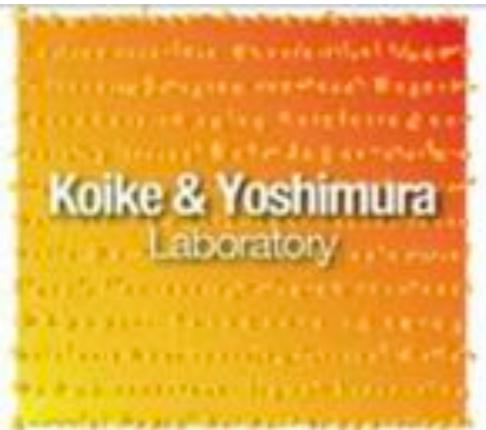


Brain-computer interface (Invasive, Non-invasive, EEG)



Natsue Yoshimura
Tokyo Institute of Technology



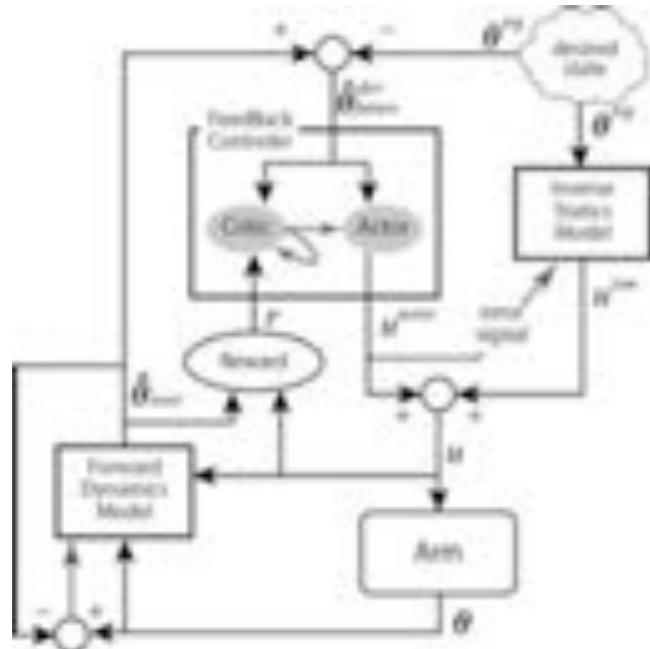
Institute of Innovative Research



Tokyo Institute of Technology



Researches in our lab



Computational Model

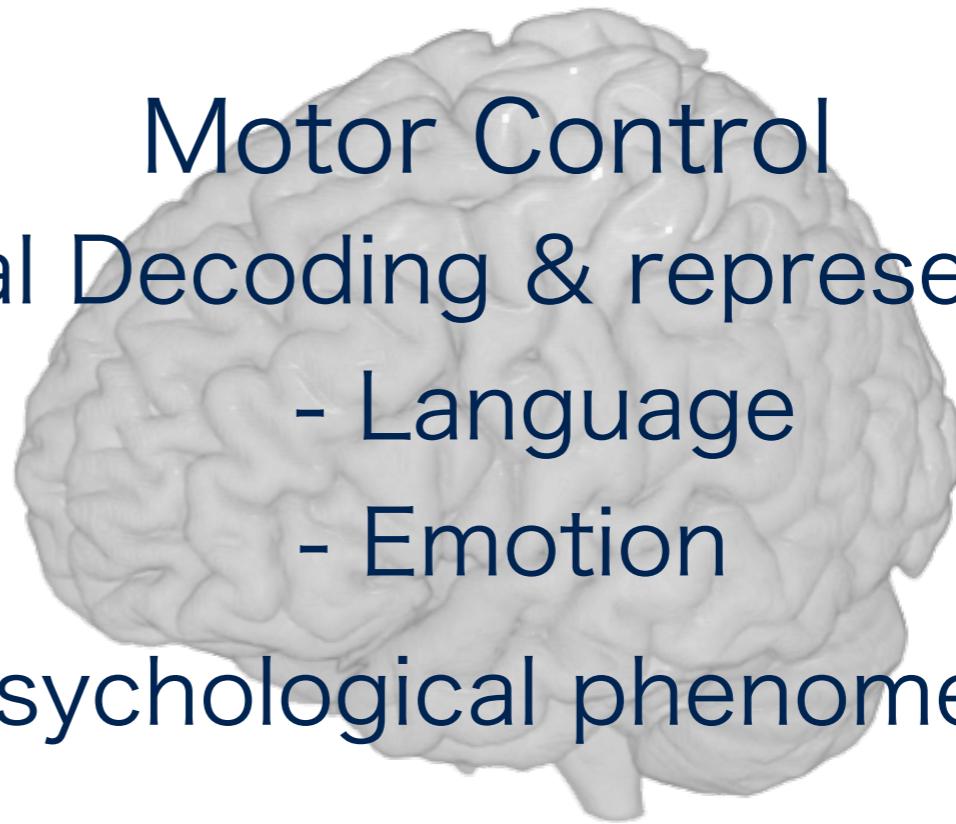


EMG-based human interfaces

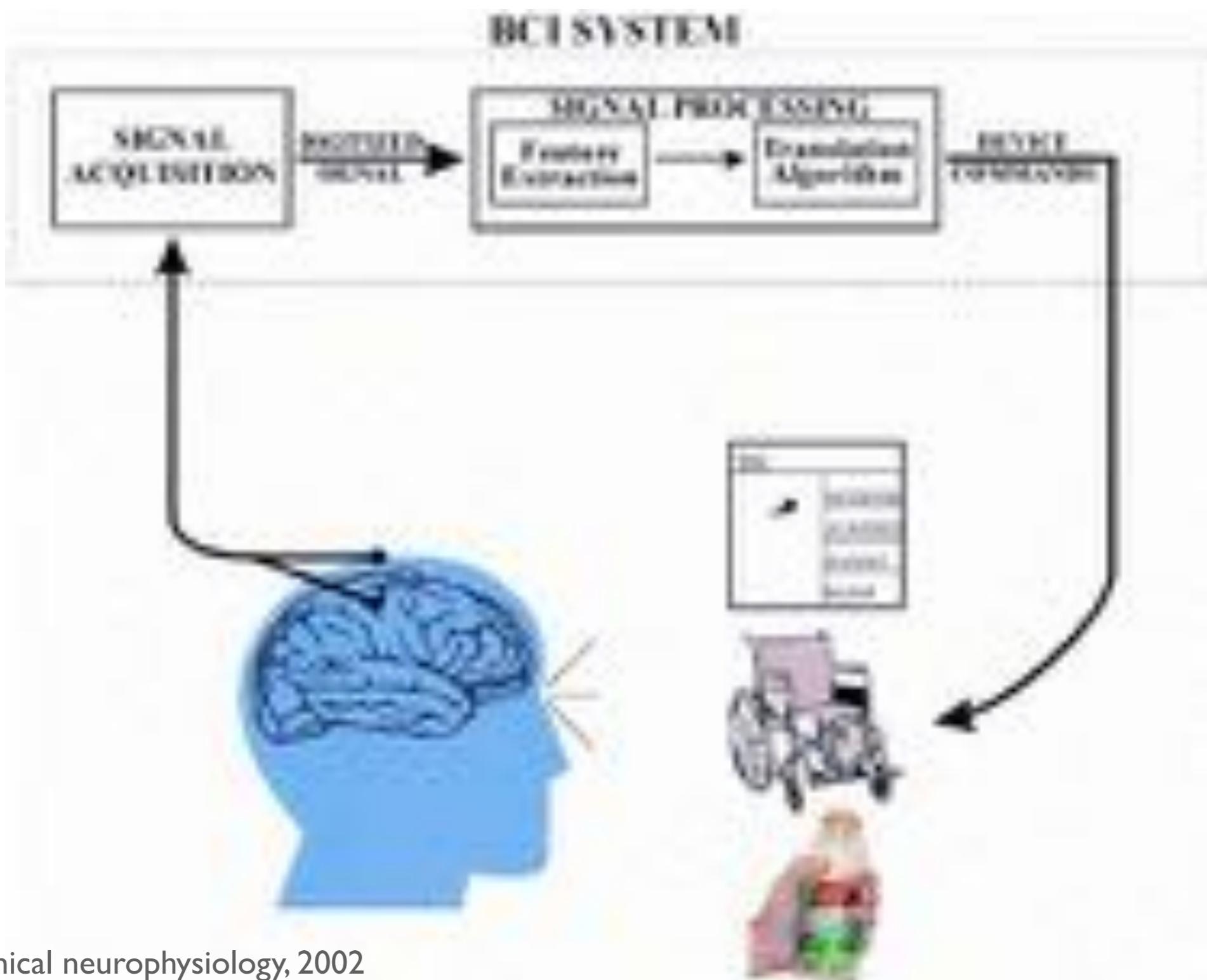


Neuroimaging

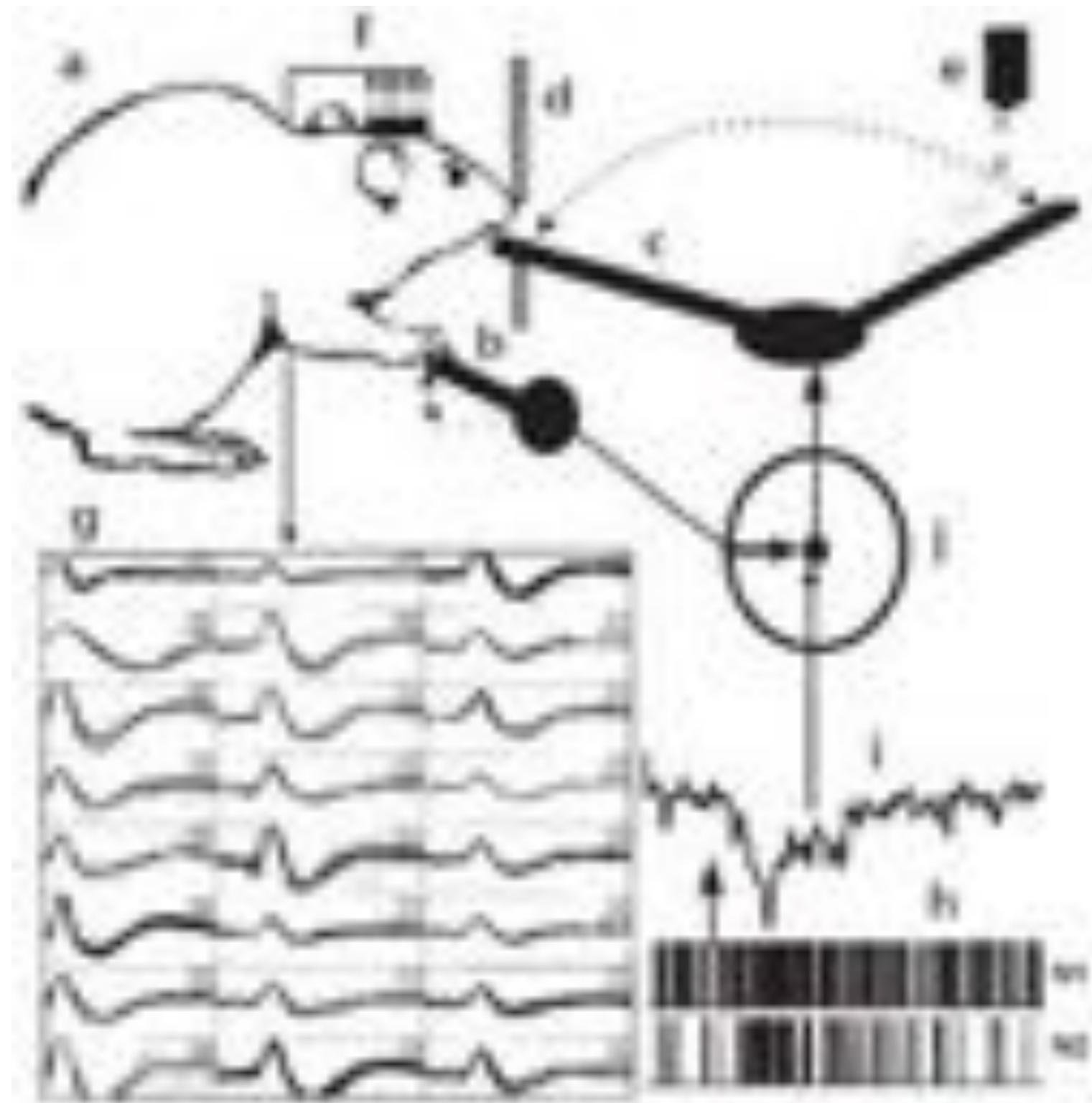
Motor Control
Neural Decoding & representation
- Language
- Emotion
Psychological phenomena



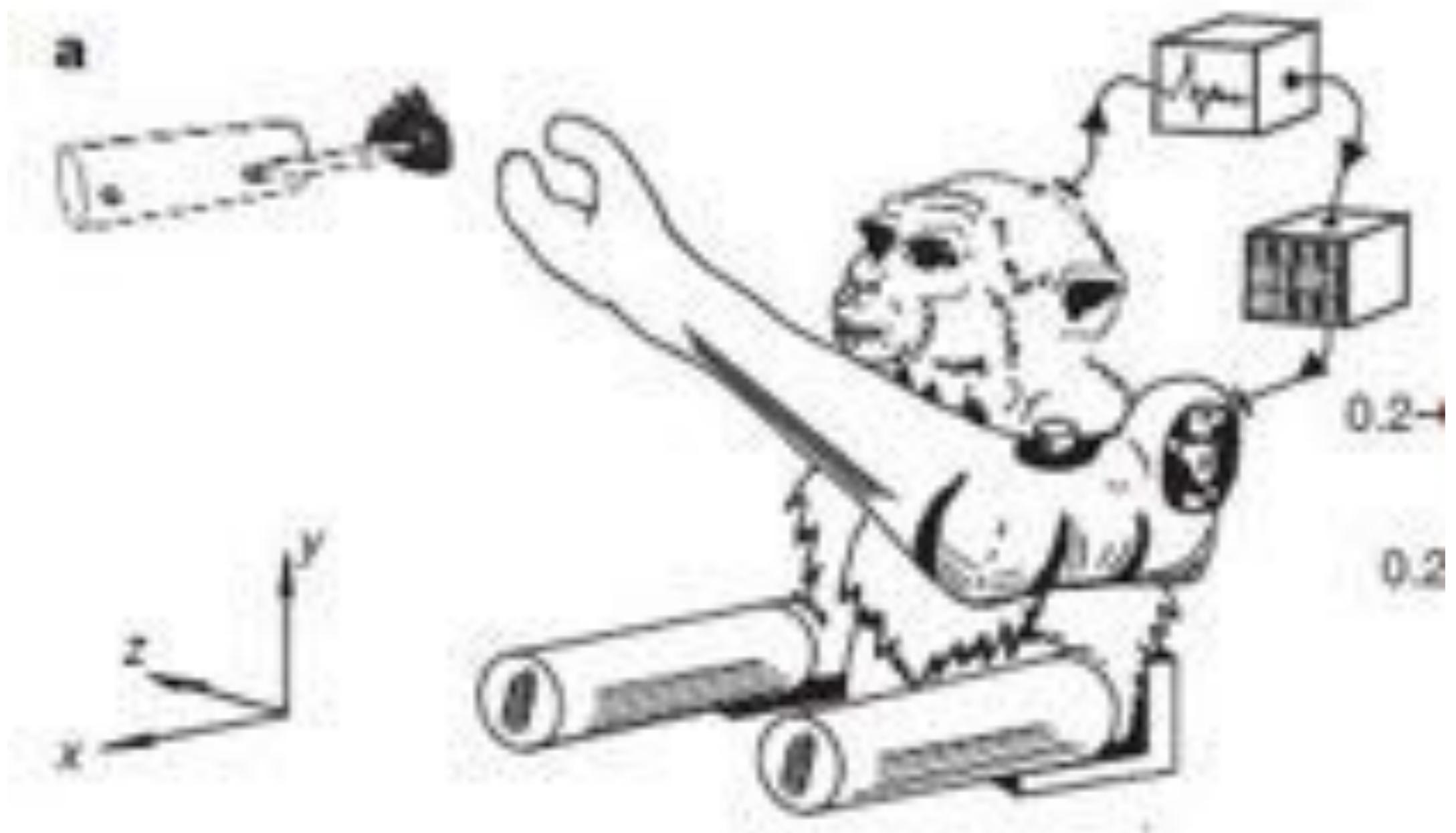
Brain-machine/computer Interfaces (BMI/BCI)



