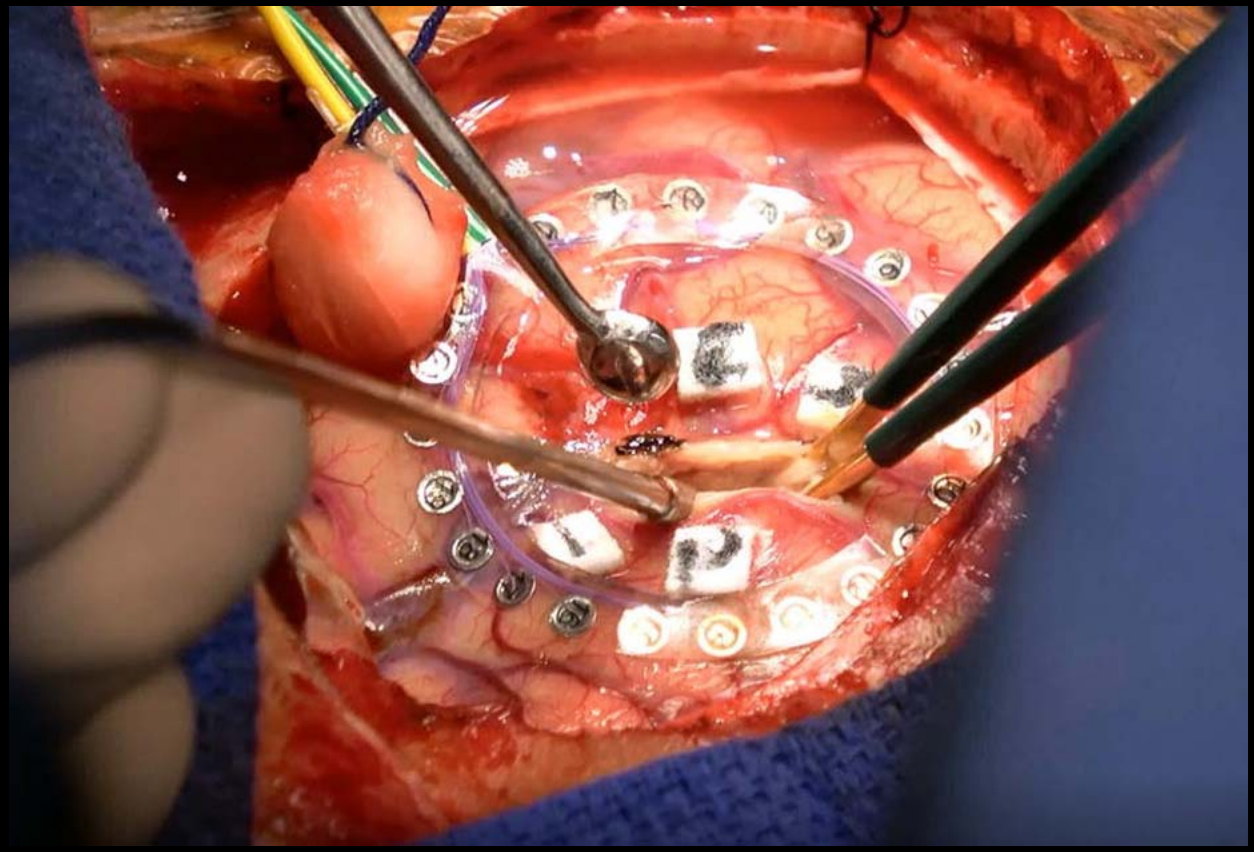


(Nakai et al., Brain 2017)



(Nakai et al., Brain 2017)

Intraoperative stimulation-based language mapping: plausible in adults who can tolerate awake craniotomy.



Tatum et al. Clin Neurophysiol 2020

Stimulation of the left medial temporal lobe structure: for assessment of the memory function.

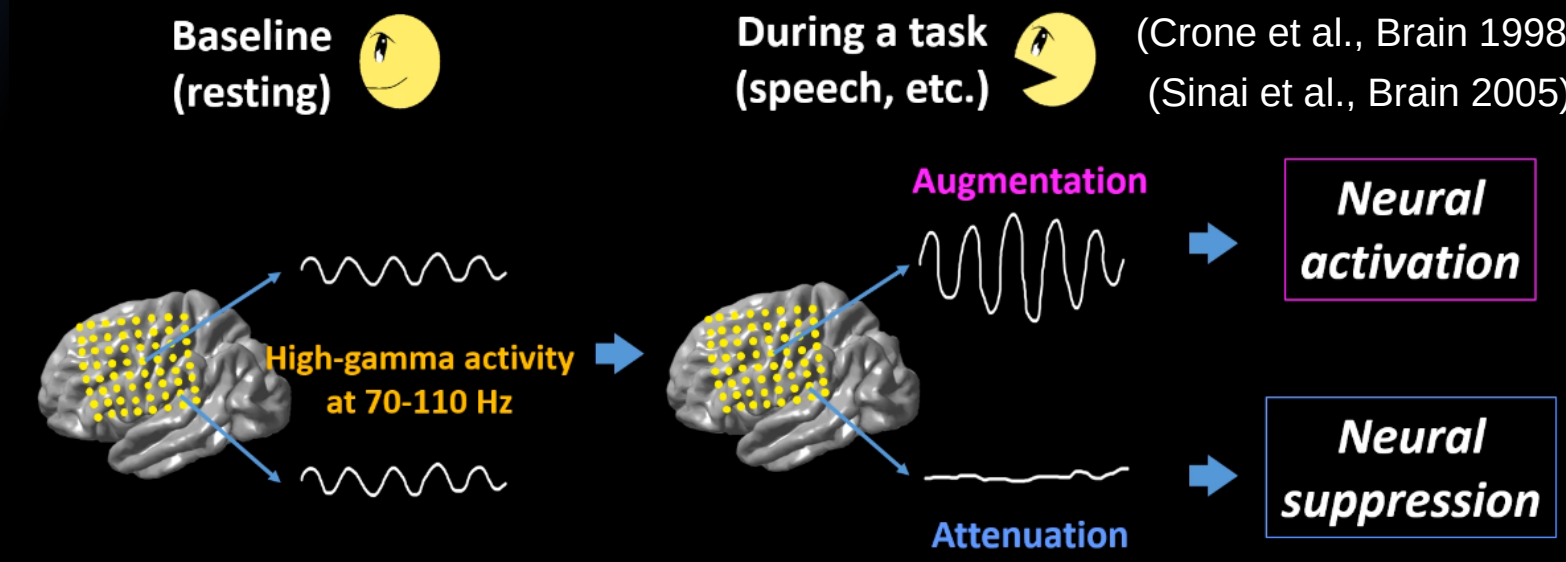
First author	Tani	Lacruz
Publication Year	J Neurosurg 2016	Neuroscience 2010
N of patients	11	12
Frequency (Hz)	50	0.2
Pulse width (ms)	0.2	1
Intensity (mA)	≤6	4 or 6
Duration (seconds)	5	Not available

Picture presentation during 5-s stimulation.