The first BMI



BMI for monkeys



BMI for human



Hochberg et al., Nature, 2006



Hochberg et al., Nature, 2012

Case I



Hochberg LR, Nature, 2012



APPENDICULAR FUNCTIONS

AUDITION

Primary auditory

0%	25%
50%	75%

Visual perception

Primary visual

0%	25%
50%	75%
75%	100%
100%	100%

EMOTION

Emotion processing

0%	25%
25%	50%
50%	75%
75%	100%

Visual perception

0%	25%
25%	50%
50%	75%
75%	100%

OLFACTORY

Odor perception

Memory

0%	25%
25%	50%
50%	75%
75%	100%

0%	25%
25%	50%
50%	75%
75%	100%

MOTOR

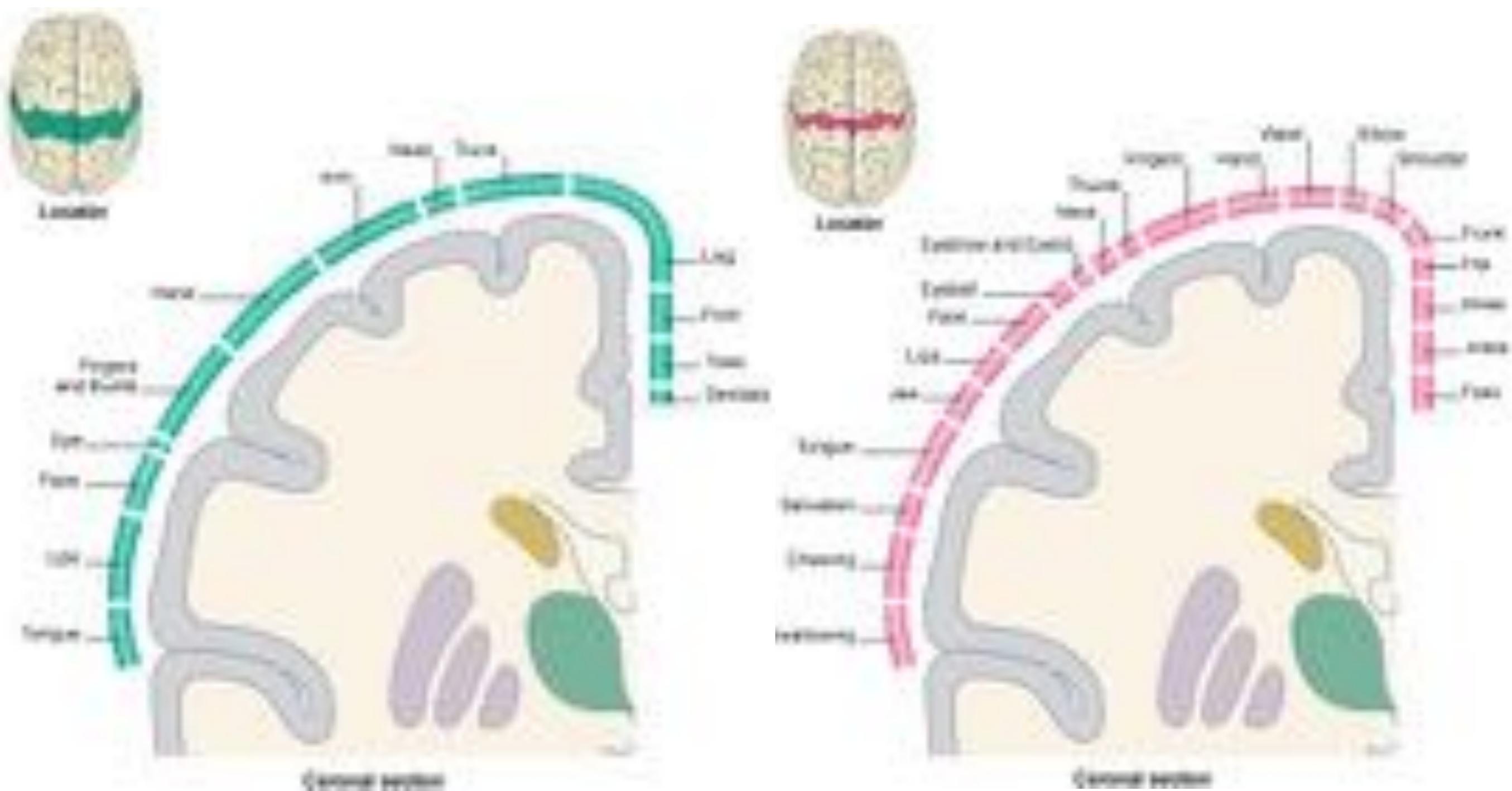
Motor function

Memory

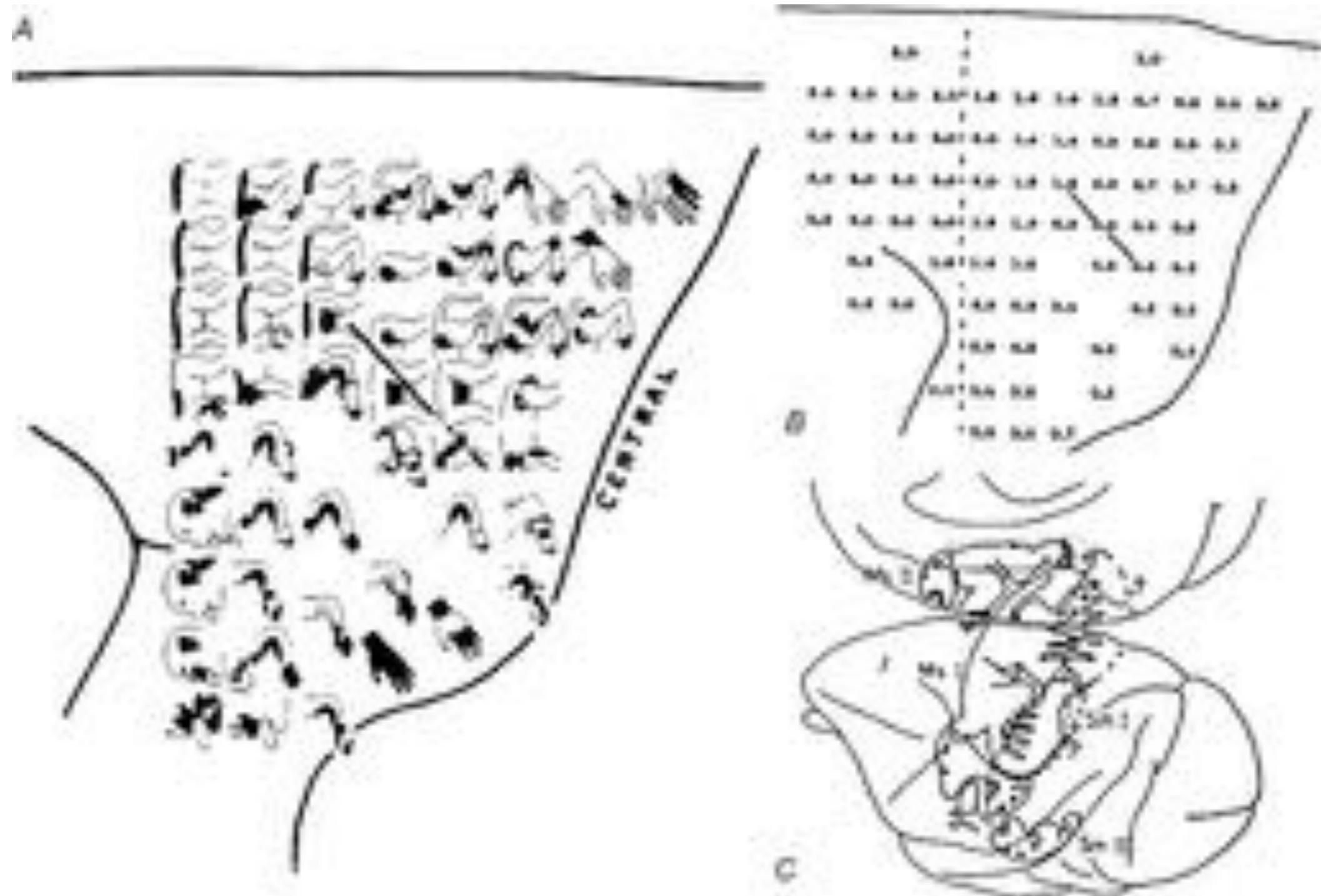
0%	25%
25%	50%
50%	75%
75%	100%

0%	25%
25%	50%
50%	75%
75%	100%

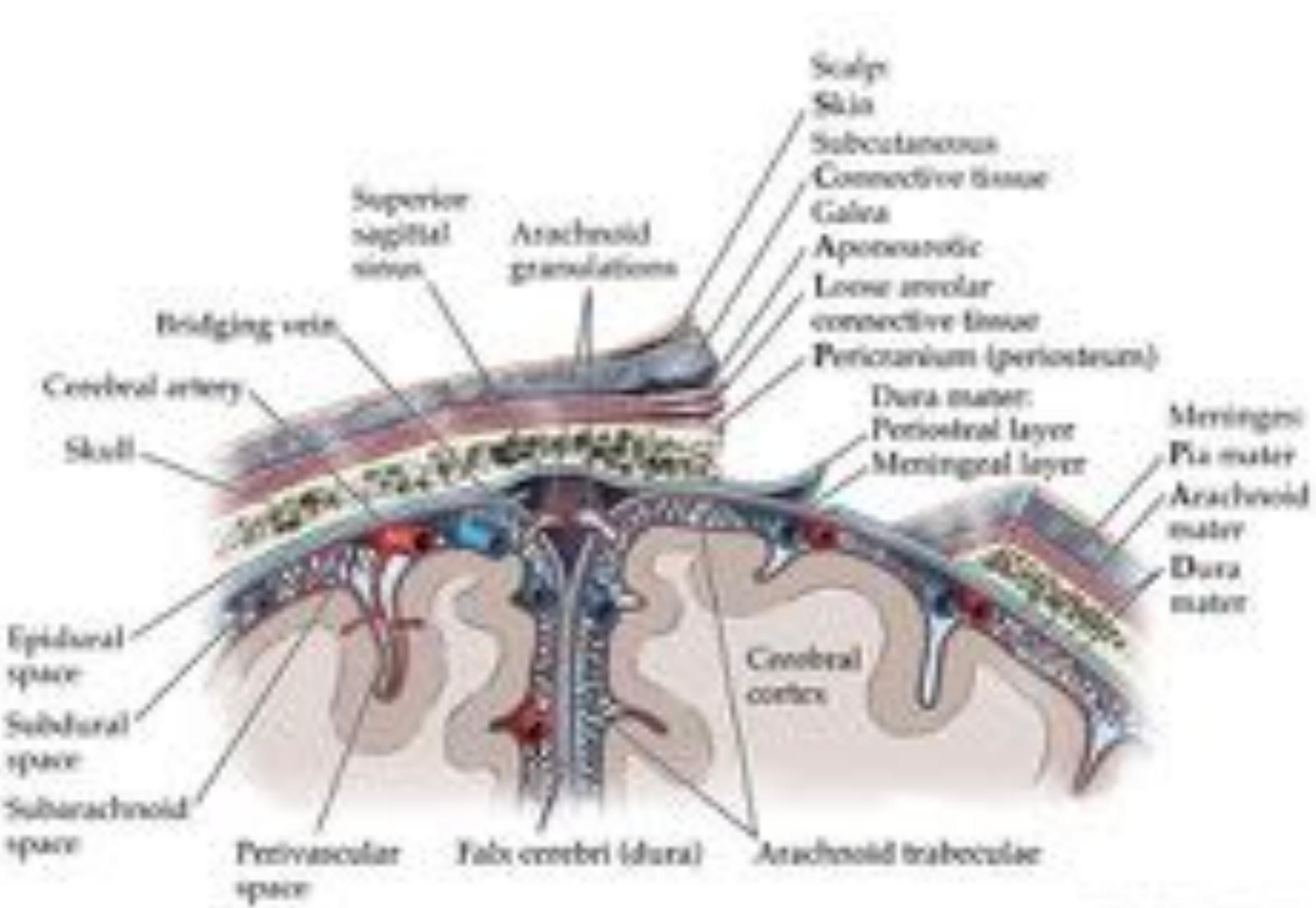
Somatotopy in Human



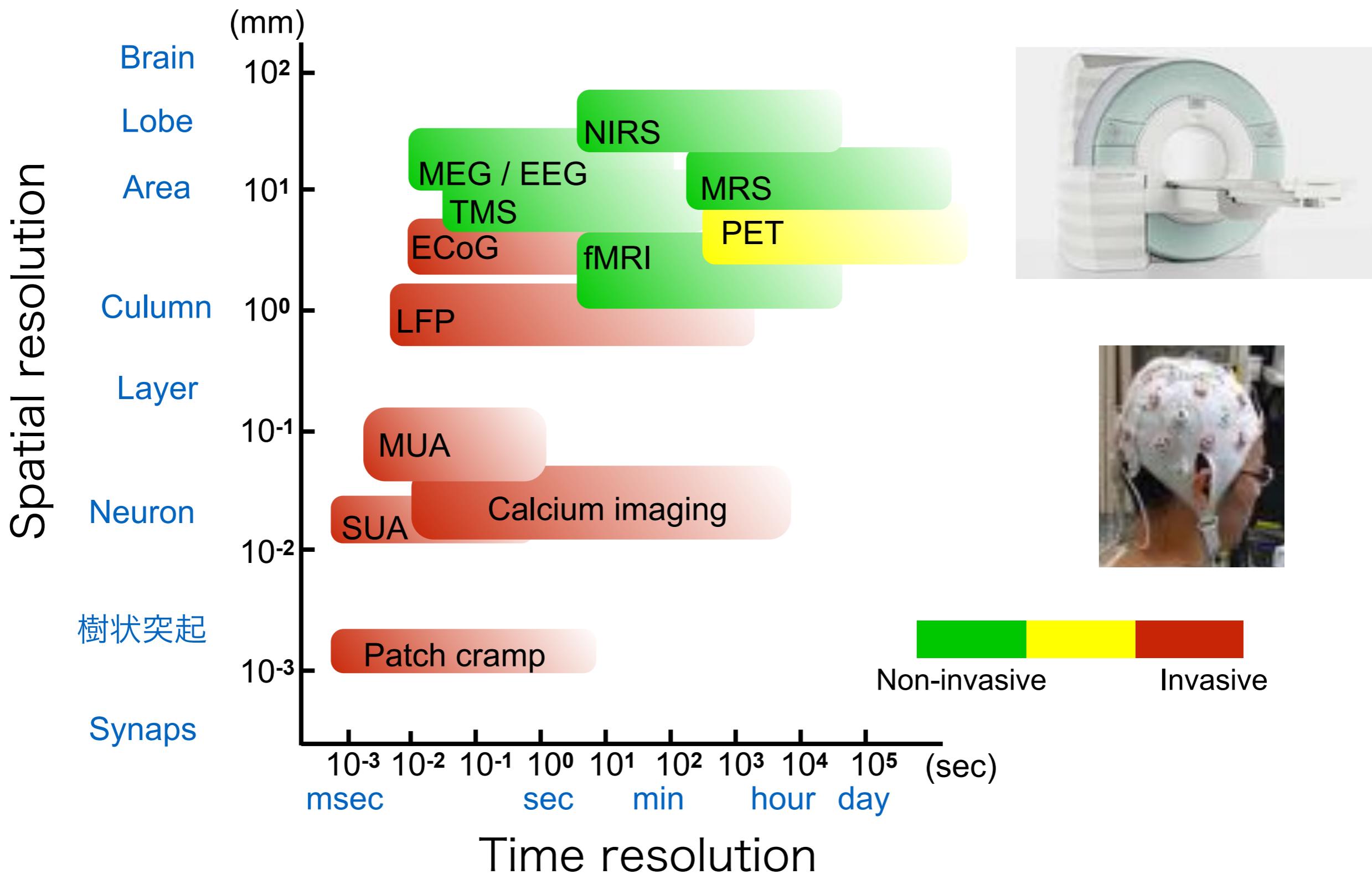
Somatotopy in Monkeys



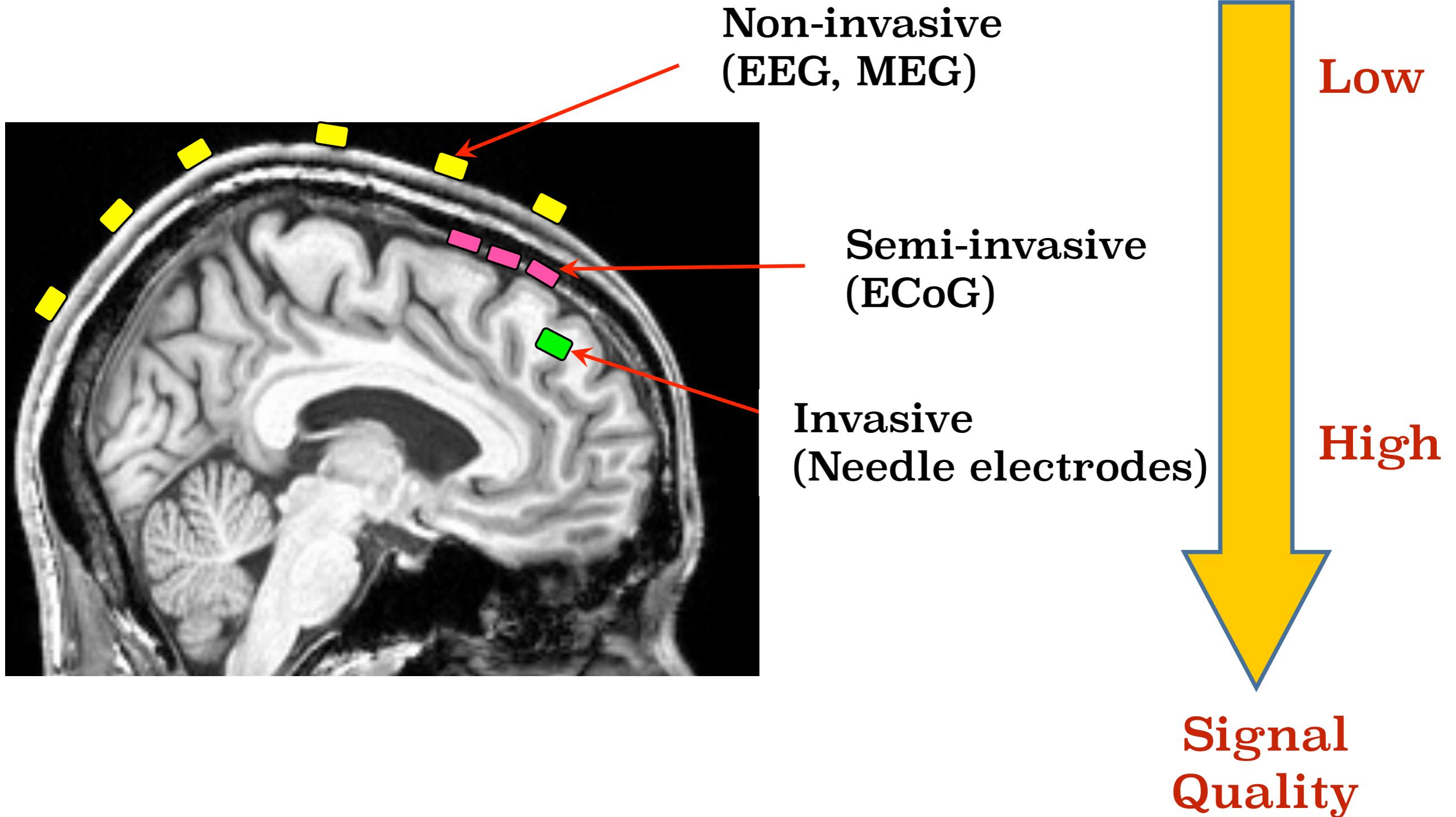
Schwartz A B J Physiol 2007;579:581-601



Time and Spacial resolution (Invasive vs. Non-invasive)

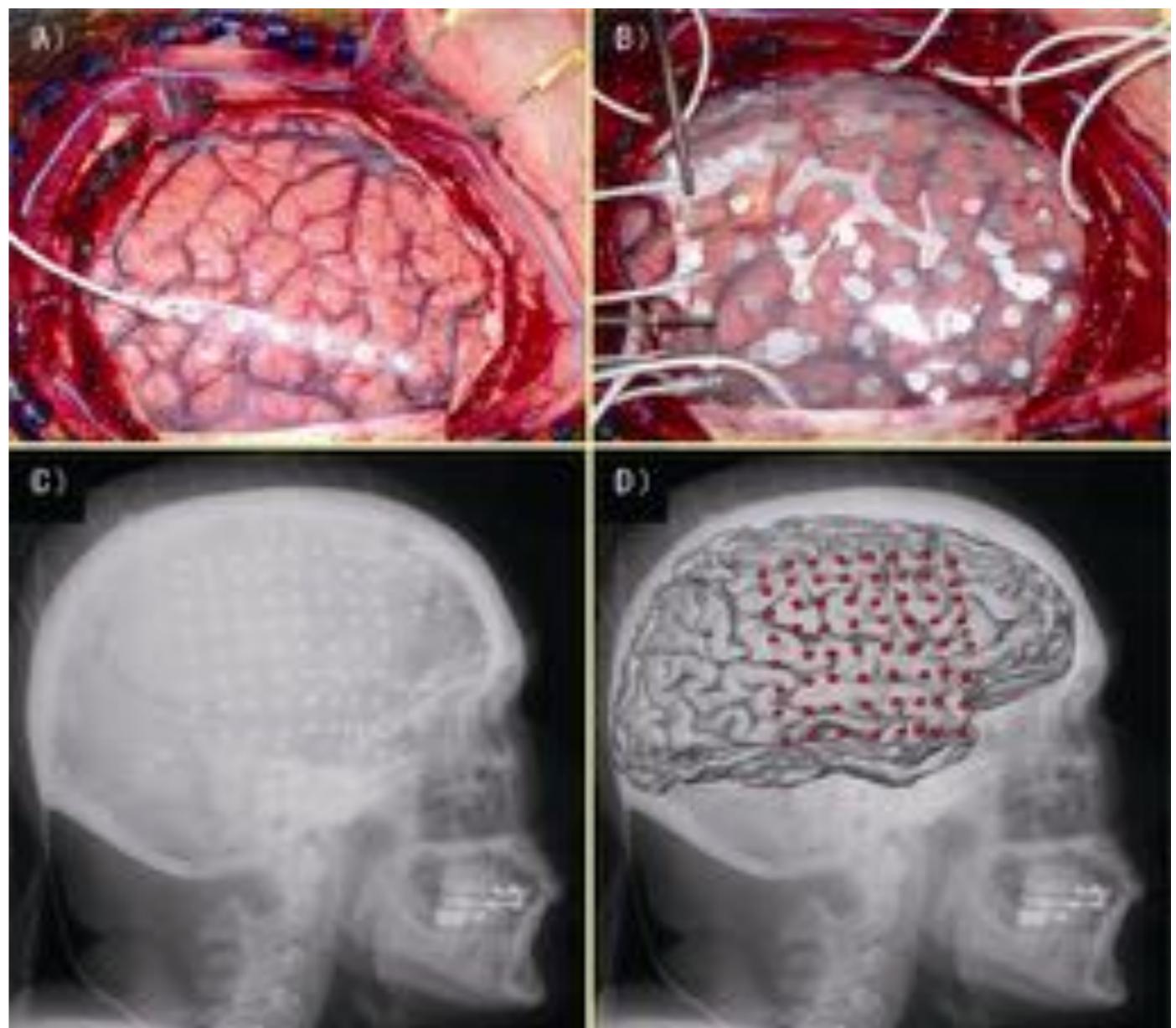


Non-, Semi-, and Invasive



Semi-invasive BMIs

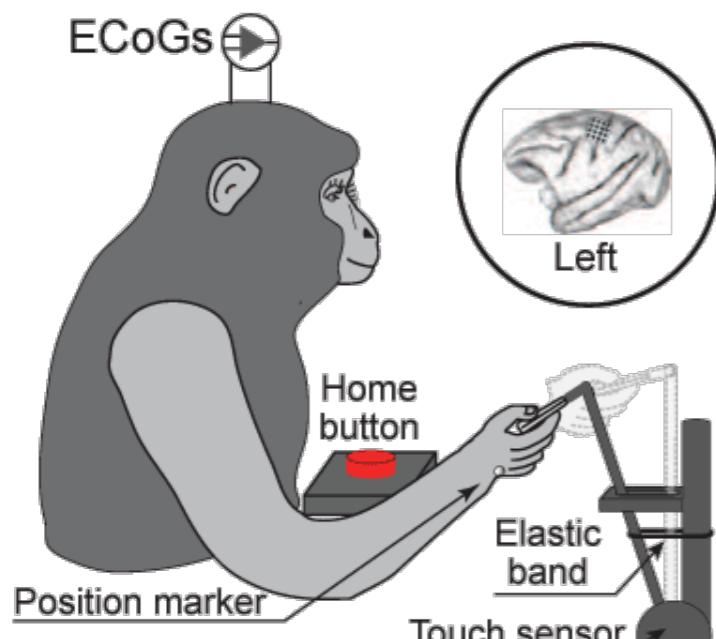
Electrocorticography (ECoG)



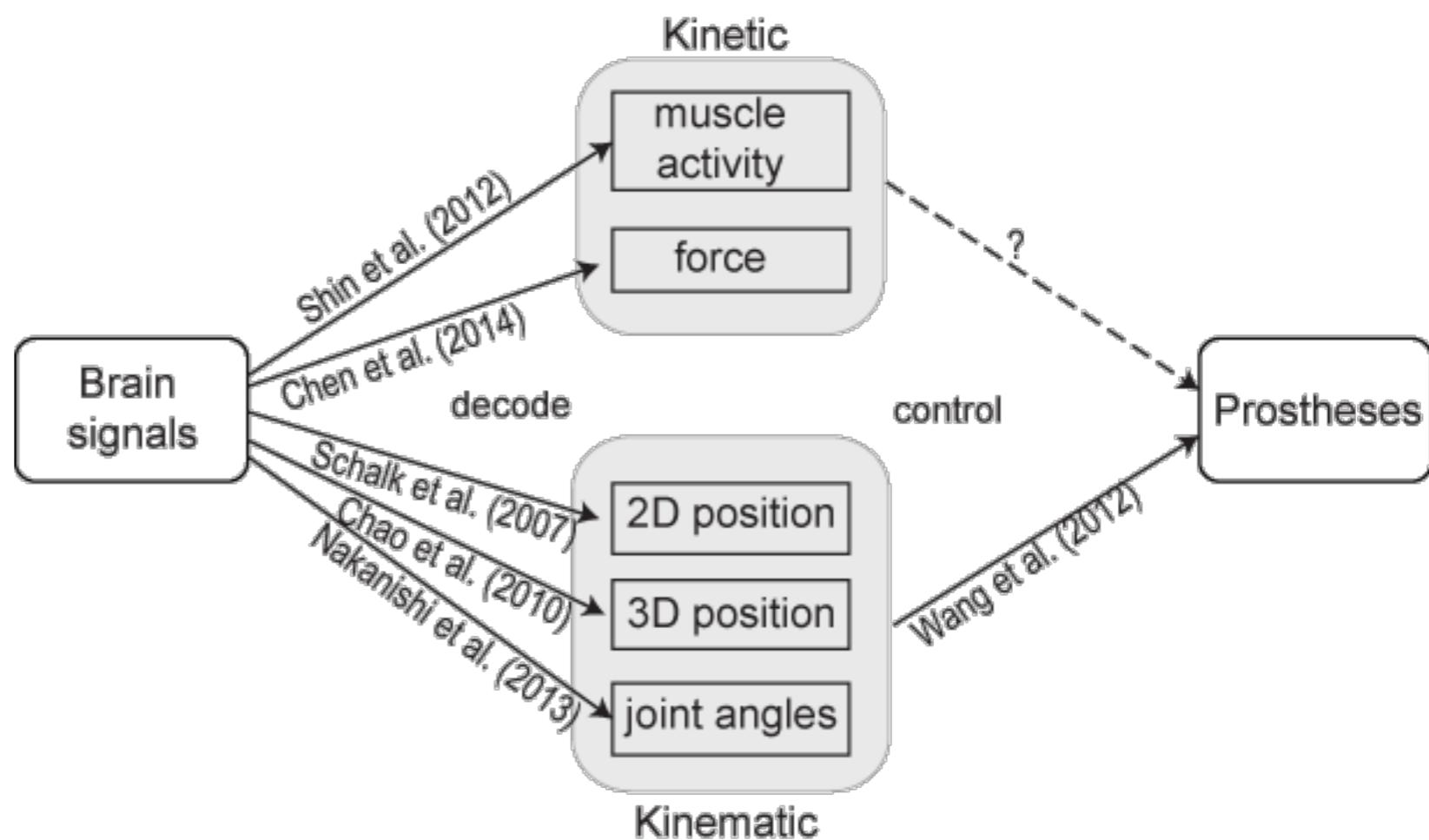
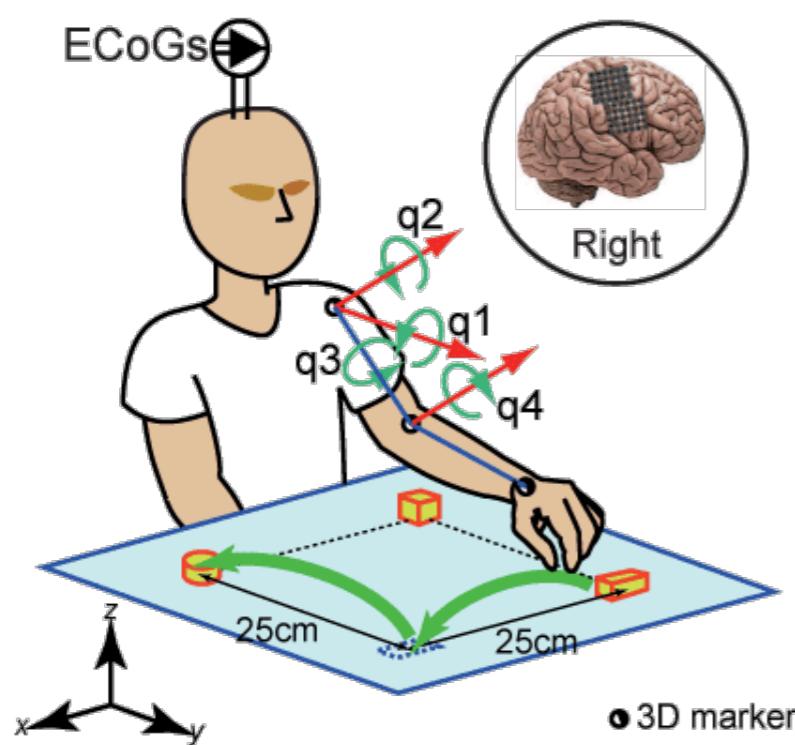
Schalk G et al., *J Neural Eng.*, 2008

What ECoG can decode?

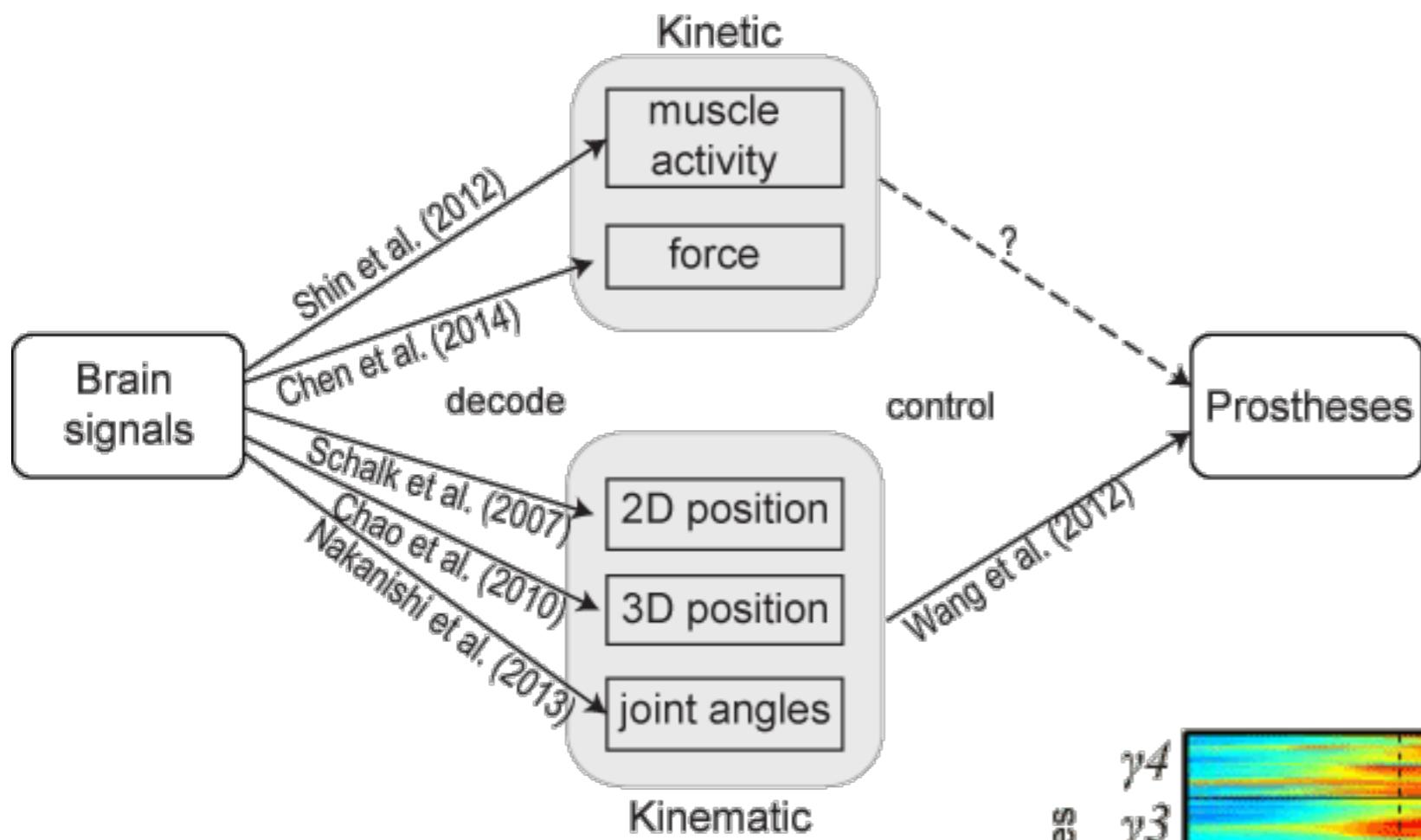
A



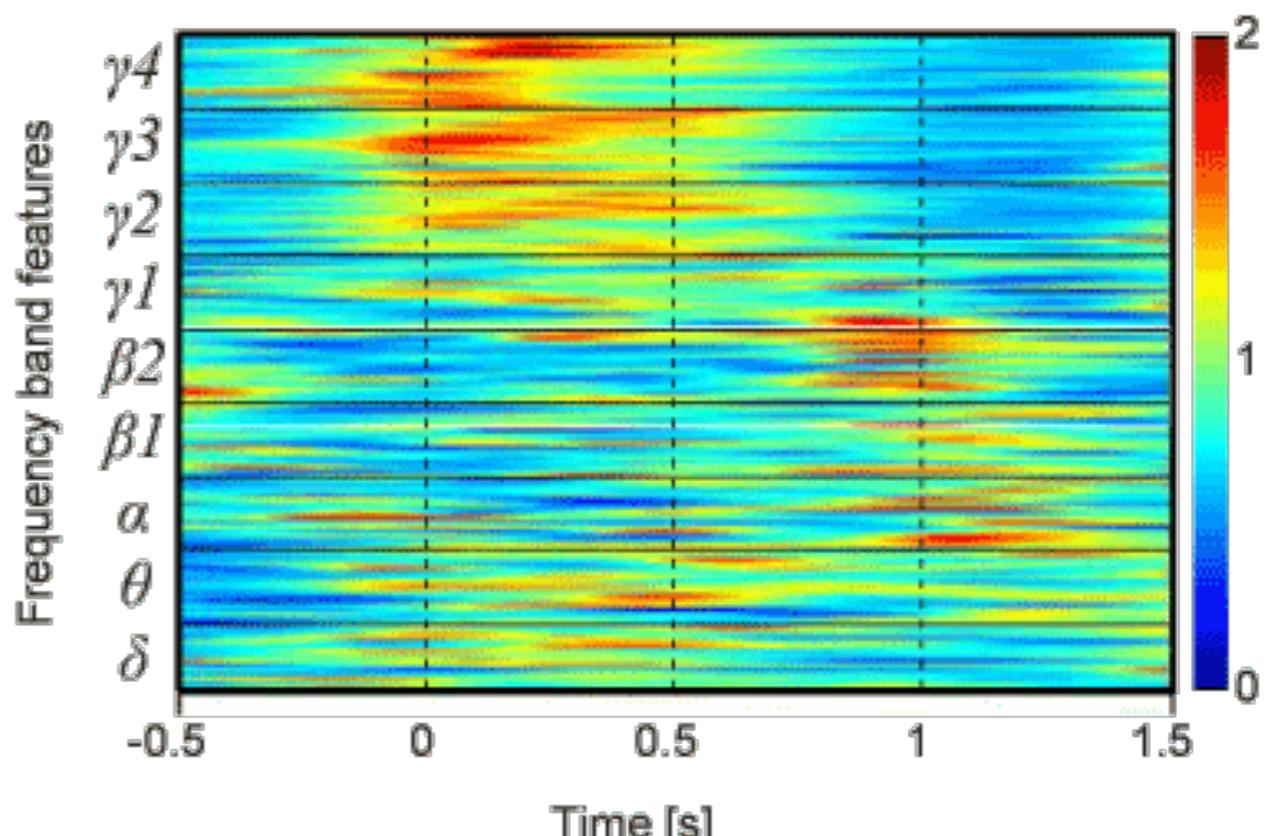
B



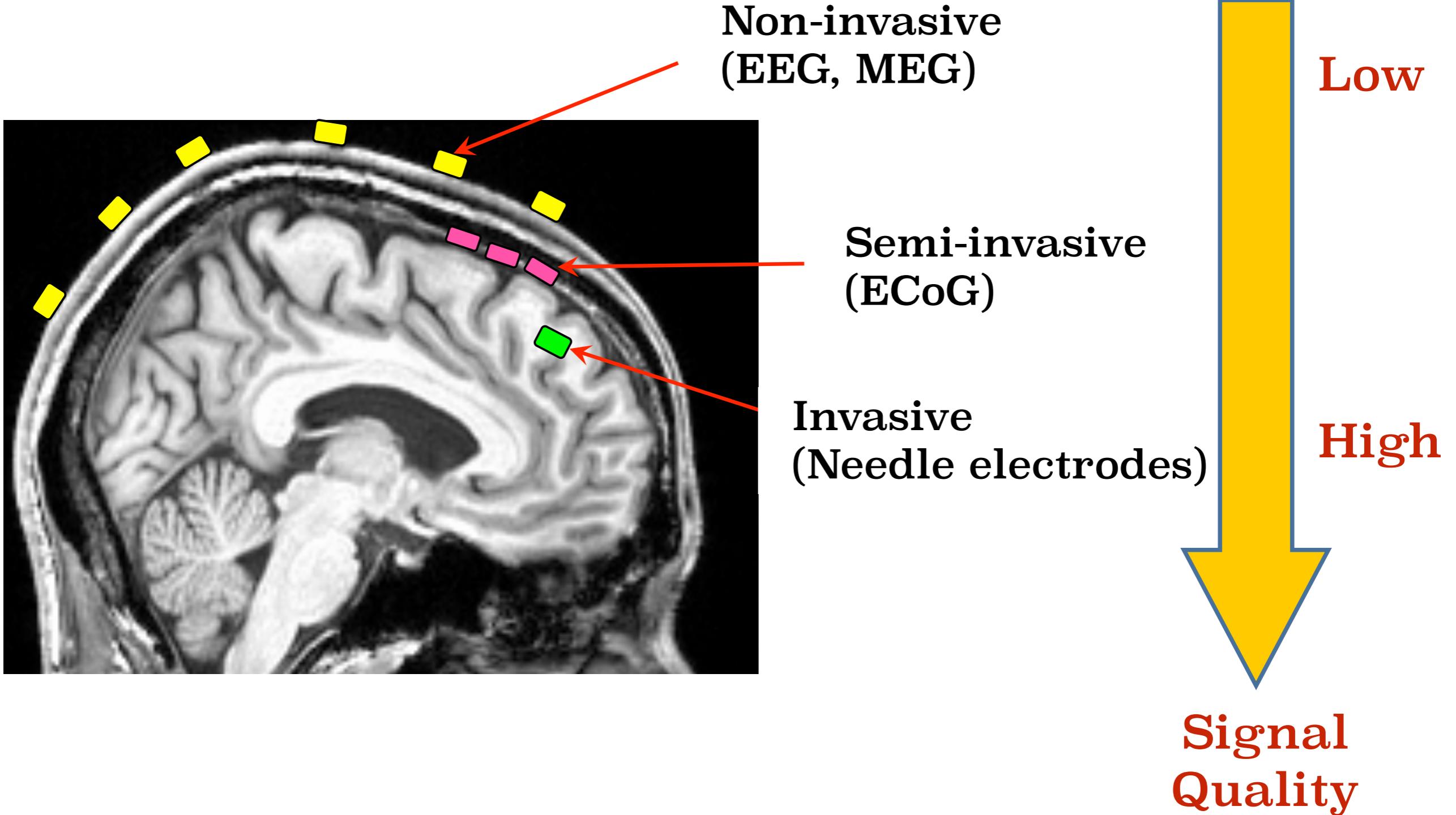
What ECoG can decode?