→

Test if a patient can recall the object several minutes after.

Principle of brain mapping using high-gamma activity on iEEG



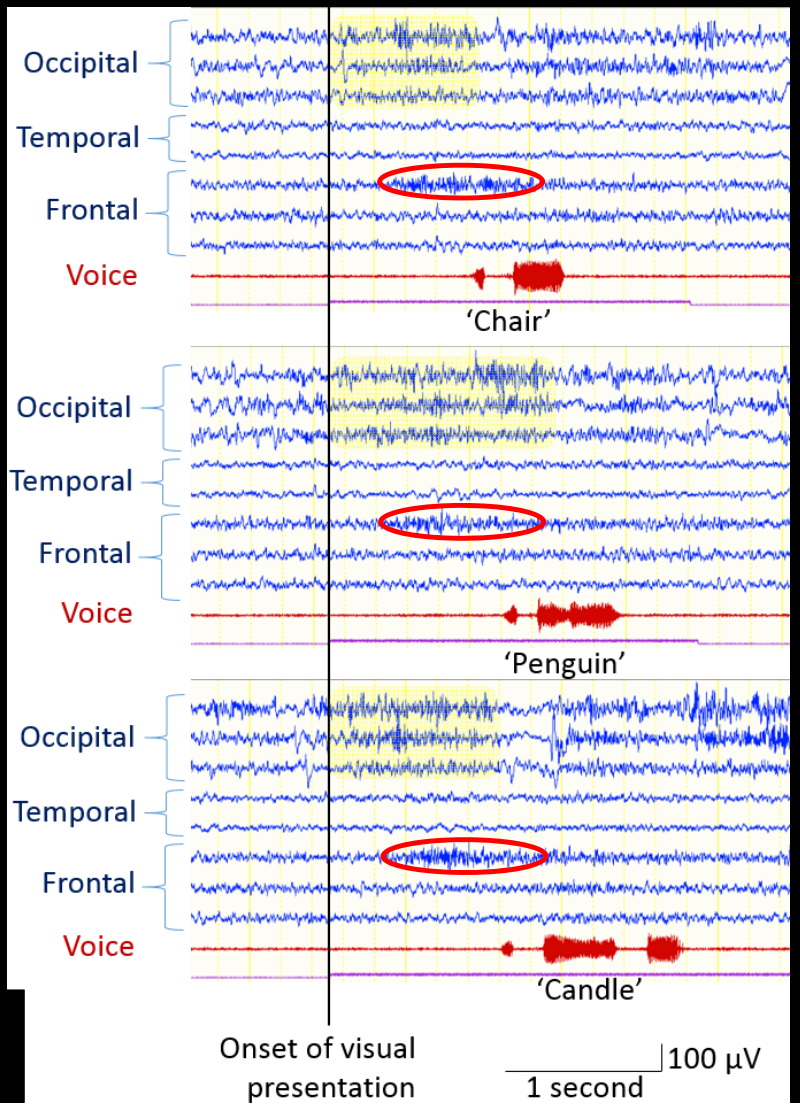
High-gamma amplitude on iEEG

- Firing on single neuron recording
  (Ray et al. J Neurosci 2008; Manning et al. J Neurosci 2009)
- Hemodynamic responses on fMRI
  (Niessing et al. Science 2005)
- Glucose metabolism on FDG PET
  (Nishida et al. NeuroImage 2009)

Assessment of naming-related high-gamma responses (Kambara et al. Clin Neurophysiol 2018)

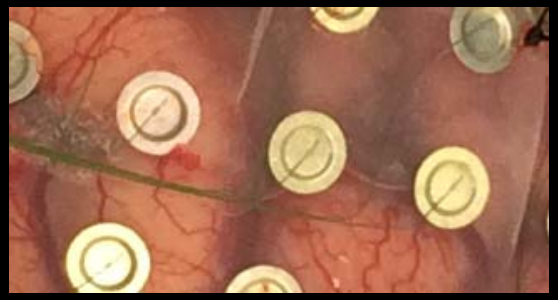
iEEG traces during picture naming

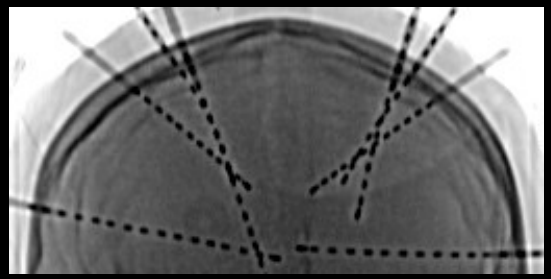
Even with visual assessment, one would appreciate event-related high-gamma augmentation.



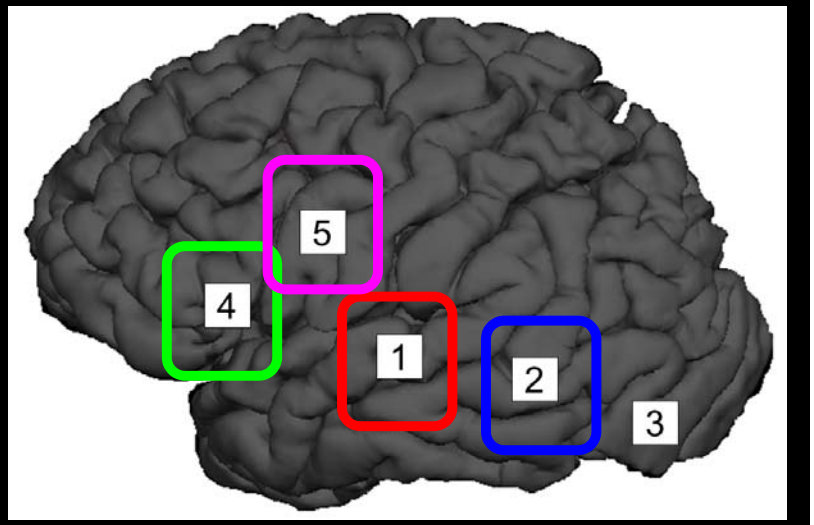
Time constant: 0.03 s
(Asano & Gotman, Neurology 2016)

One can use either subdural and stereo-EEG electrodes
for measurement of event-related high-gamma modulations.

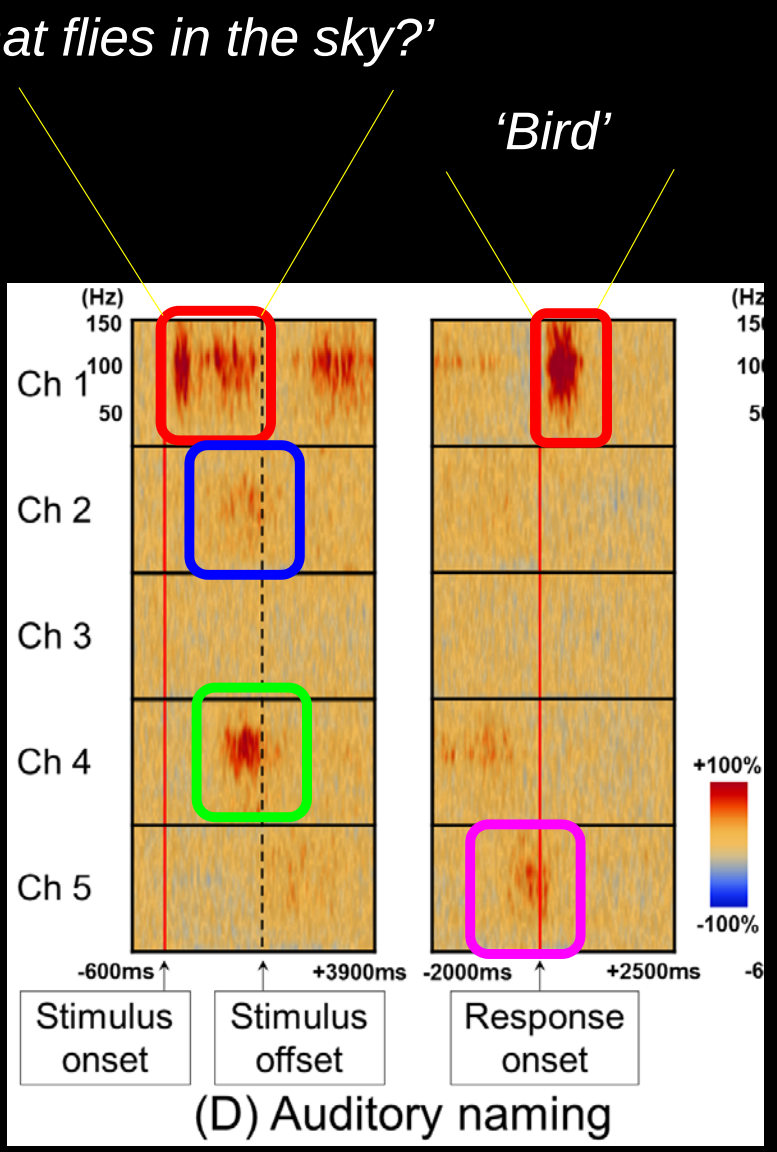




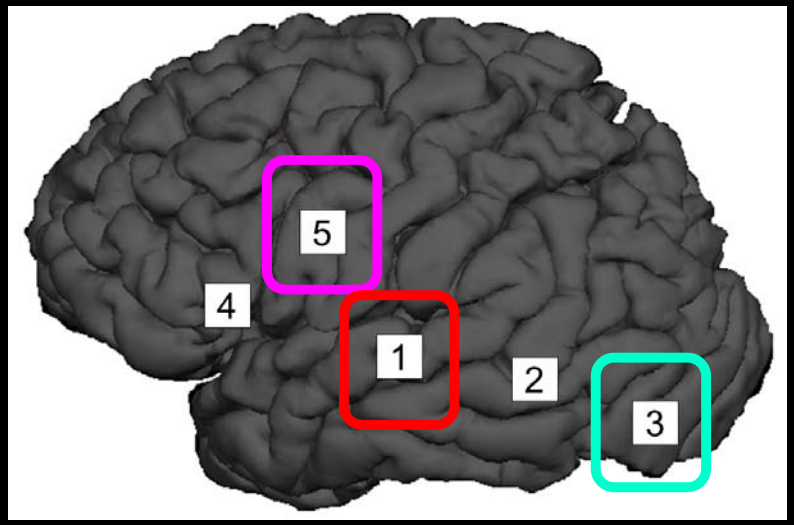
Auditory naming-related high-gamma augmentation in a 12-year-old boy.



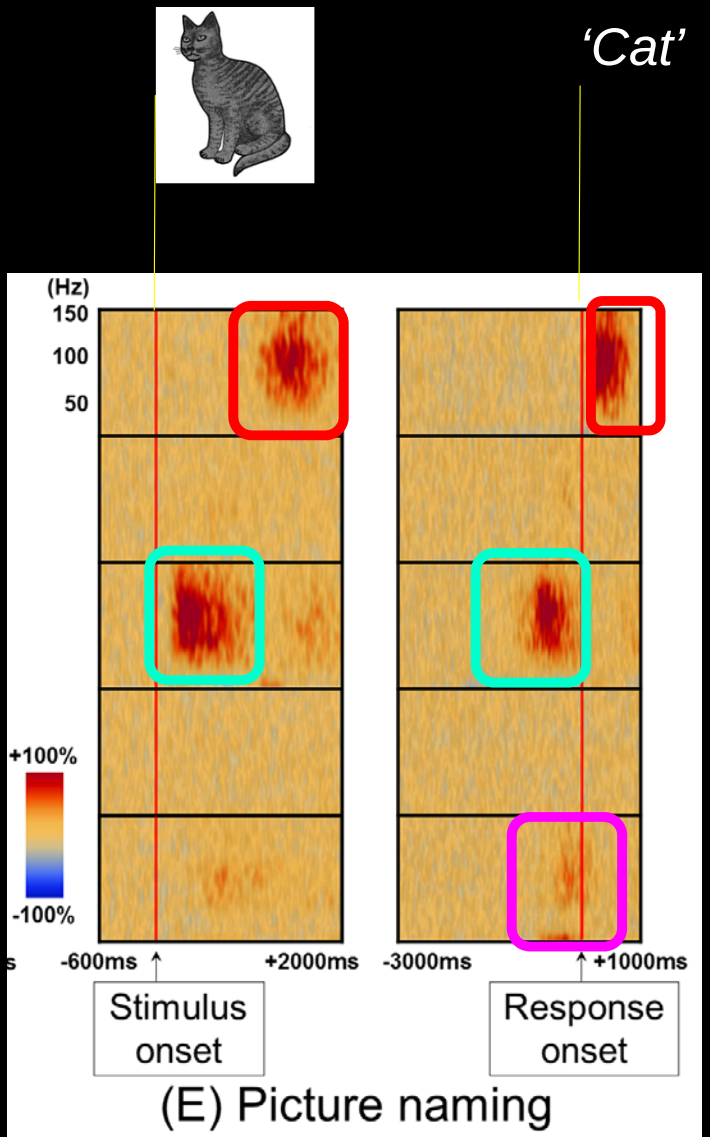
(Kambara et al., Clin Neurophysiol 2018)



Picture naming-related high-gamma augmentation in a 12-year-old boy.