γ_4	: 120 ~ 150 Hz
γ_3	: 90 ~ 120 Hz
γ_2	: 50 ~ 90 Hz
γ_1	: 30 ~ 50 Hz
β_2	: 20 ~ 30 Hz
β_1	: 14 ~ 20 Hz
α	: 8 ~ 14 Hz
θ	: 4 ~ 8 Hz
δ	: ~ 4 Hz



Non-, Semi-, and Invasive



Non-invasive BMIs

Electroencephalography(EEG),
Magnetoencephalography(MEG)

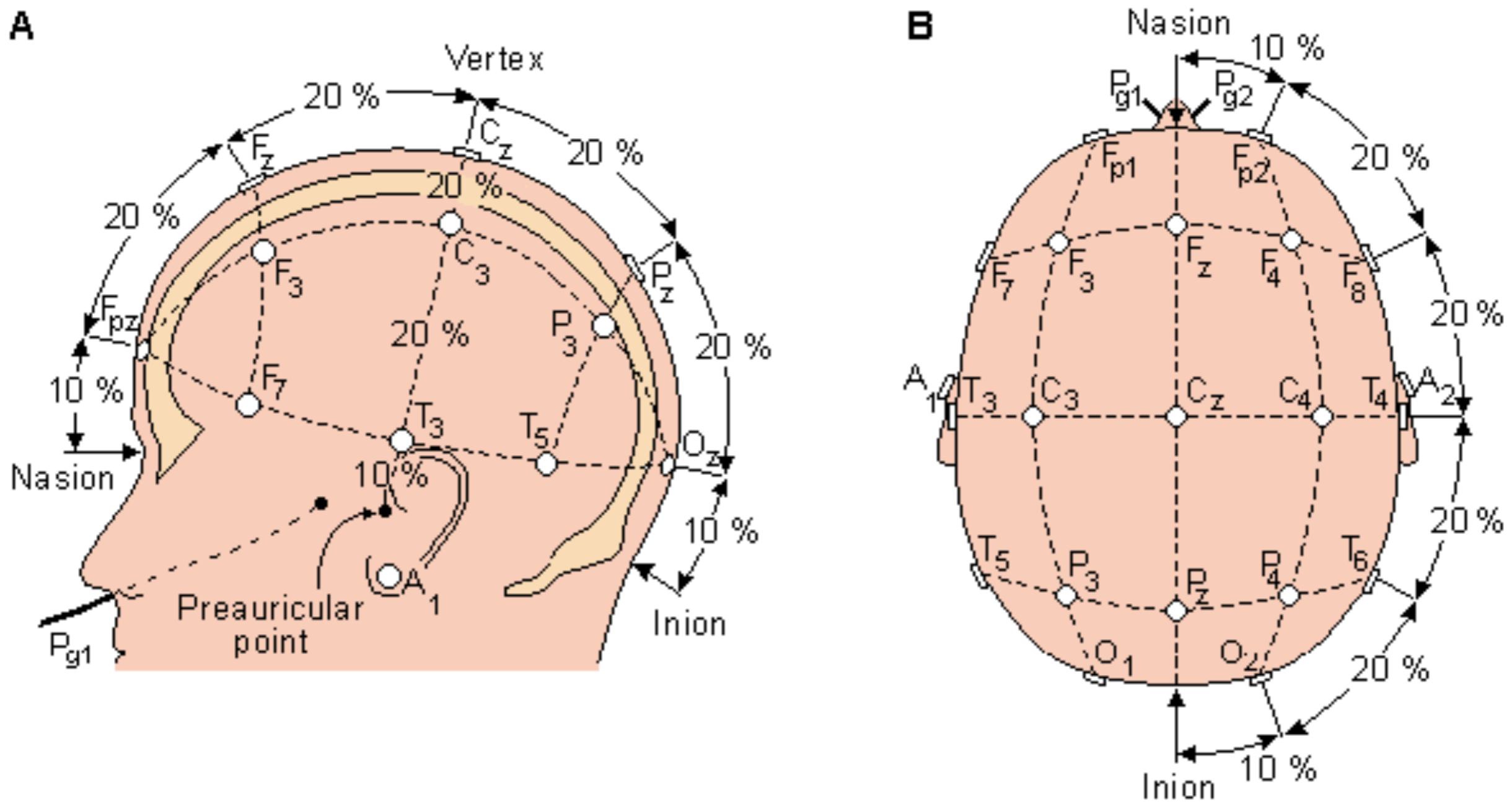


NIRS
(near-infrared spectroscopy)



fMRI
(functional Magnetic
Resonance Imaging)

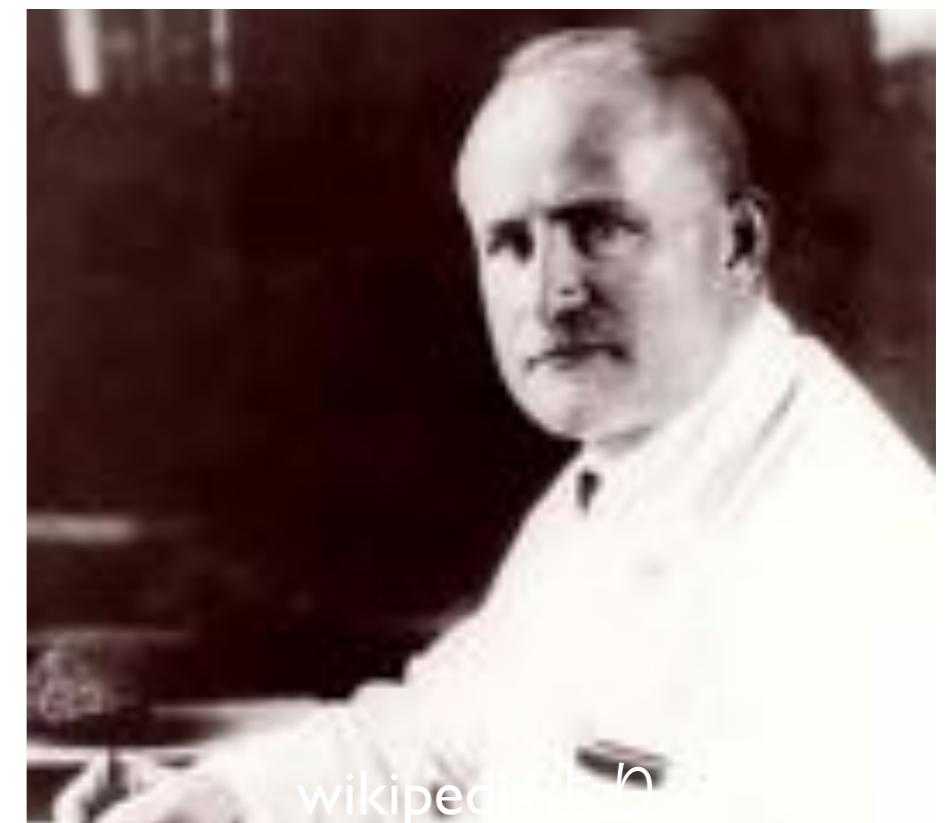
EEG electrode positions International 10/20 system



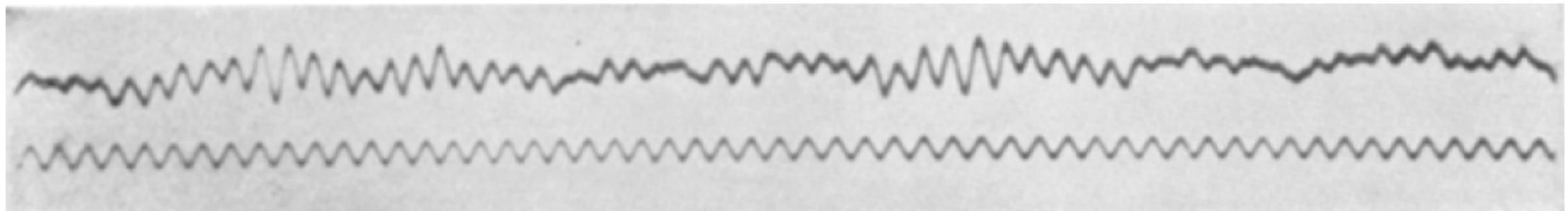
EEG

- Hans Berger, (May 21, 1873 - June 1, 1941)
- Discovery of α -wave

waves	Frequency band
δ	1-4 Hz
θ	4-7 Hz
α	8-13 Hz
β	14-30 Hz
γ	25-100 Hz



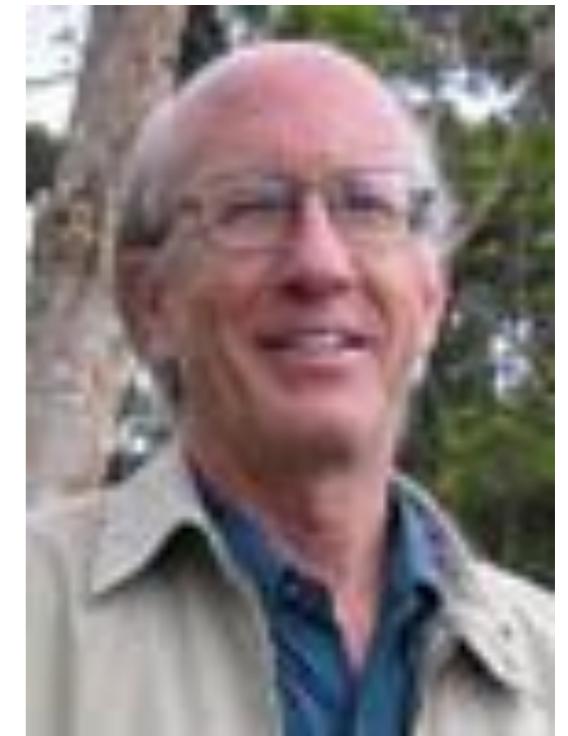
wikipedia



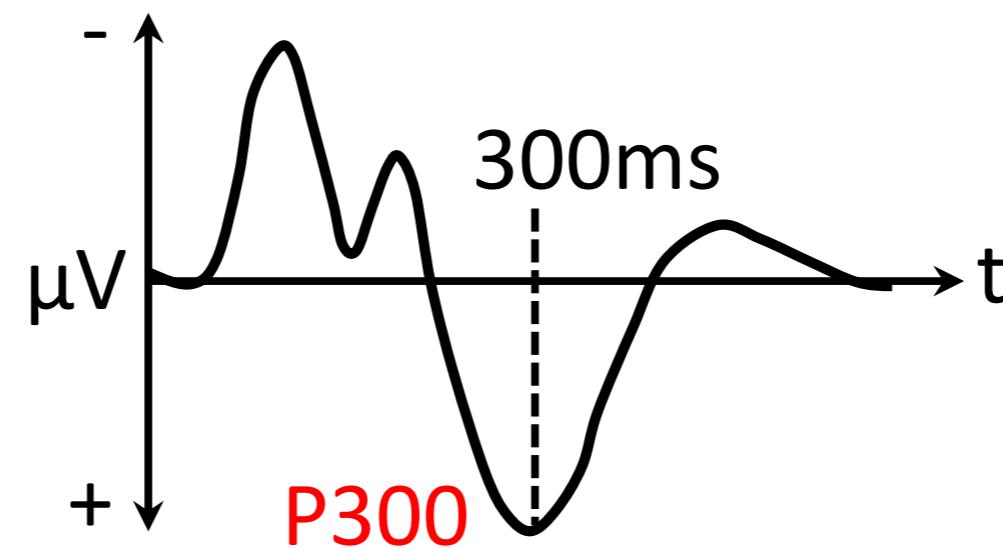
EEG

- Evoked potentials
 - Light, Sound, Tactile, ...
- Event-related potentials (ERP)
 - Higher-order cognitive processing
- Spontaneous signals (resting-state)
 - Personality, ability, ...

Steven Hillyard (UCSD)



- Research on attention using ERP
- P300: Oddball paradigm



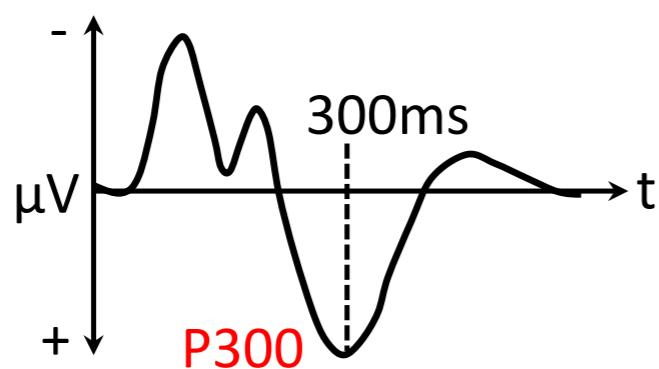
The most popular EEG-based BCIs

- P300 (Event-related potentials)

Polygraph



Is this yours?



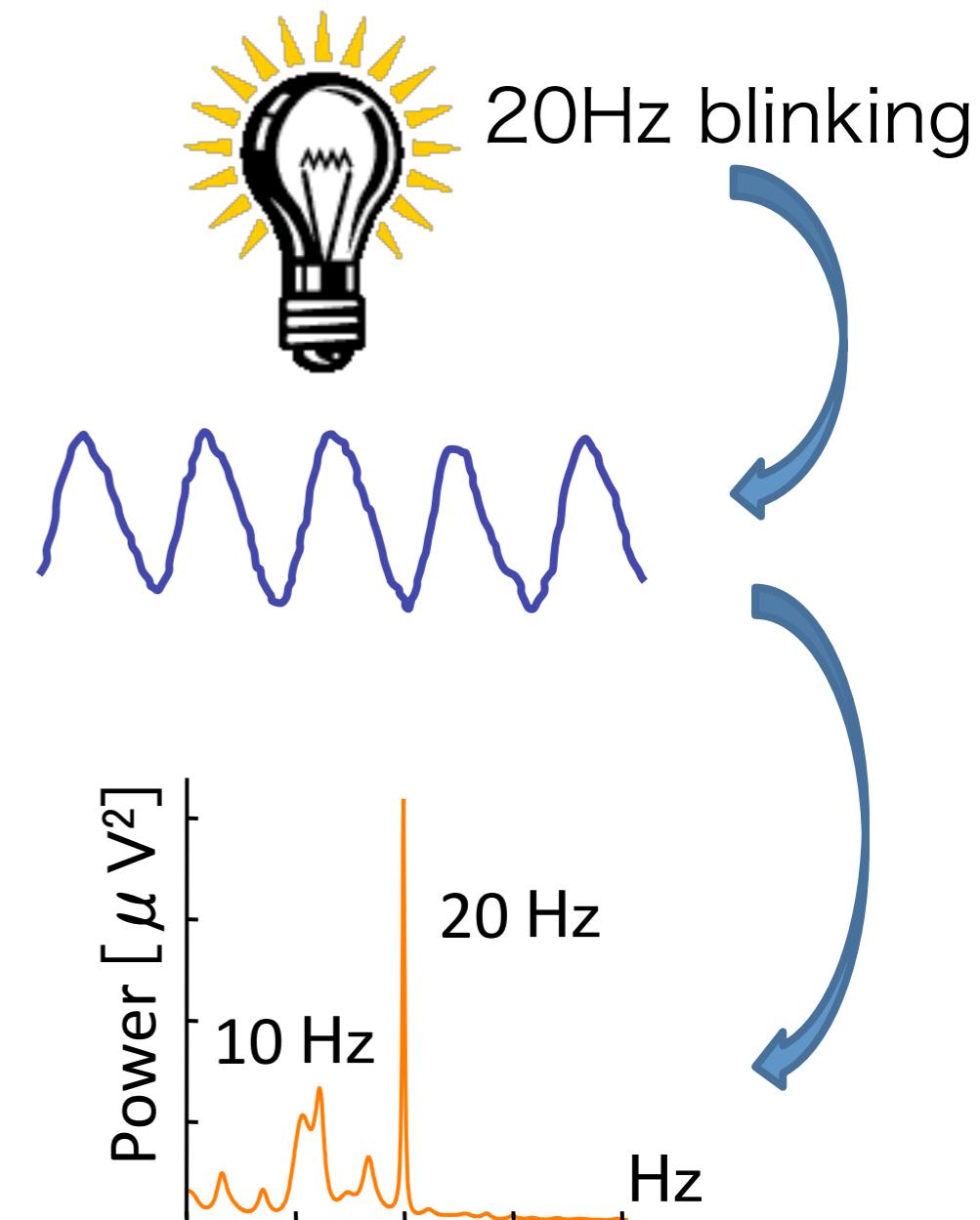
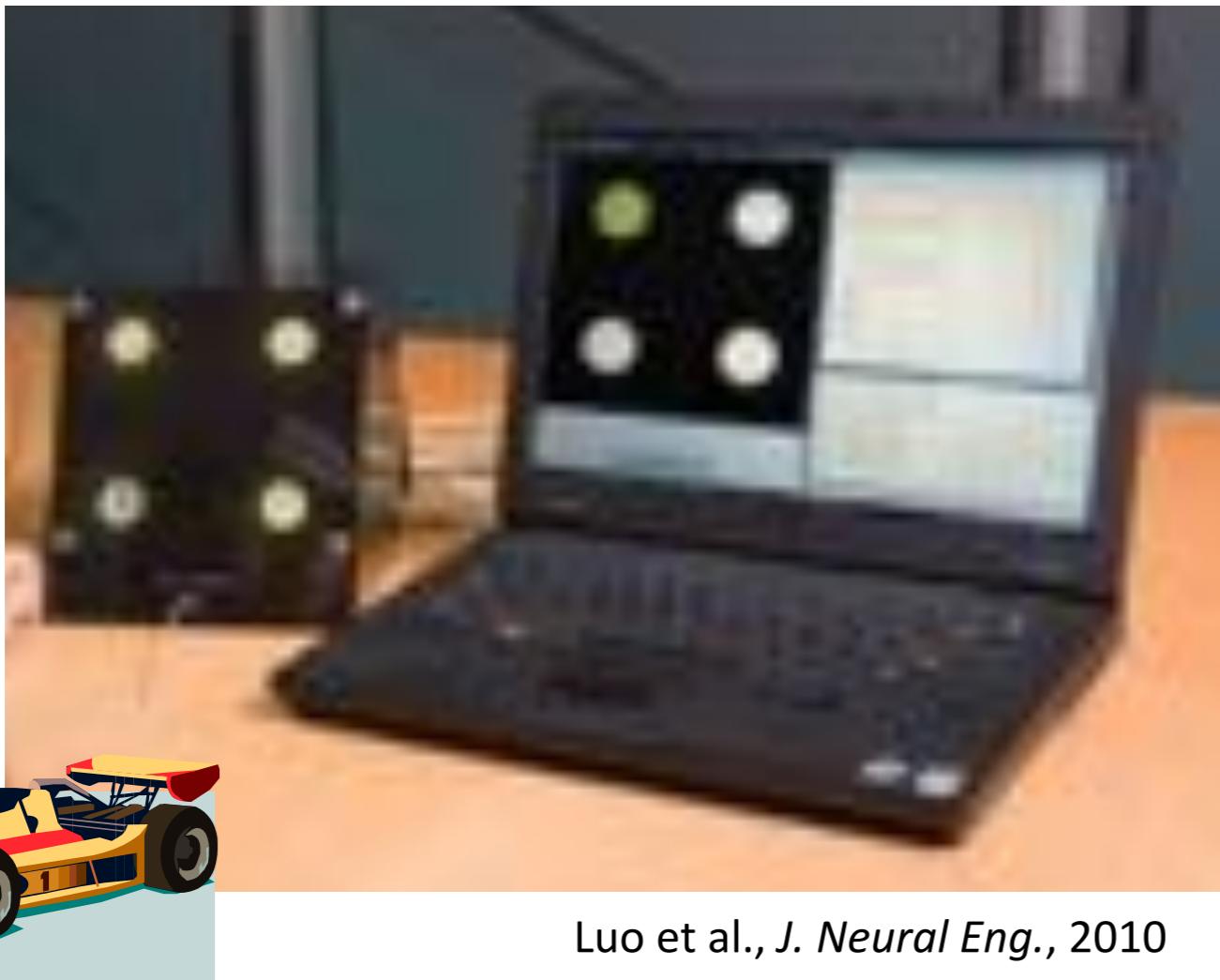
Spellers