(Kambara et al., Clin Neurophysiol 2018)



Meta-analysis of 15 studies (Arya et al., Epilepsy Behav 2018):

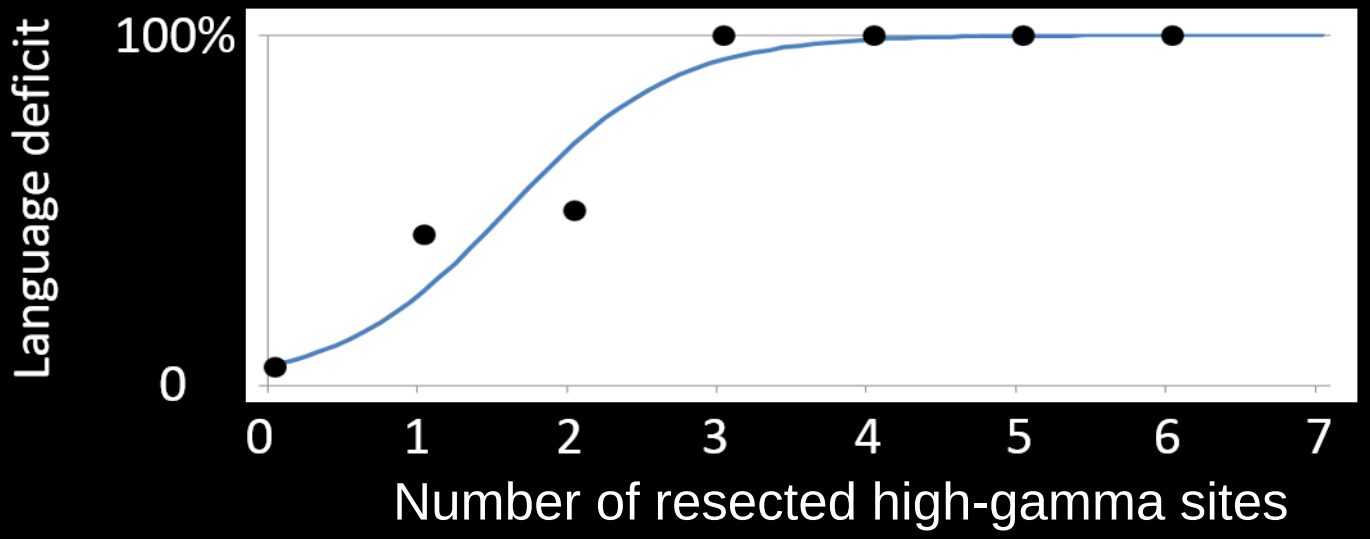
Event-related high-gamma mapping is capable of predicting language areas defined by electrical stimulation mapping.

Diagnostic odds ratio: 6.4.

Naming-related high-gamma activity predicted acute language deficits requiring speech therapy.

(Kojima et al., Clin Neurophysiol 2013)

New post-surgical language deficits: 15/77 patients



Odds Ratio: 6.0

Advantage of event-related high-gamma mapping:

- Signal fidelity >100 times better than scalp recording (Ball et al. NeuroImage 2009)

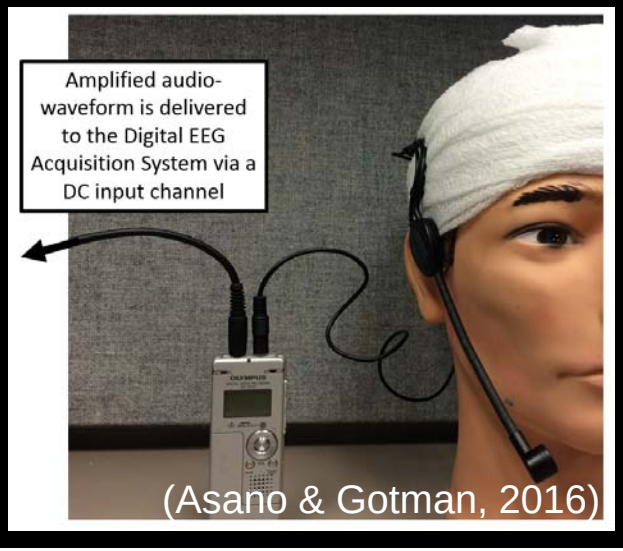
- Temporal resolution of tens of ms
- Spatial resolution of 5-10 mm
- Sampling from deep regions

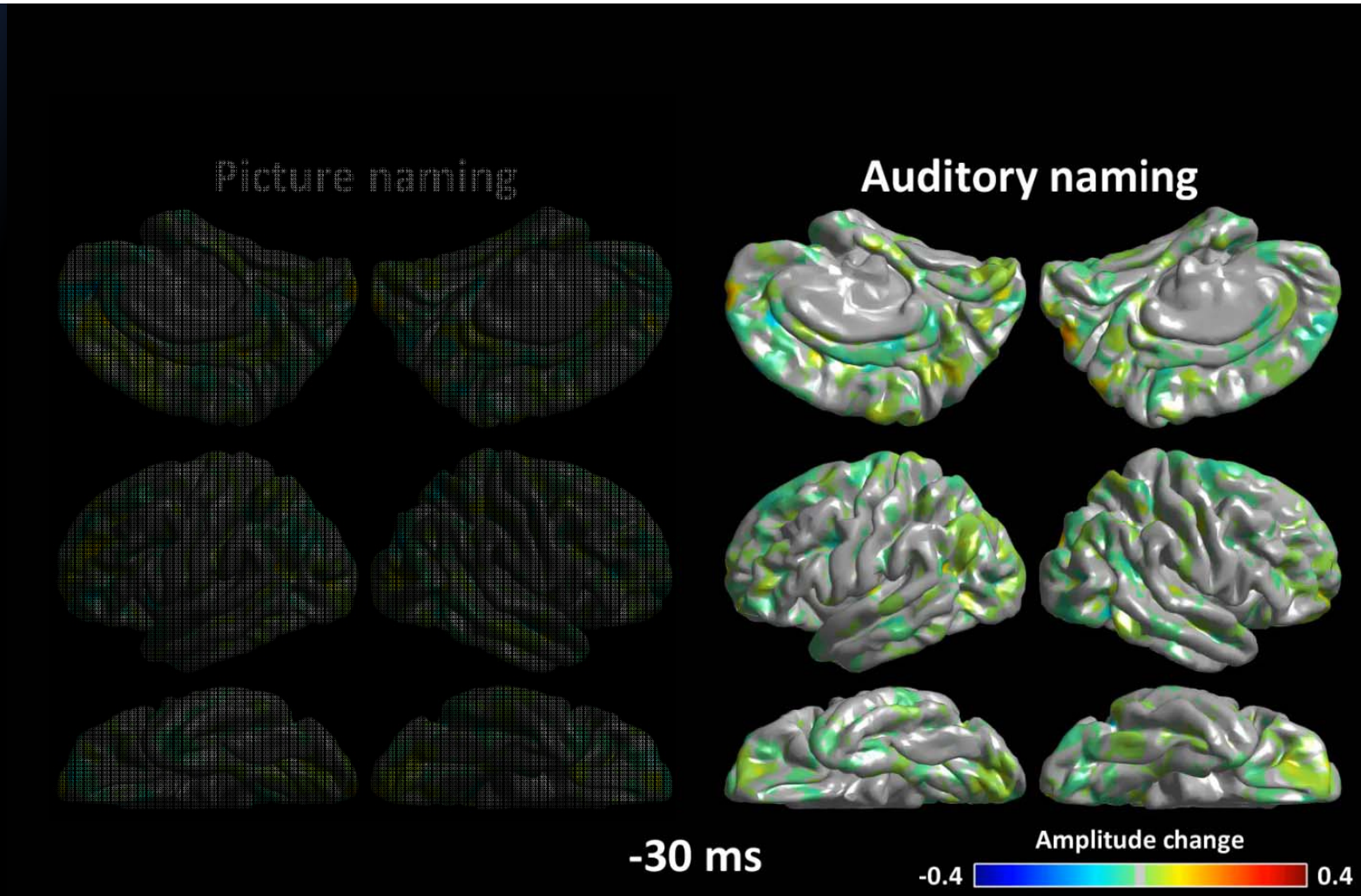
- Small start-up funding

↓ EMG artifacts
Patient can loudly talk during a task.

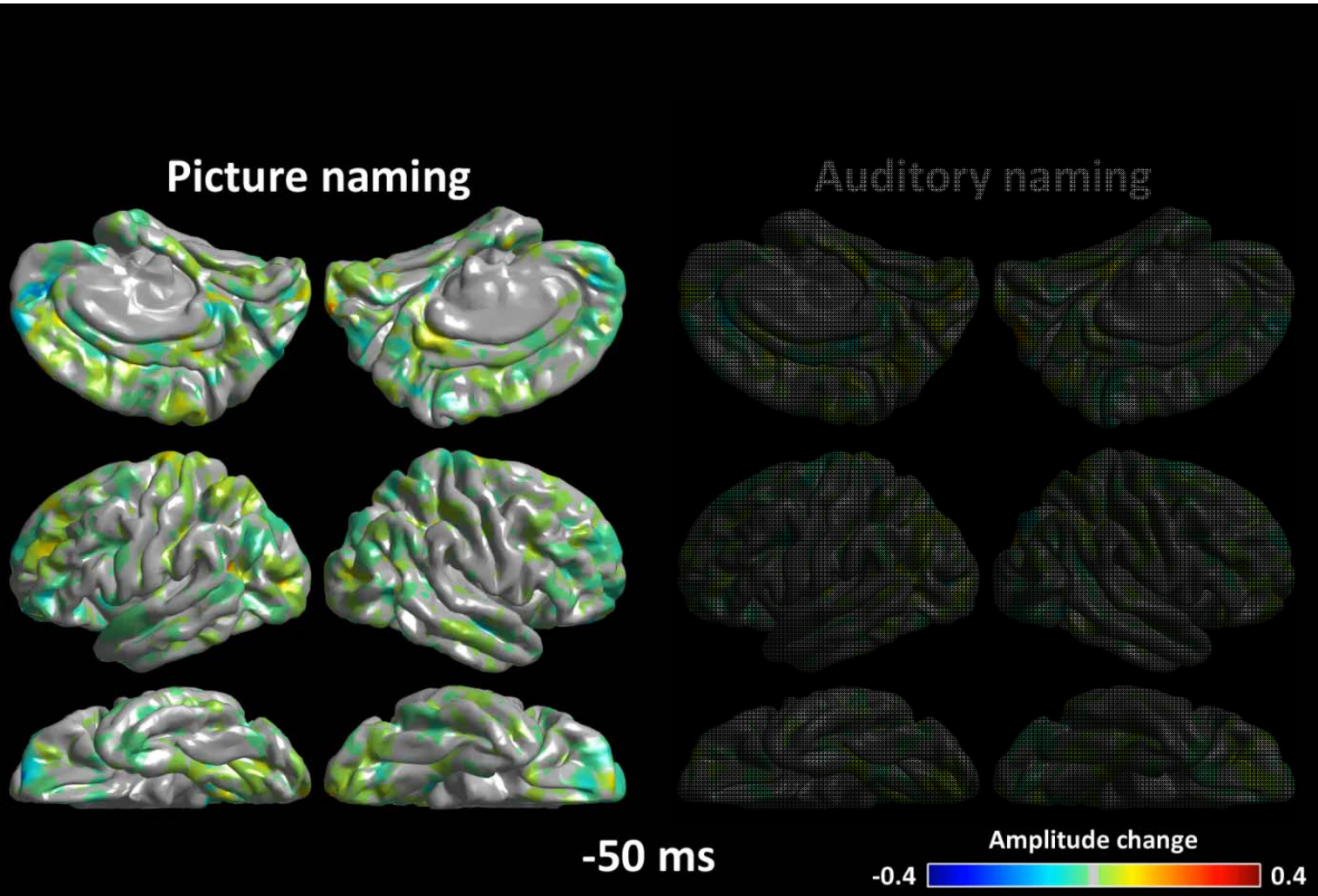
Rapid temporal dynamics
3D space
Whole brain level

4D functional atlas





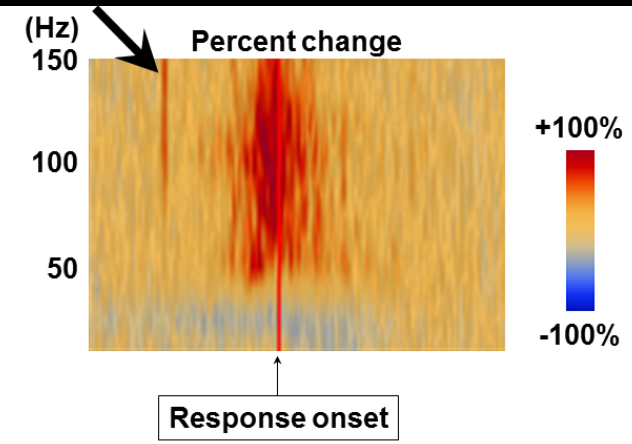
Whole-brain level 4D atlas of auditory language function
(Nakai et al., Brain 2017)



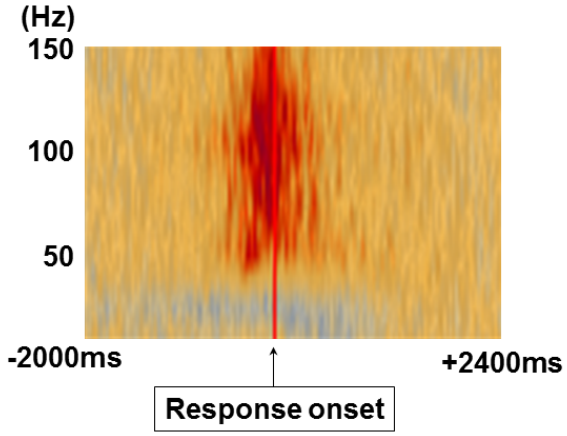
Whole-brain level 4D atlas of visual language function
(Nakai et al., Epilepsia 2019)

Unwanted effect of interictal spikes on high-gamma mapping

(Kambara et al., Clin Neurophysiol 2018)



(A) Before excluding a trial affected by a spike discharge.