A	B	C	D	E	F
G	H	I	J	K	L
M	N	O	P	Q	R
S	T	U	V	W	X
Y	Z	SPC	DEL	LEX	RET

Ahi et al., 2011

Evoked potential-based BMI

- Visual Evoked Potentials (VEPs)



Spontaneous EEG-based BMI

- α and β waves
- Event Related Desynchronization (ERD)



'NeuroBoy' and 'Star Wars Force Trainer'
(by Neurosky)

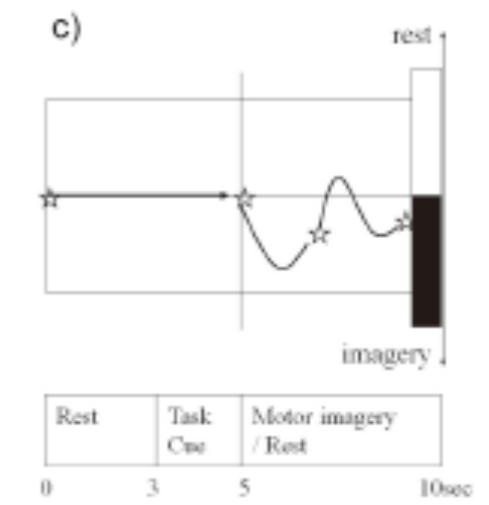
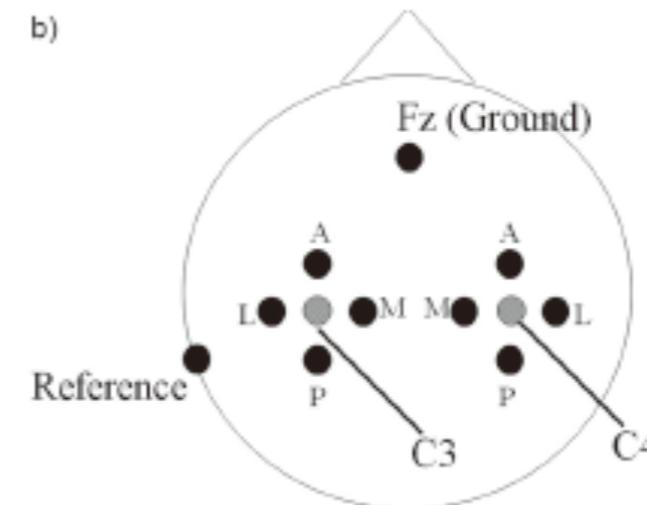
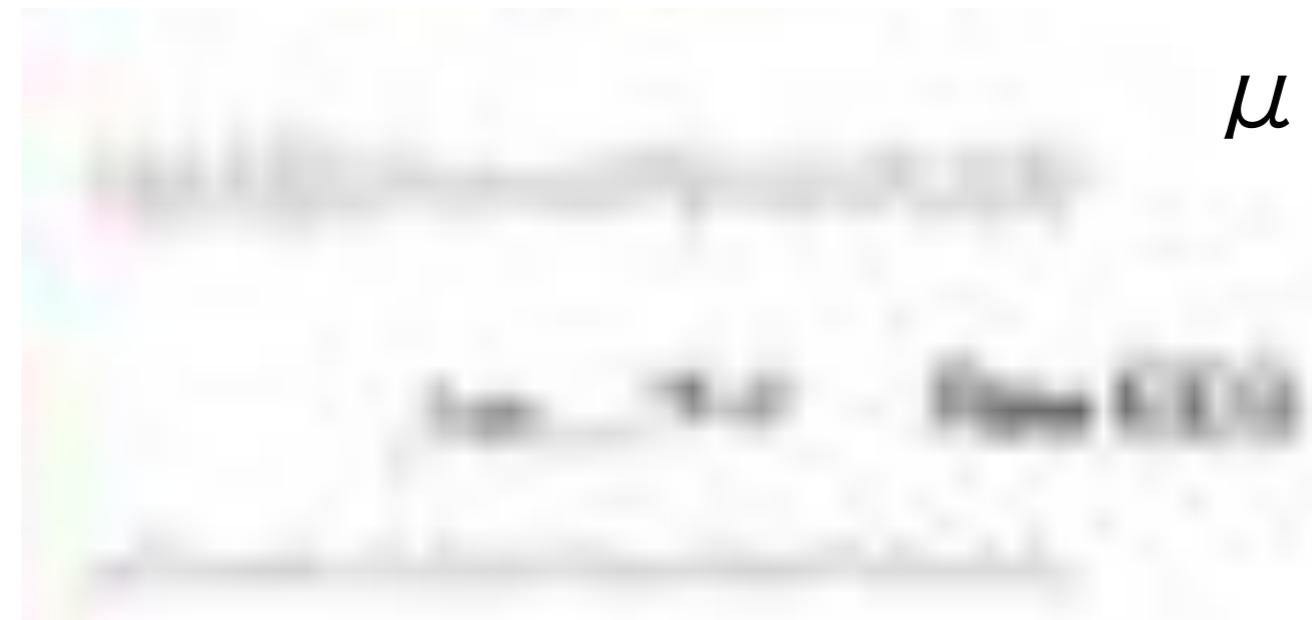


EEG-controlled Wheelchair
(by RikenBSI-TOYOTA)



Neuro-rehabilitation

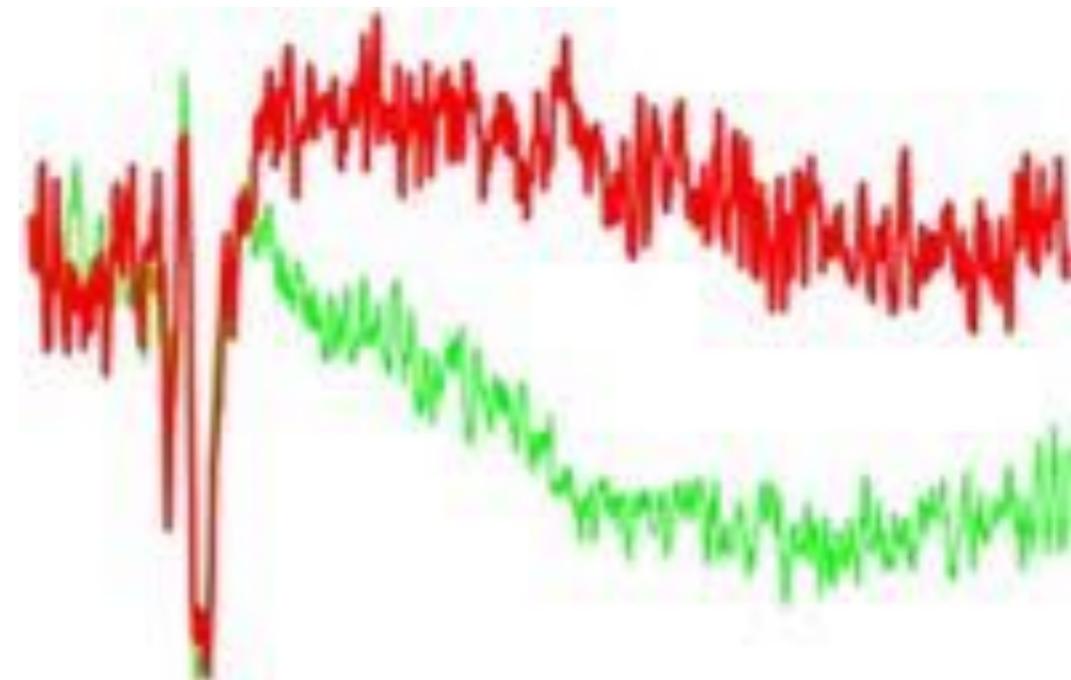
μ : 8~12Hz



Shindo et al., J Rehabil Med, 2011

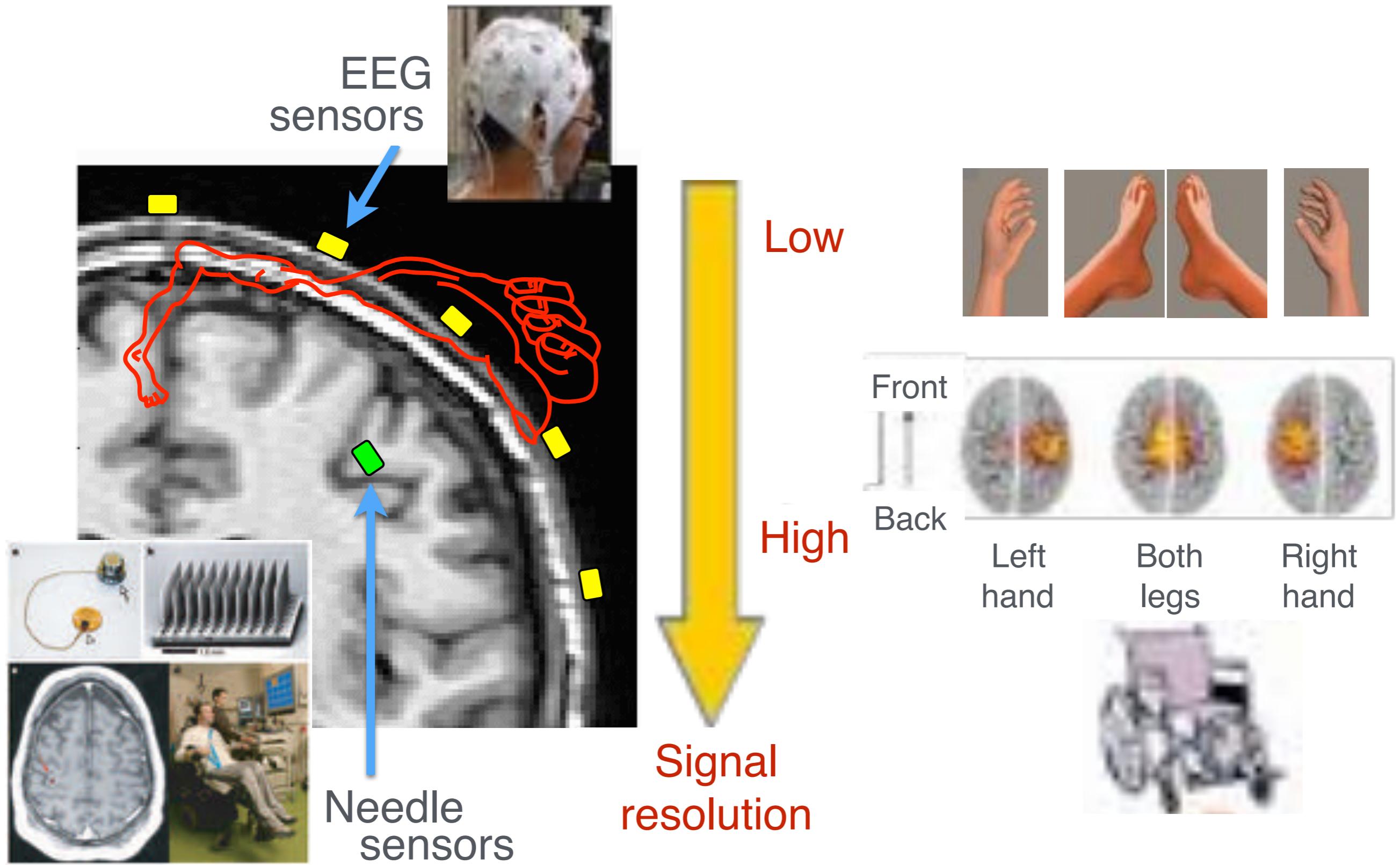
Neuro-feedback

Slow Cortical Potential

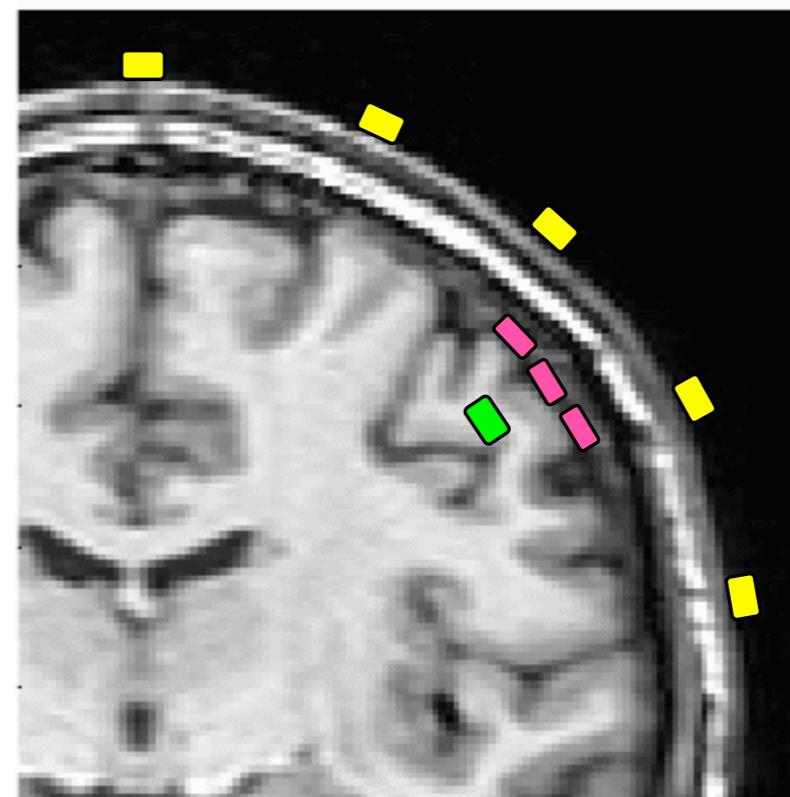
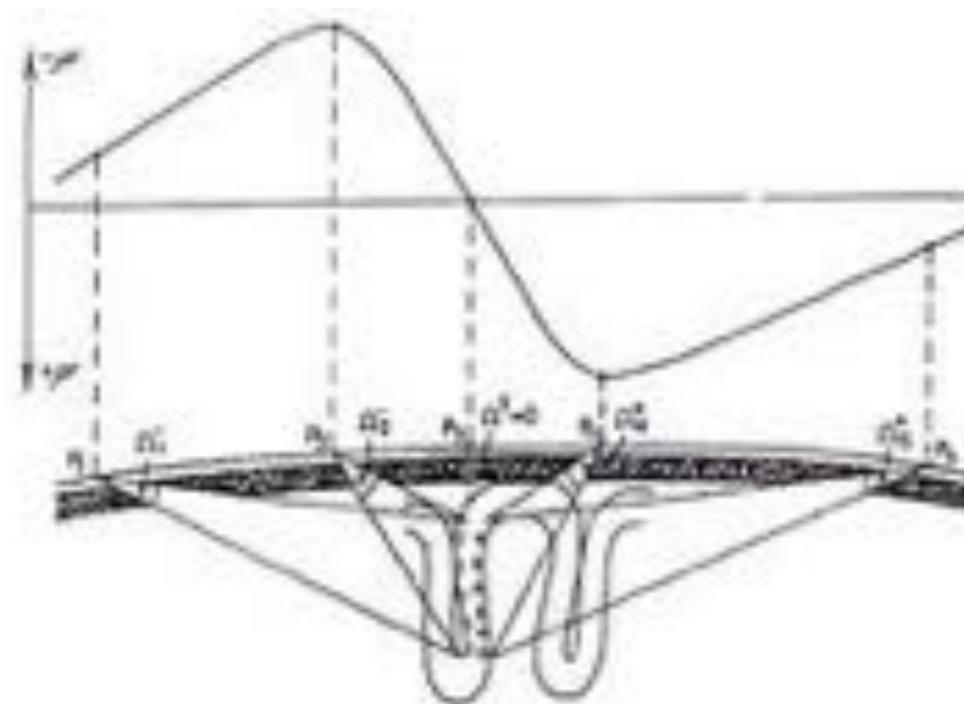
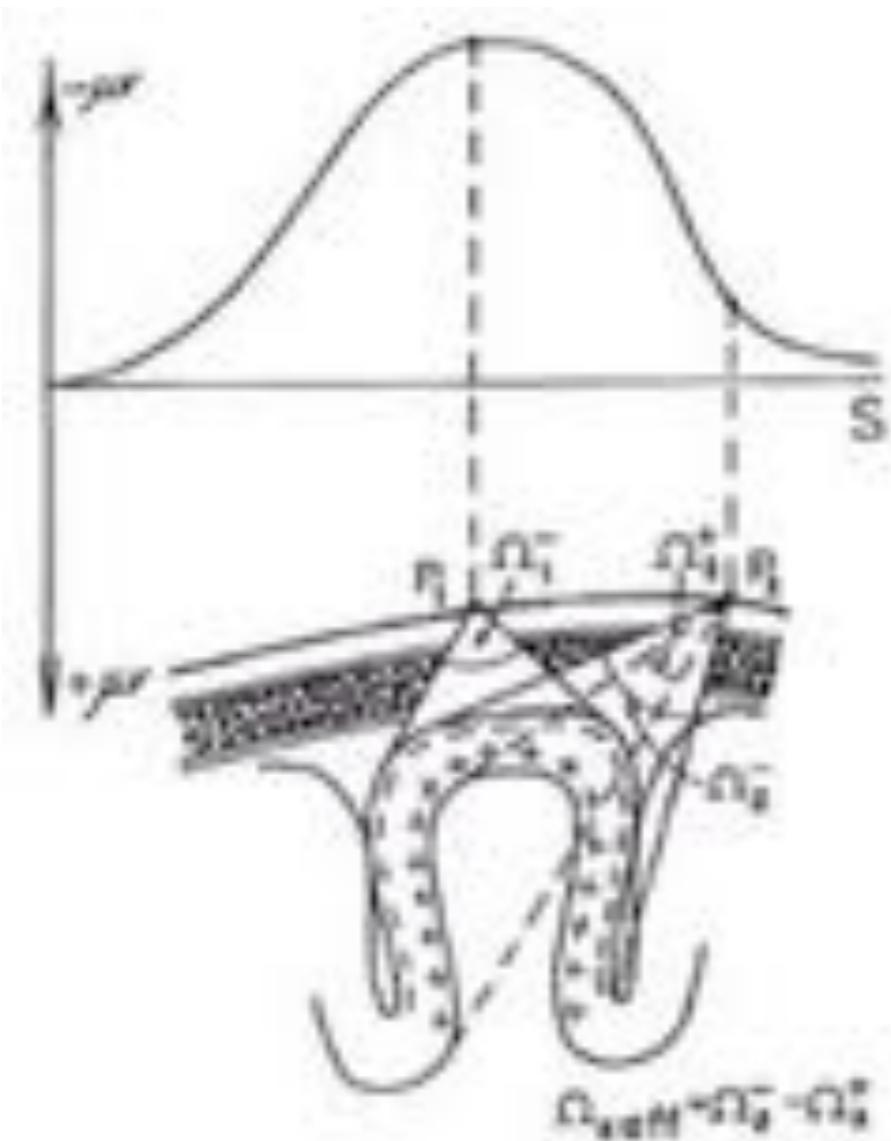


Strehl et al., 2006

Difficult for EEG?