(B) After excluding a trial affected by a spike discharge.

Real-time high-gamma-based mapping. Verbal stimulus listening induced high-gamma changes in the superior temporal gyrus.

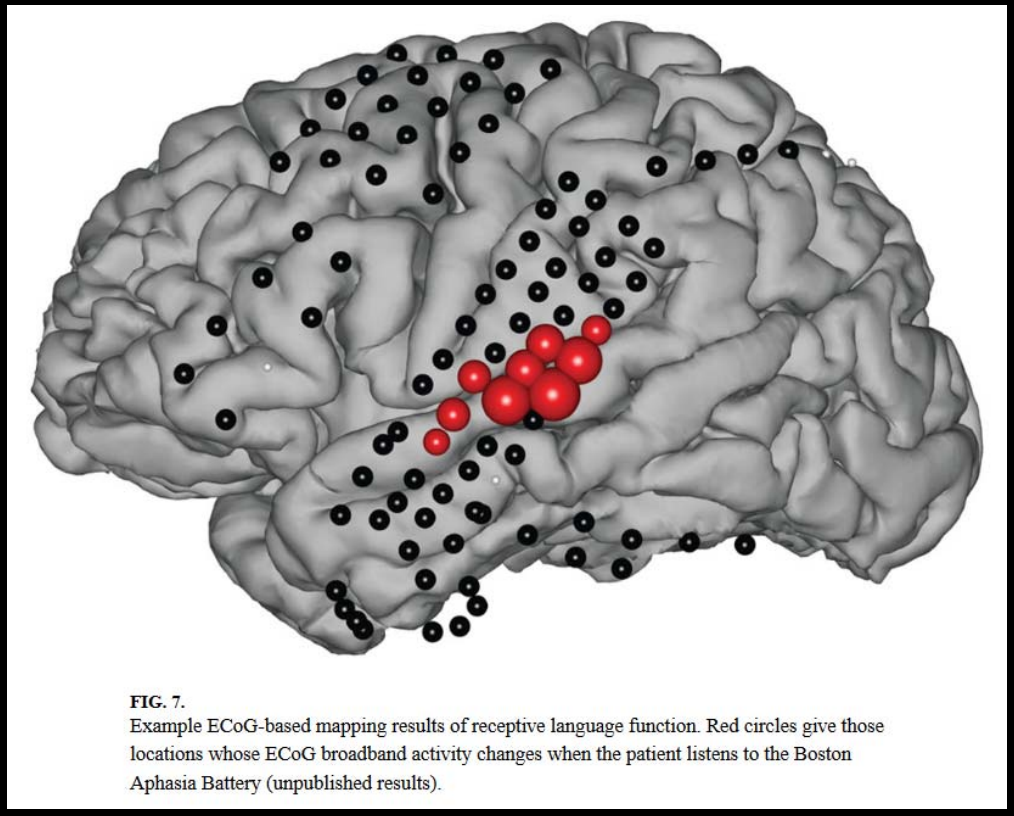
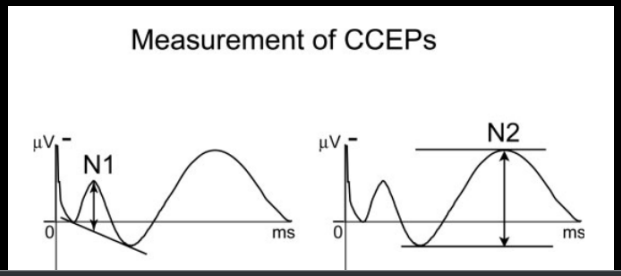


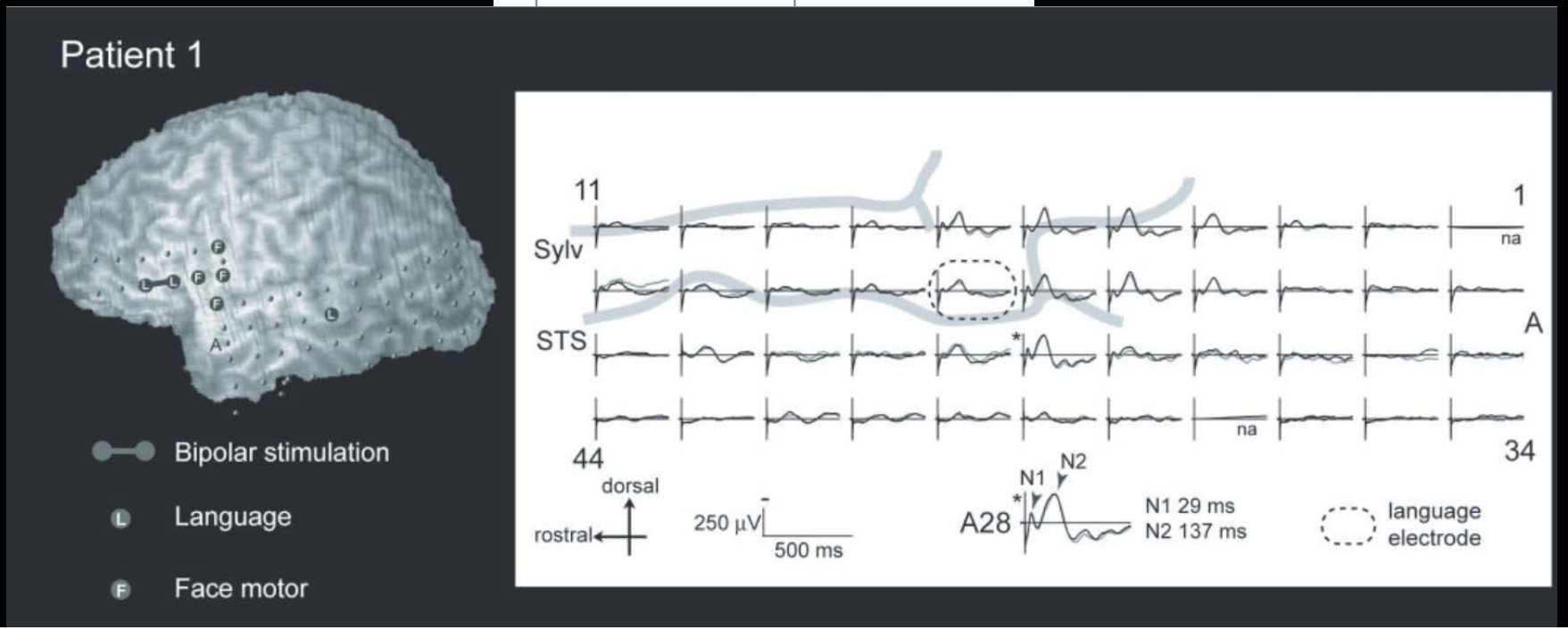
FIG. 7.
Example ECoG-based mapping results of receptive language function. Red circles give those locations whose ECoG broadband activity changes when the patient listens to the Boston Aphasia Battery (unpublished results).