Neural origins and EEG signals



Brain-machine interfaces



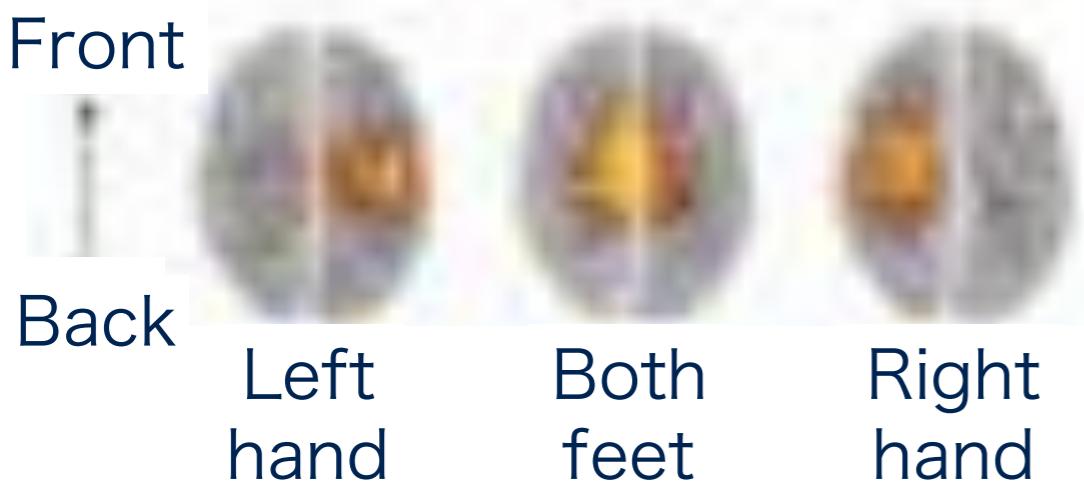
Hochberg LR, Nature, 2012

Is this possible for non-invasive methods?

To control the robot arm by EEG ...

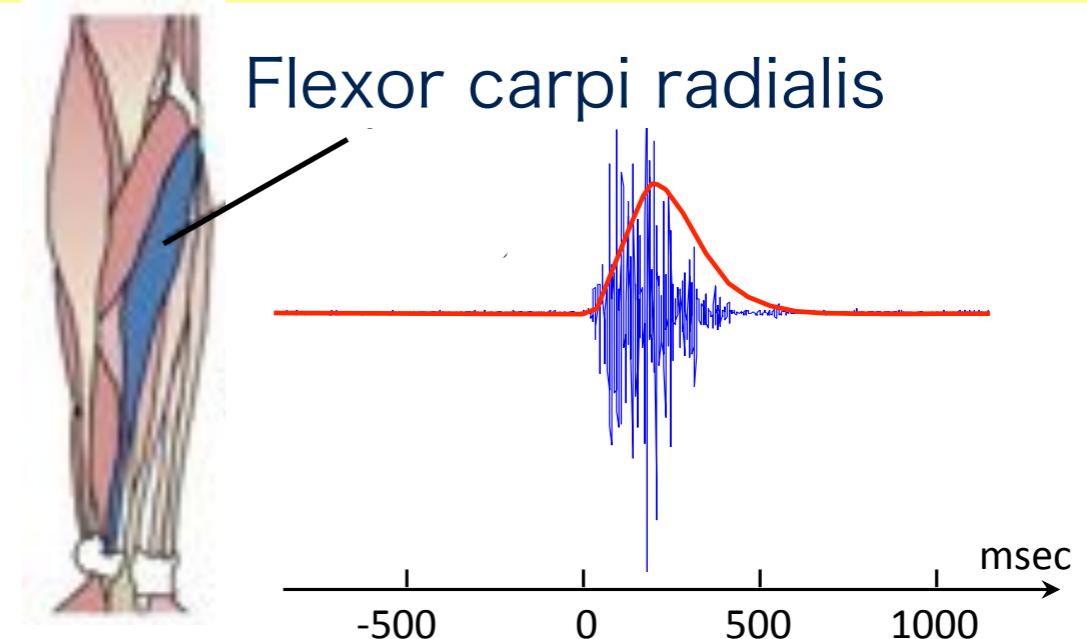
- Conventional EEG-BMI

Classify body parts

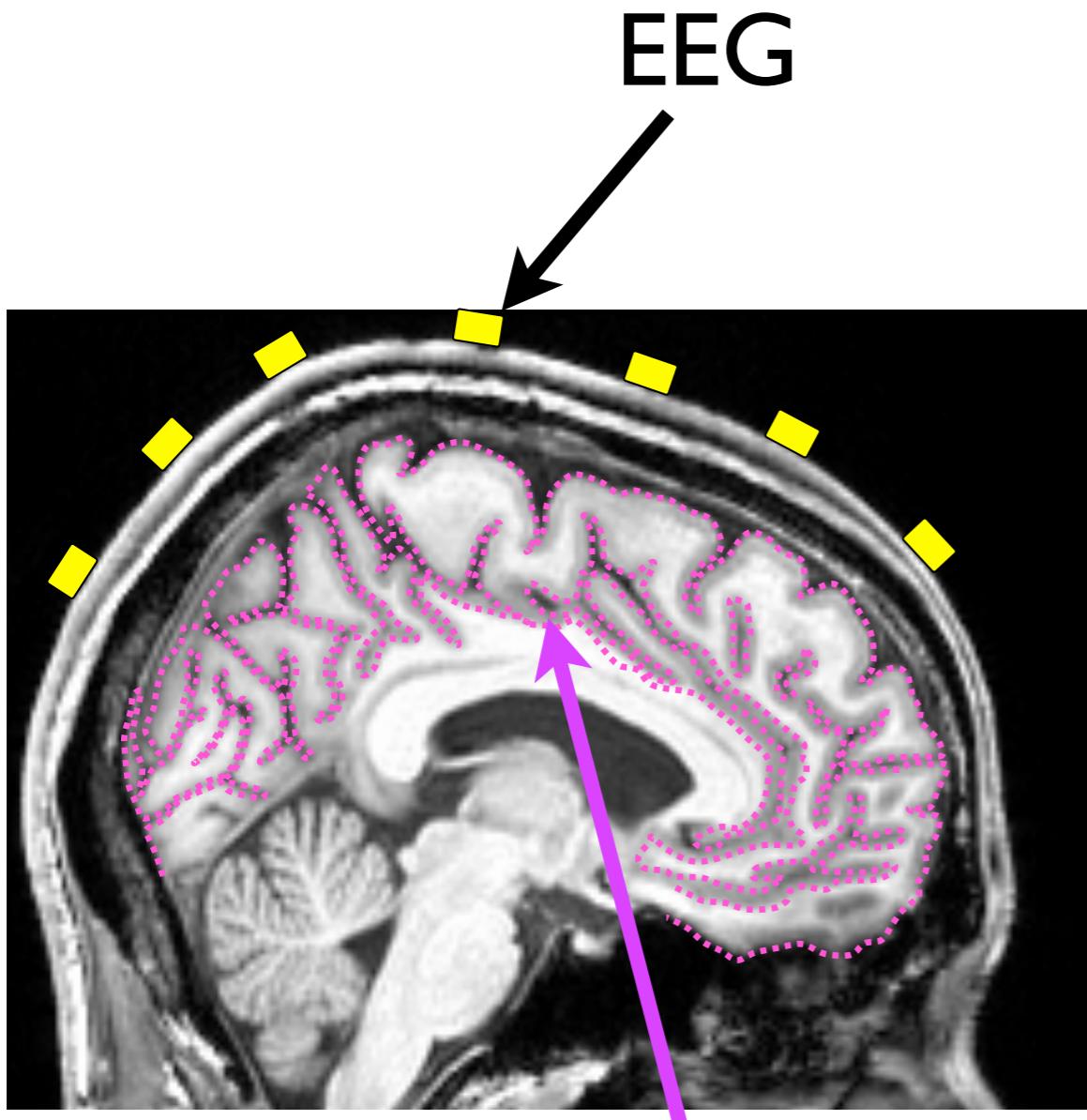


- Our method

Reconstruct muscle activity signals



Which body parts?
When?
How much force?
How long?



Current Sources

30ch EEG

VBMEG

100~200 Current sources

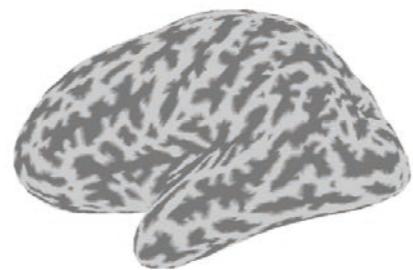
SPR

20~30 Current sources

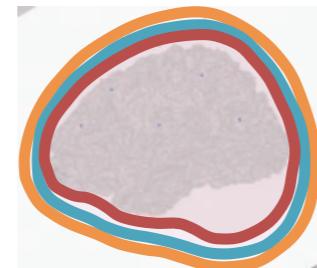
2ch EMG

Leadfield matrix

Anatomical
MRI image

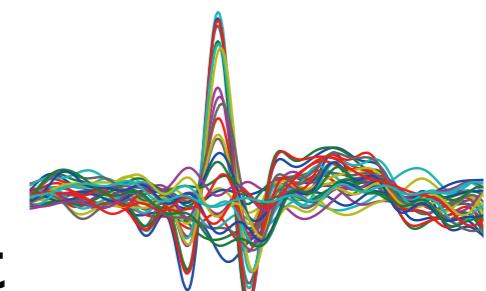


Brain cortical model

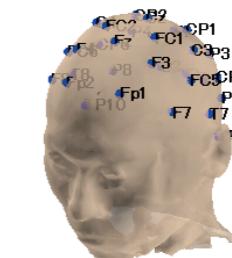


Three-layer model

EEG experiment

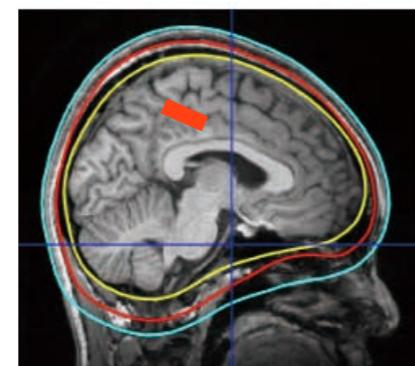


EEG signals



Electrode positions

Three layer model
(scalp, skull, CSF)



CSF: cerebrospinal fluid

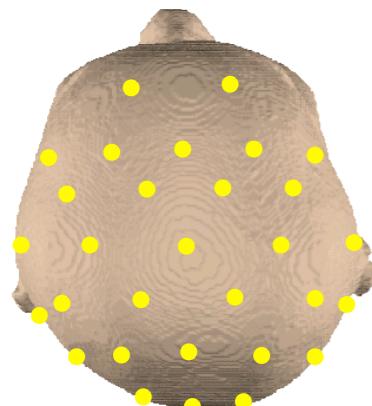
EEG electrodes
coordinate position



Current source estimation

$$B(t) = GJ(t)$$

electrodes : $\sim 10^2$



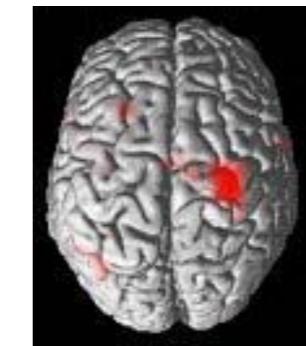
$$J(t) = LB(t)$$

current sources : $10^3 \sim 10^4$

Inverse Problem



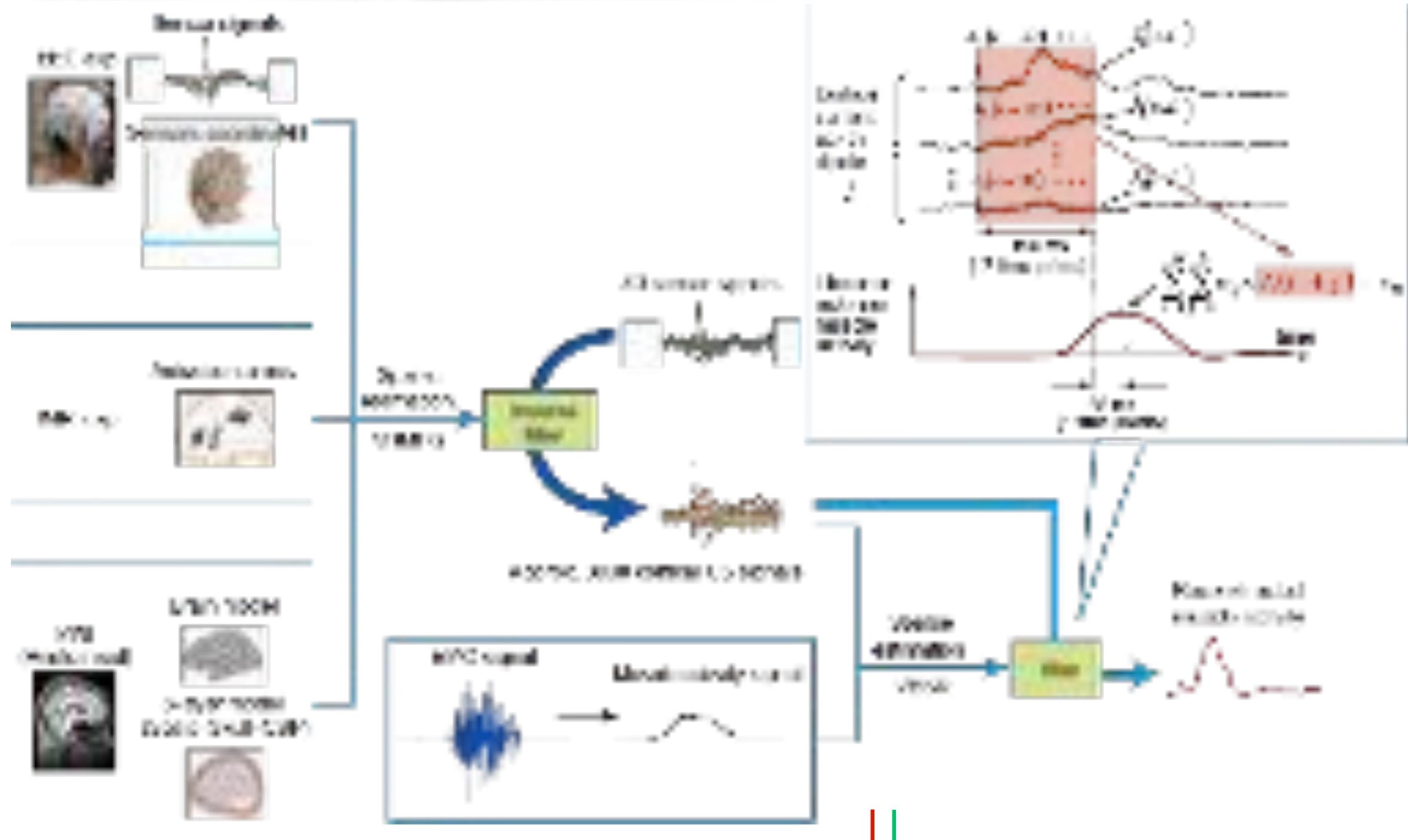
Hierarchical
Bayesian (HB)
Estimation



- Based on variational baves
- fMRI data as a prior

B: electric field, *G*: Lead Field matrix, *J*: current, *L*: inverse filter

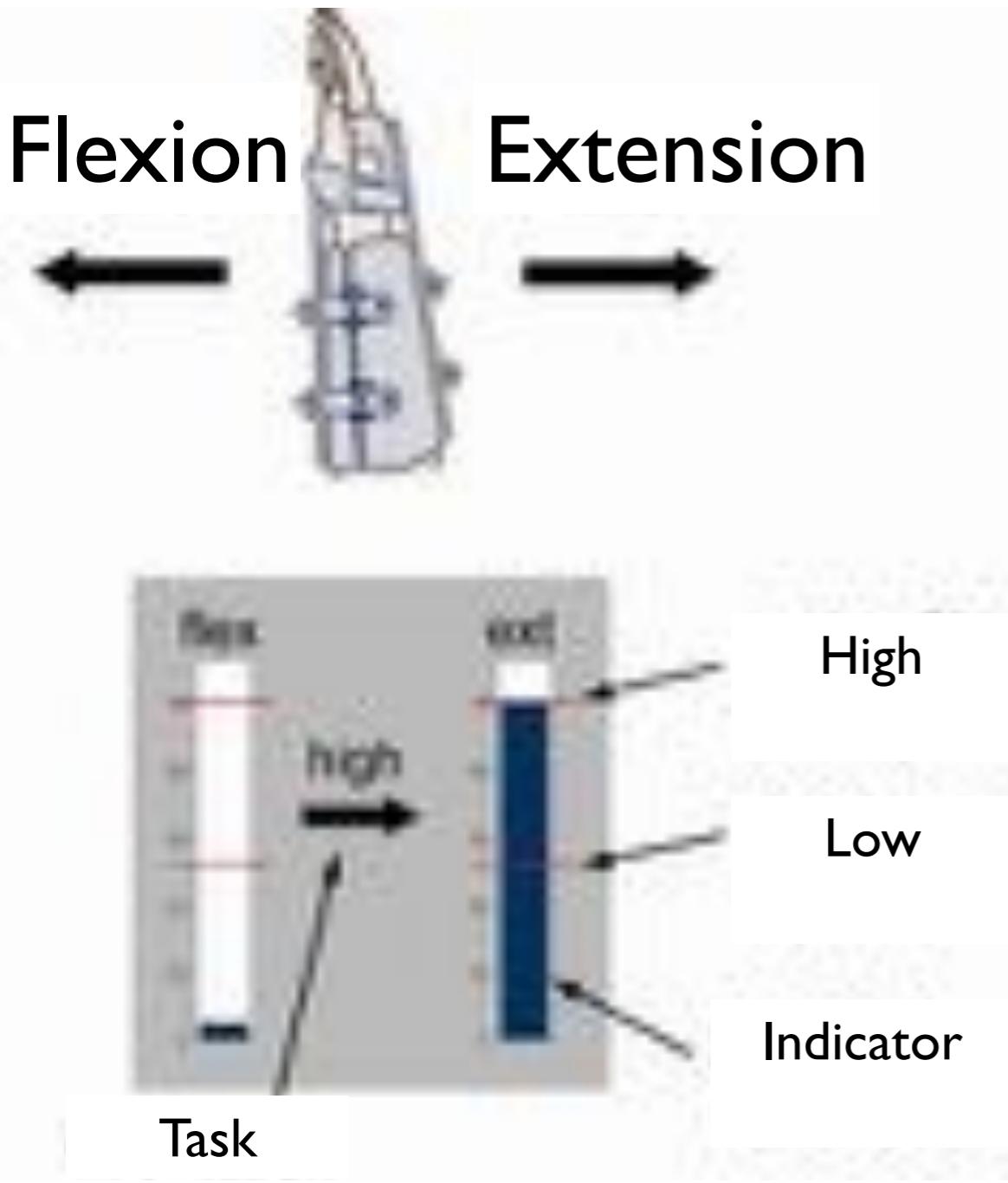
Reconstruction of muscle activity signals



Variational Bayesian multimodal encephalography
method (VBMEG)
http://www.cns.atr.jp/cbi/sparse_estimation/sato/VBSR.html
<http://vbmeg.atr>

Sparse Regression model

Isometric Contraction Exp.



Five Tasks

Flexion (High)	Extention (High)
Flexion (Low)	Extension (Low)

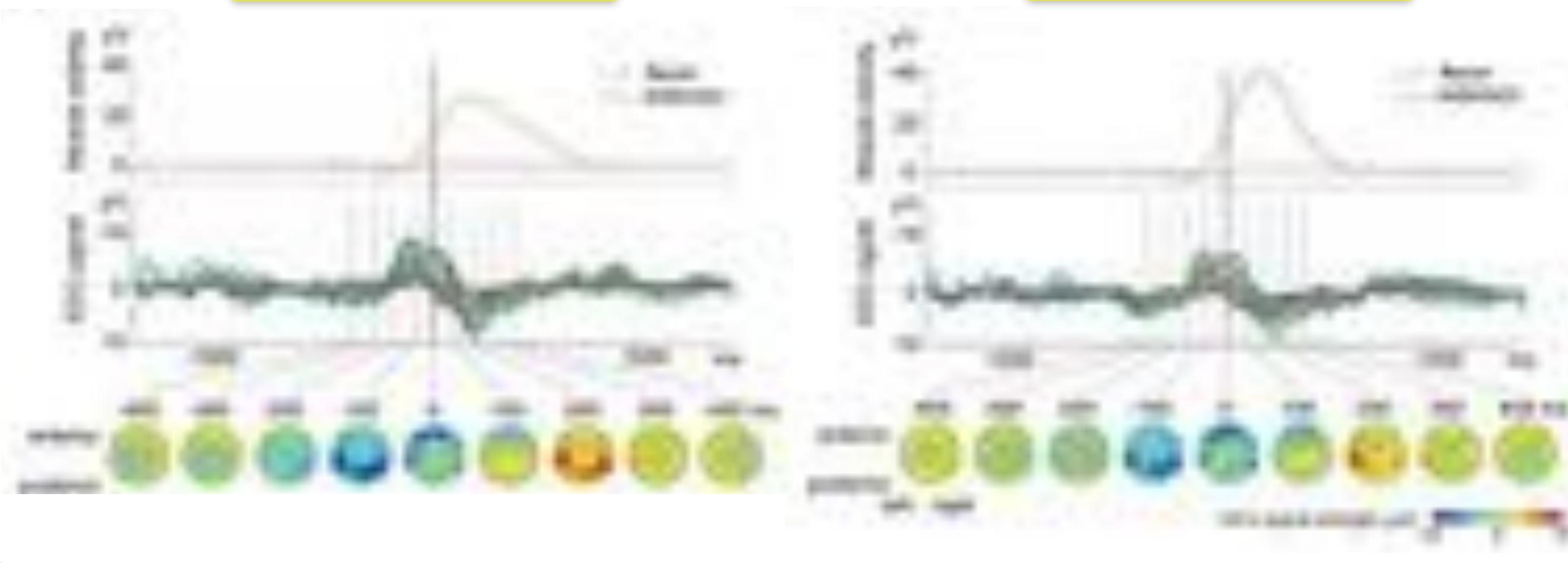
Still



EEG and fMRI activation

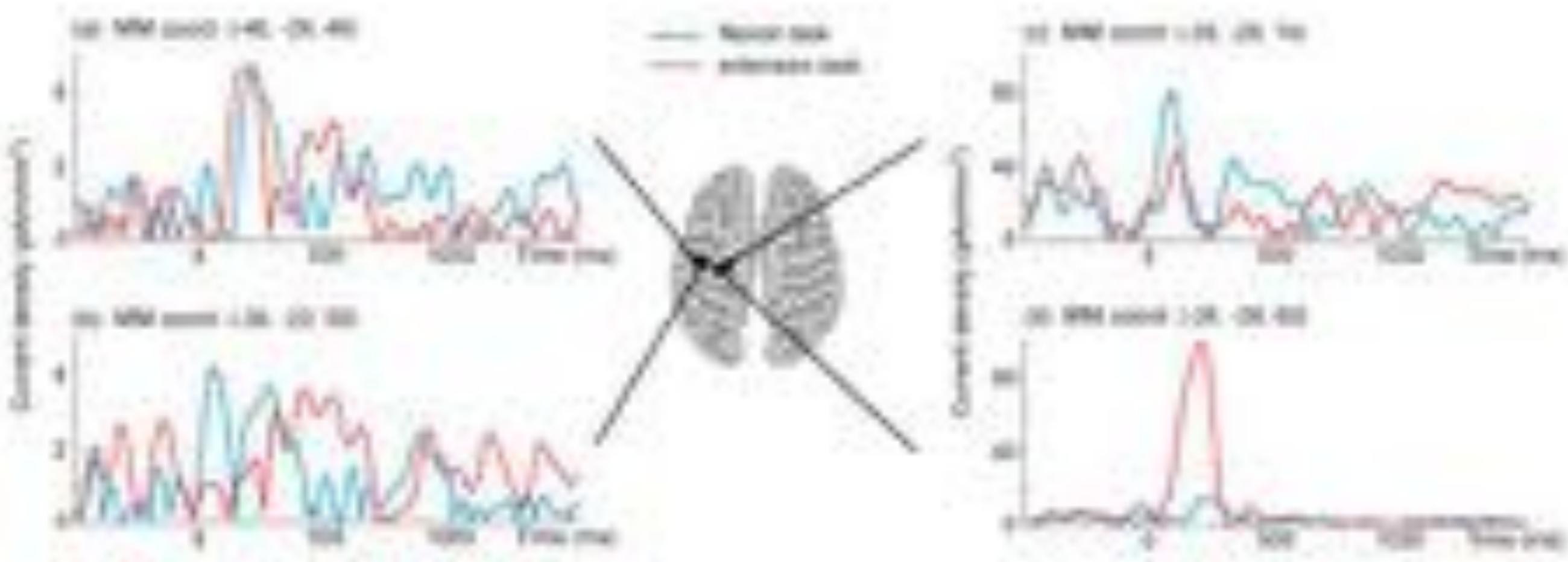
Flextion (low)

Extension (low)

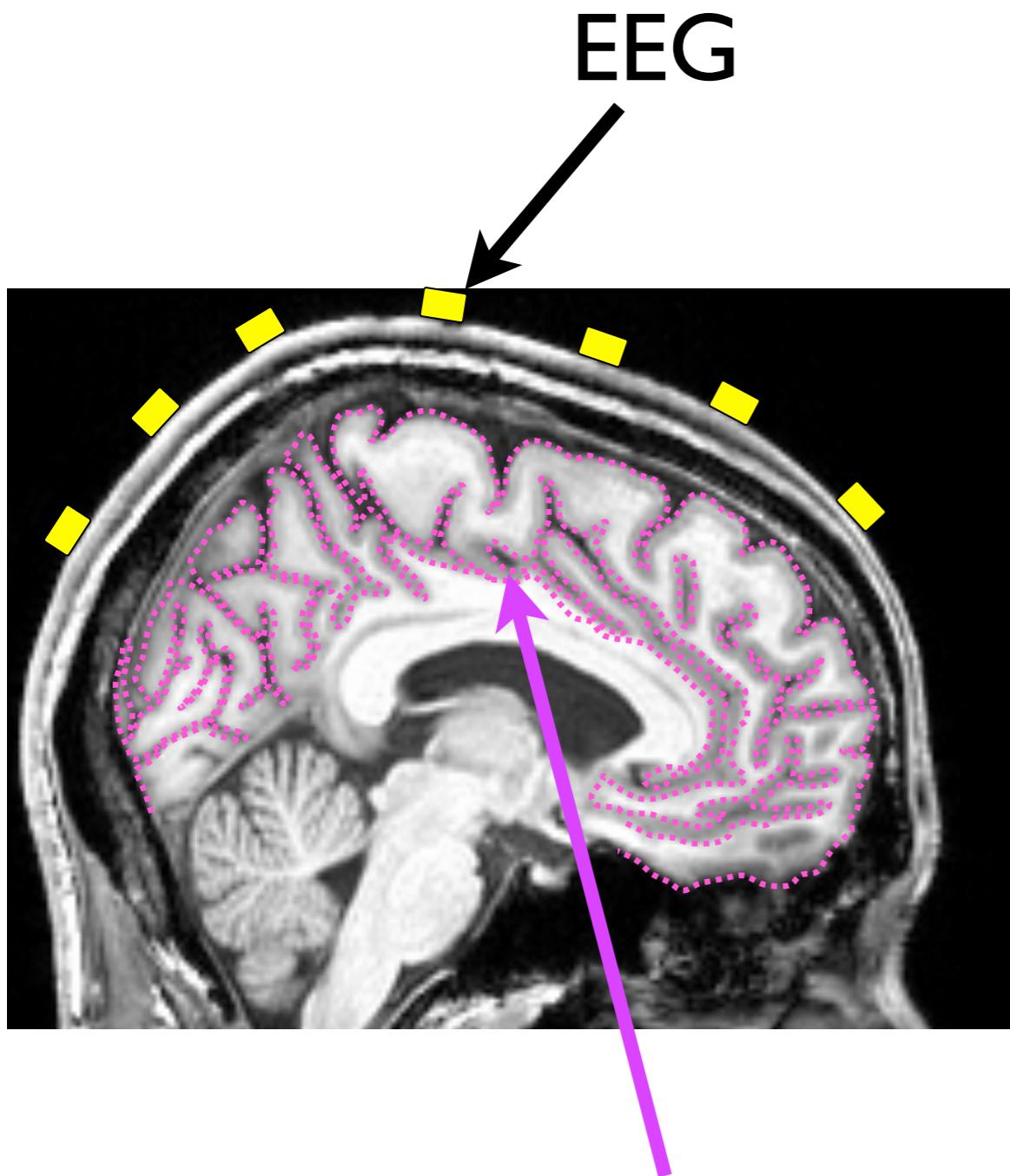


EEG is quite similar
fMRI activation is different

Current source signal wave form



Near current source pattern in different
Current source of Flexion / Extension task is different