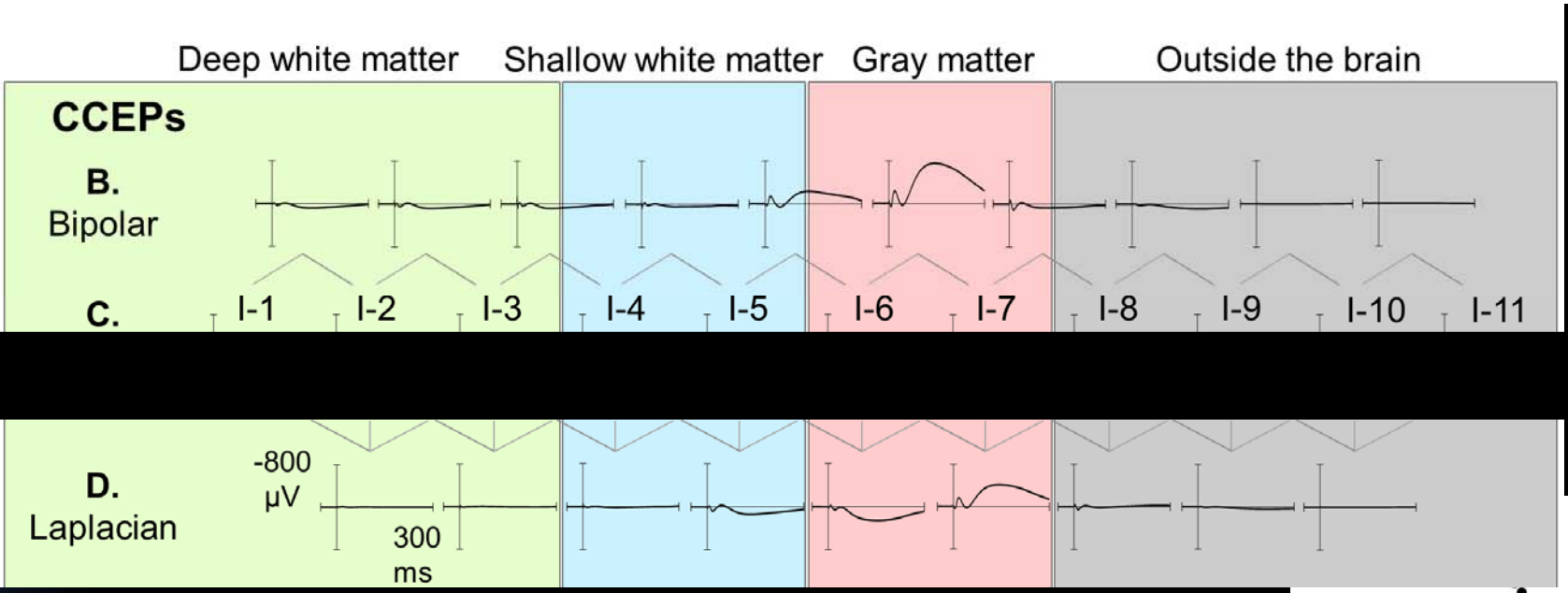
Ritaccio et al., J Clin Neurophysiol 2018

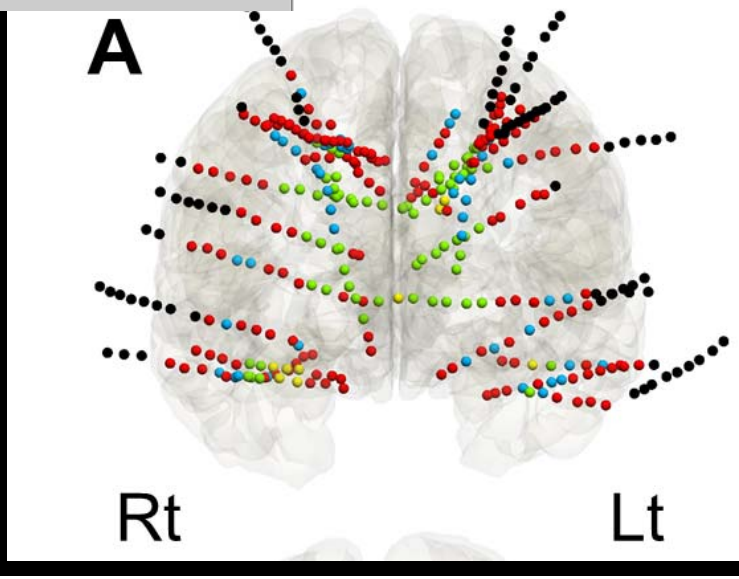
Single-pulse stimulation-induced neural responses.

Cortico-cortical evoked potential (CCEPs) (Matsumoto et al. Brain 2004)





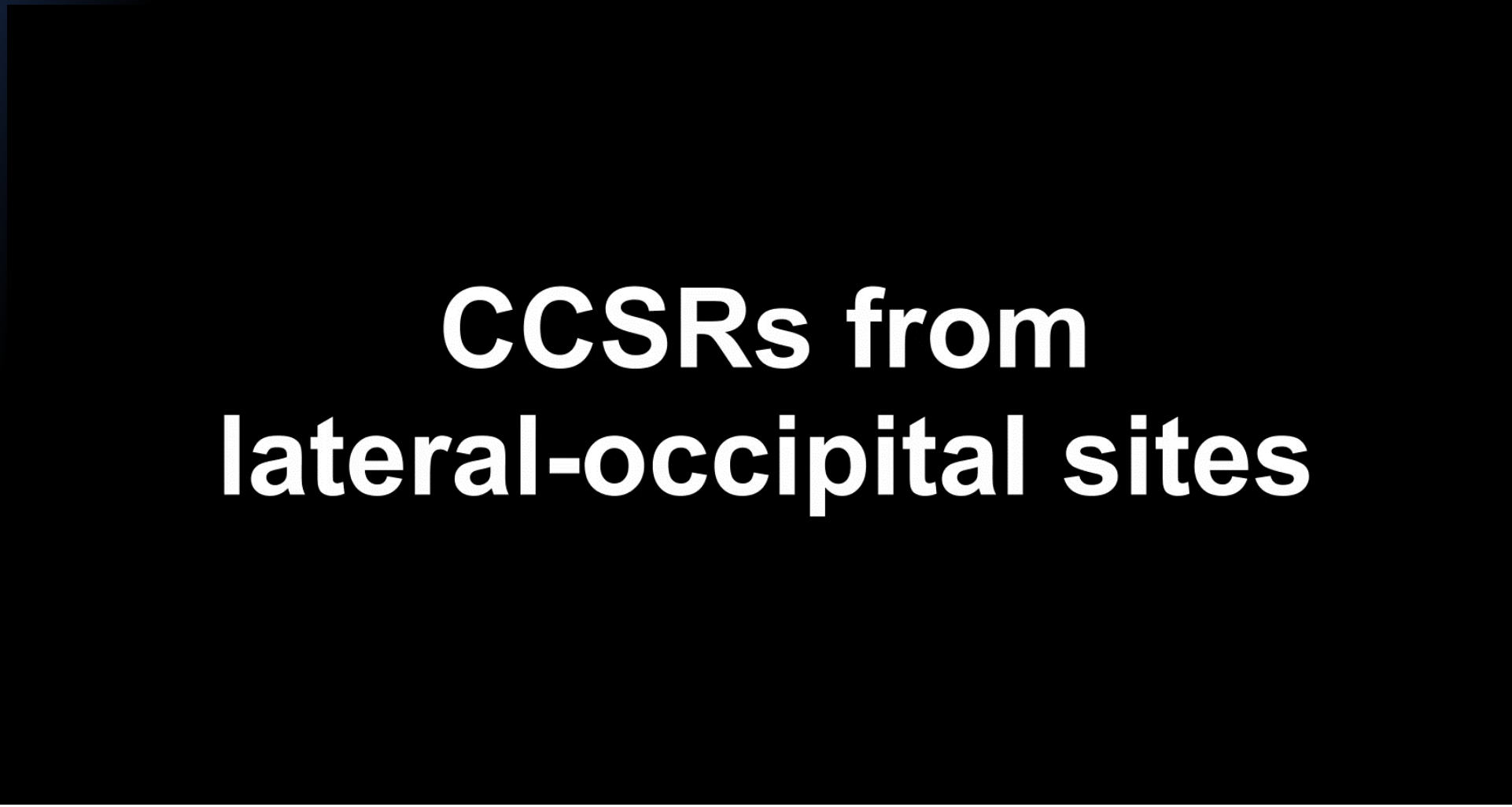




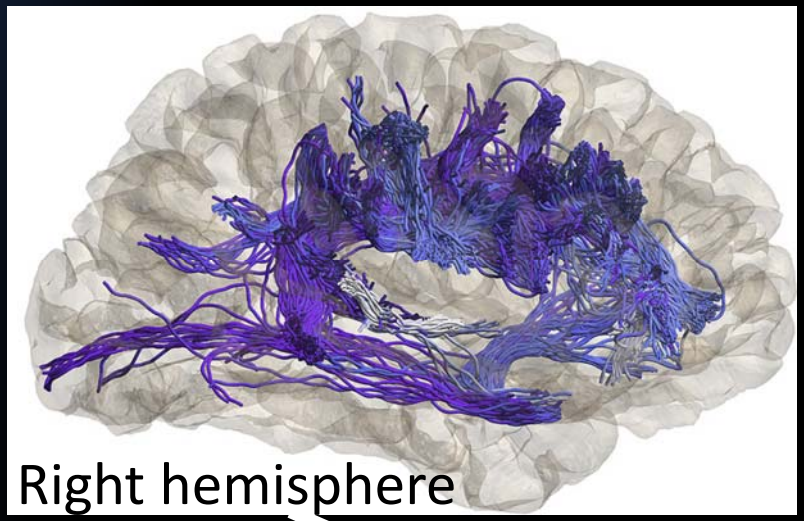
Mitsuhashi et al.
Clin Neurophysiol
2020.

4D visualization of CCEP/CCSR-based effective connectivity

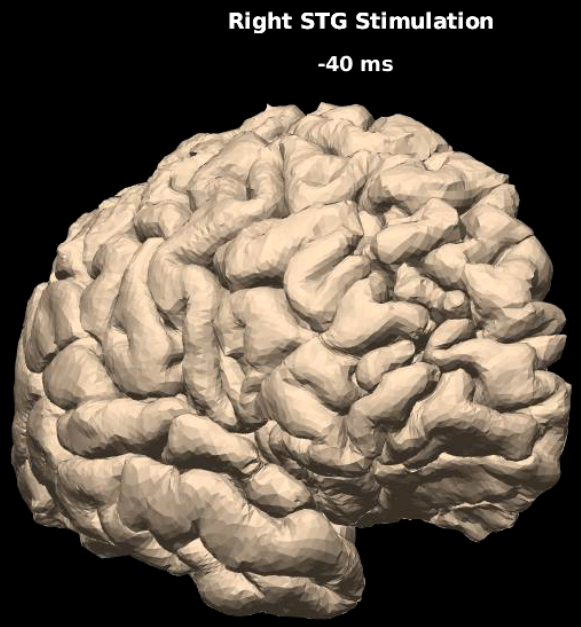
(e.g., Sugiura et al., NeuroImage 2020)



4D dynamic tractography animates neural propagations via white matter tracts.



Right hemisphere



CCEP or CCSR

(Brian Silverstein et al. NeuroImage 2020)

CCEP/CCSR are useful measures to assess the effective connectivity from distant sites.

Advantage:
No need of patient cooperation.
Intraoperative measurement is possible.

Limitation:
Need to incorporate additional information (e.g., anatomy, stimulation results) for the optimal interpretation.

4D dynamic tractography: a potential to improve the understanding of network dynamics supporting cognitive function.

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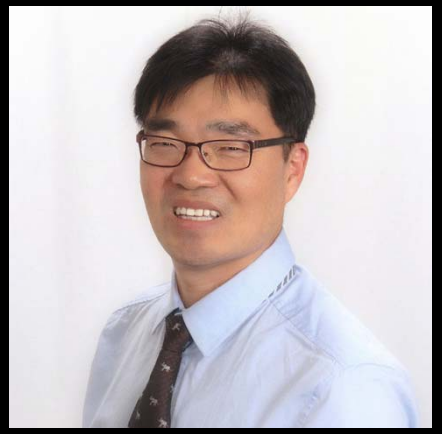

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