30ch EEG

VBMEG

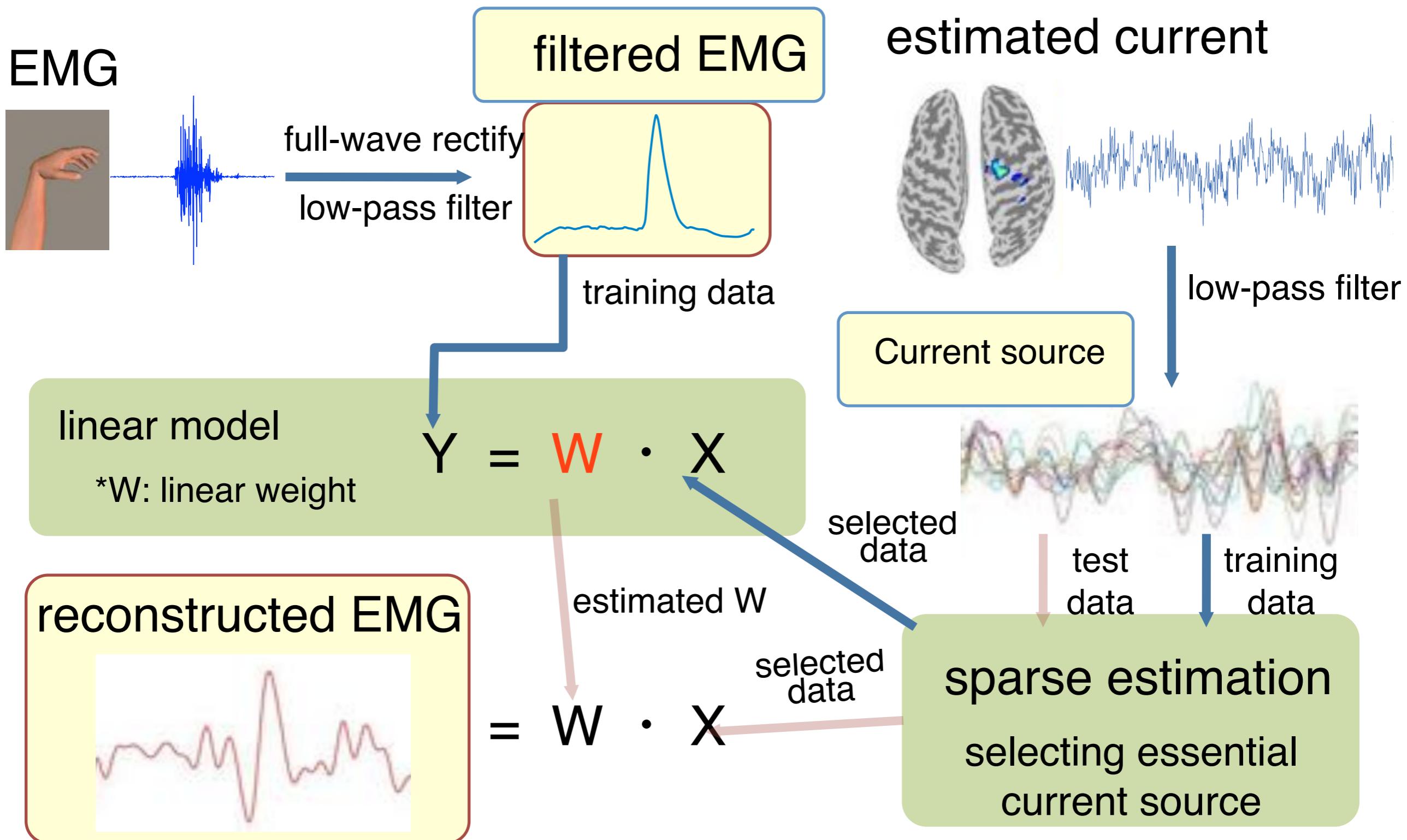
100~200 Current sources

SPR

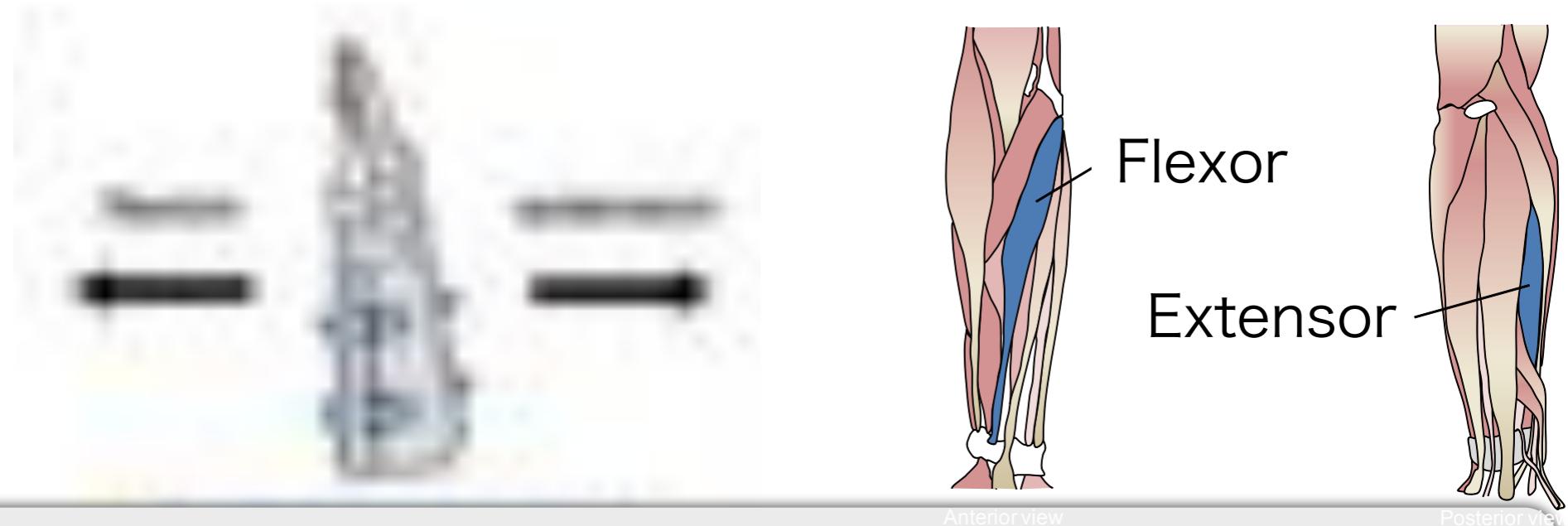
20~30 Current sources

2ch EMG

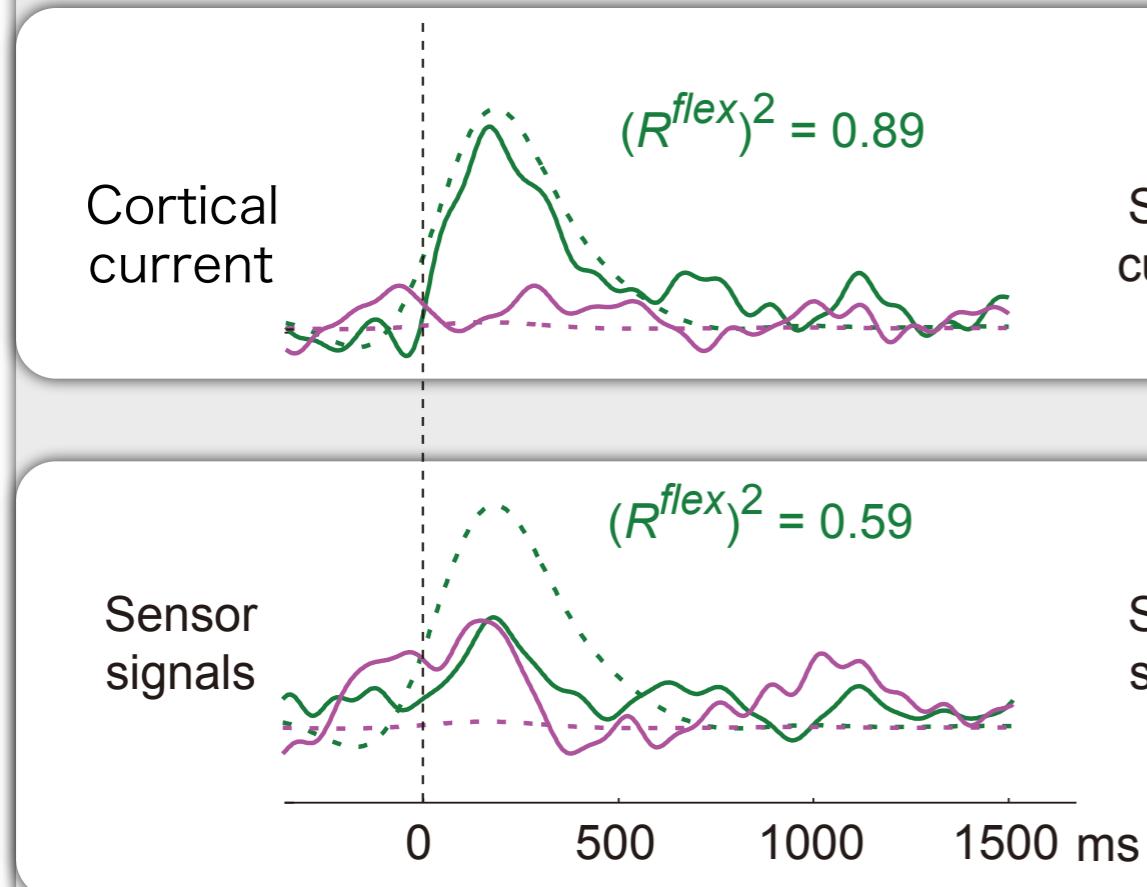
Sparse Linear Regression



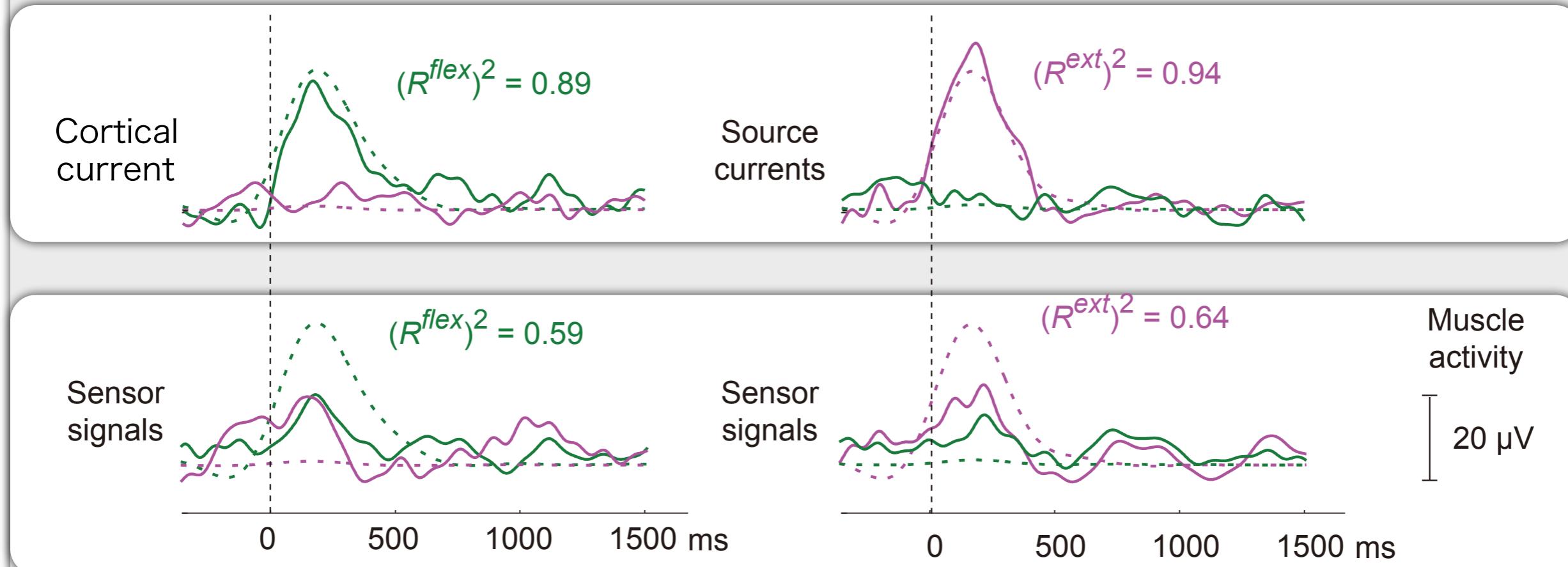
Result



task: FlexLow



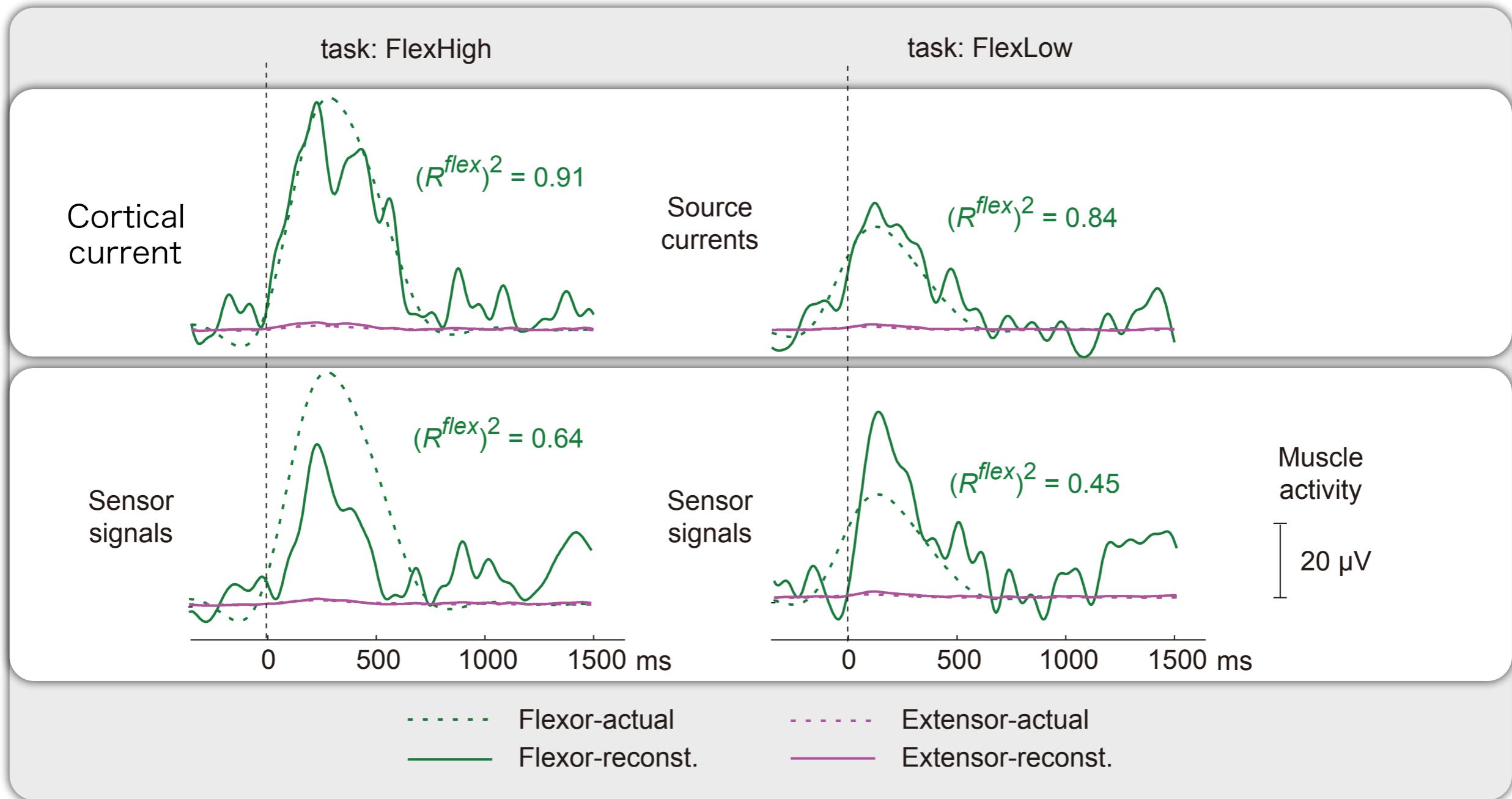
task: ExtLow



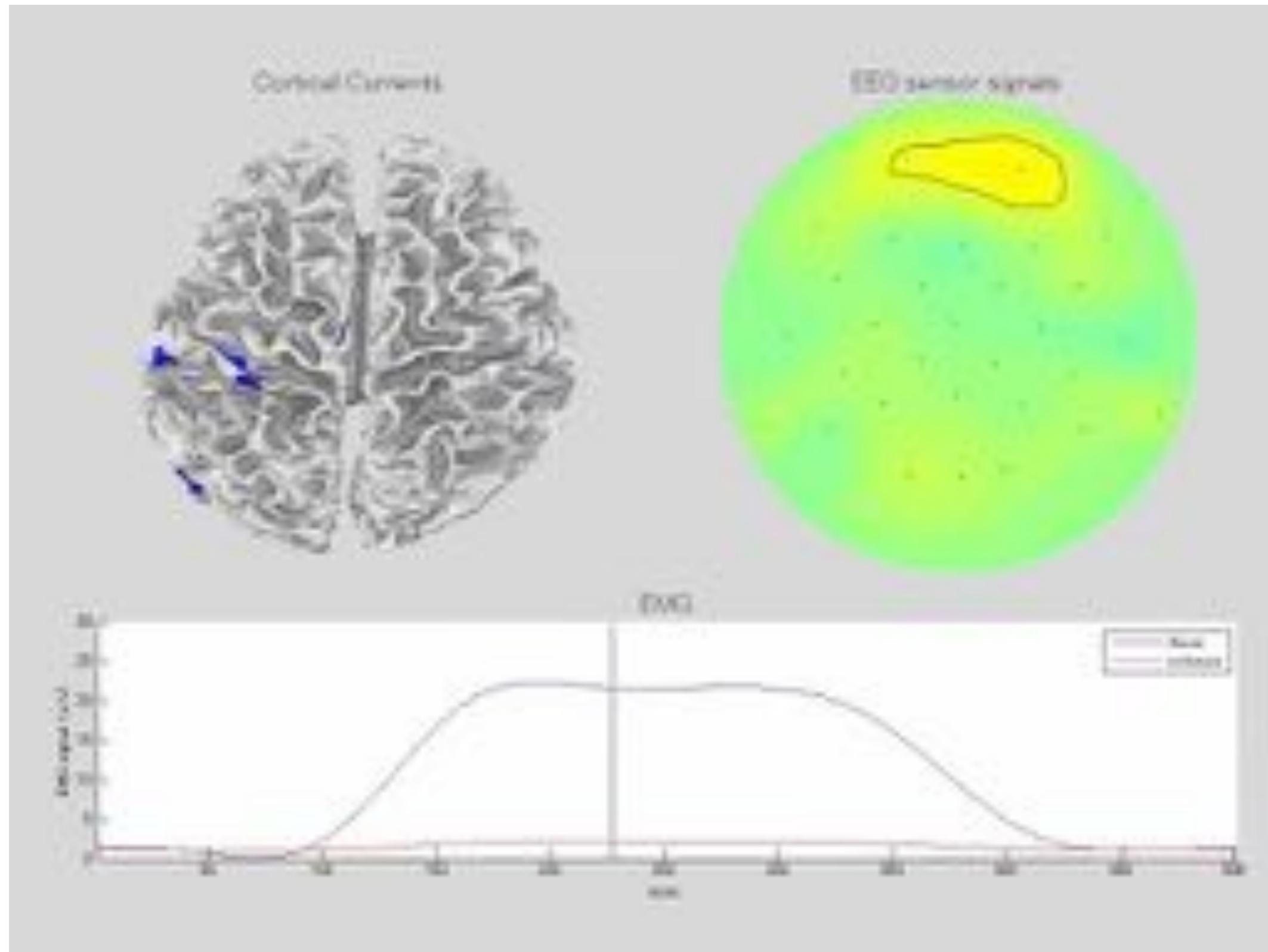
Flexor-actual
Flexor-reconst.

Extensor-actual
Extensor-reconst.

Result: Force difference



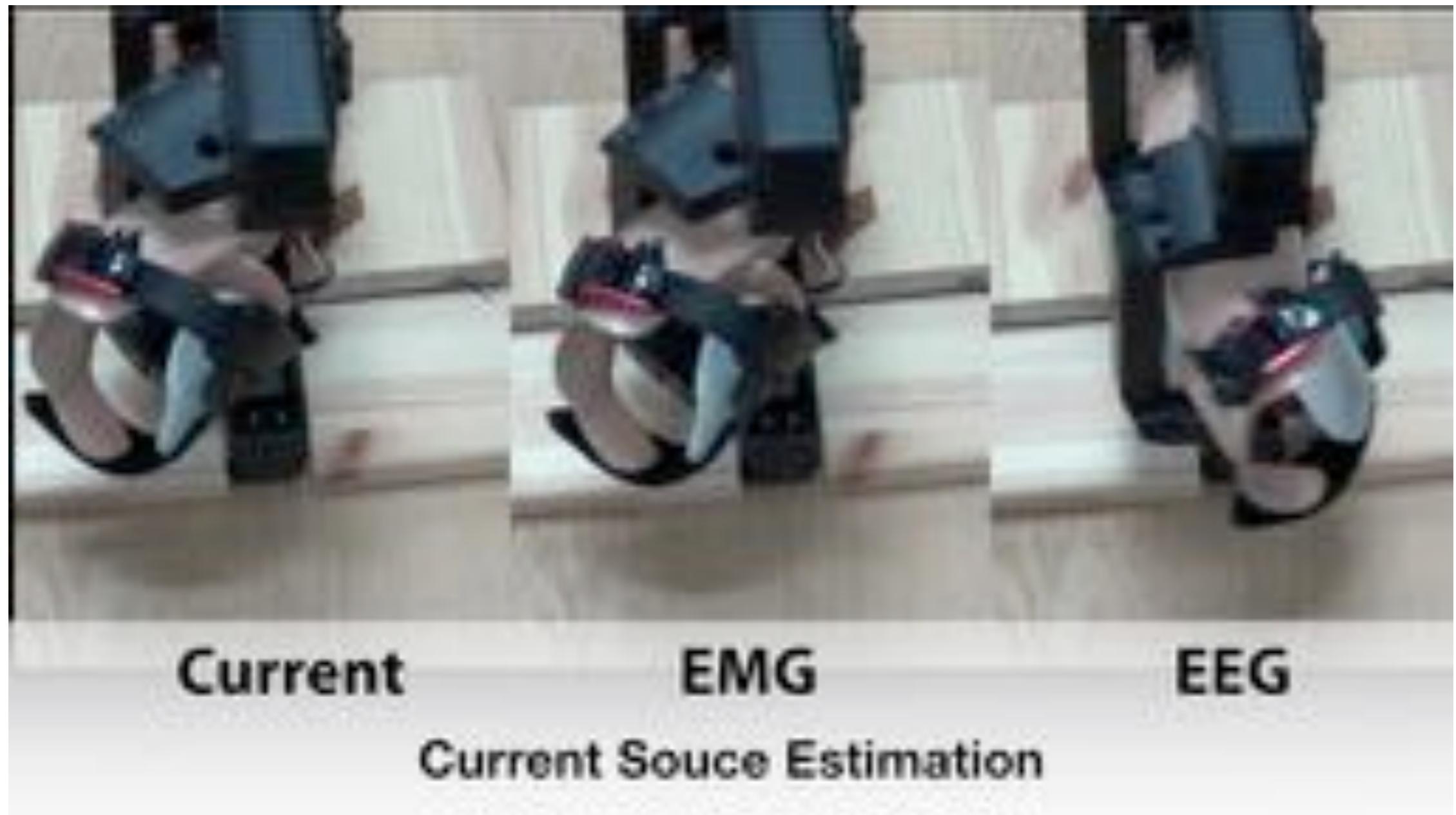
Brain activity pattern



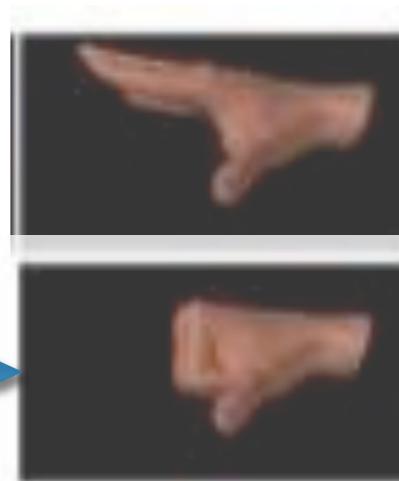
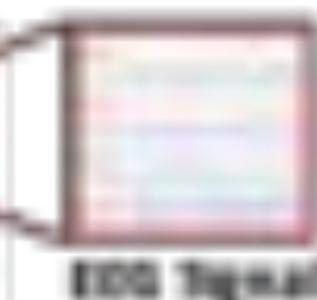
EMG-based poser assist device ver. I



Toward an EMG-driven brain-machine interface robot

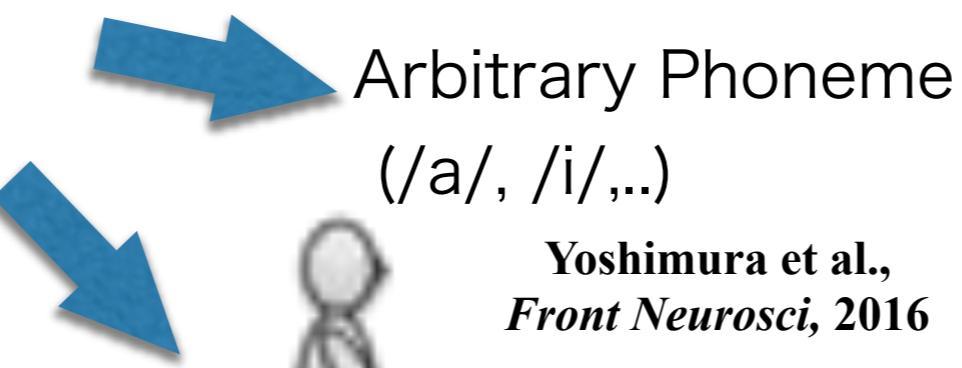


Usabilities of EEG cortical current sources



Grasp
vs.
Open

Yoshimura et al., *BCI meeting 2016*



Arbitrary Phoneme
(/a/, /i/...)

Yoshimura et al.,
Front Neurosci, 2016



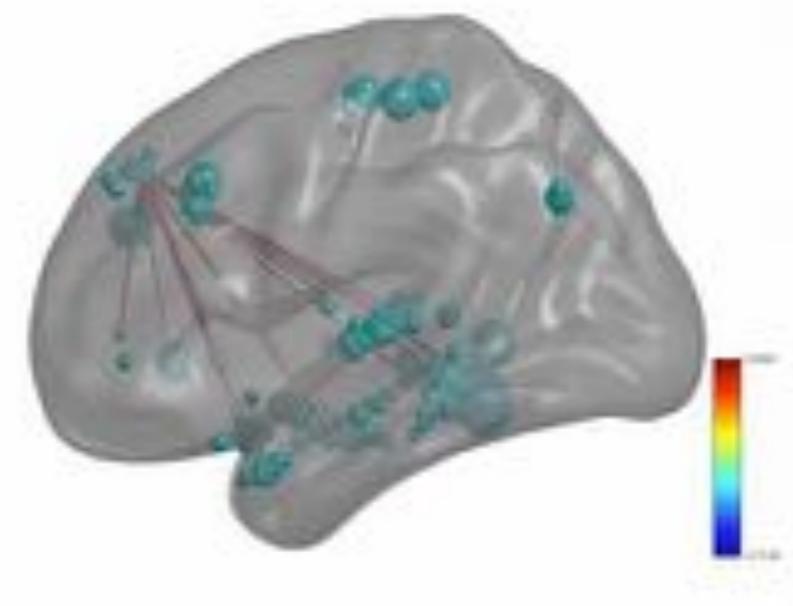
Gait intention

Mejia Tobar et al.,
Front Neurosci, 2018

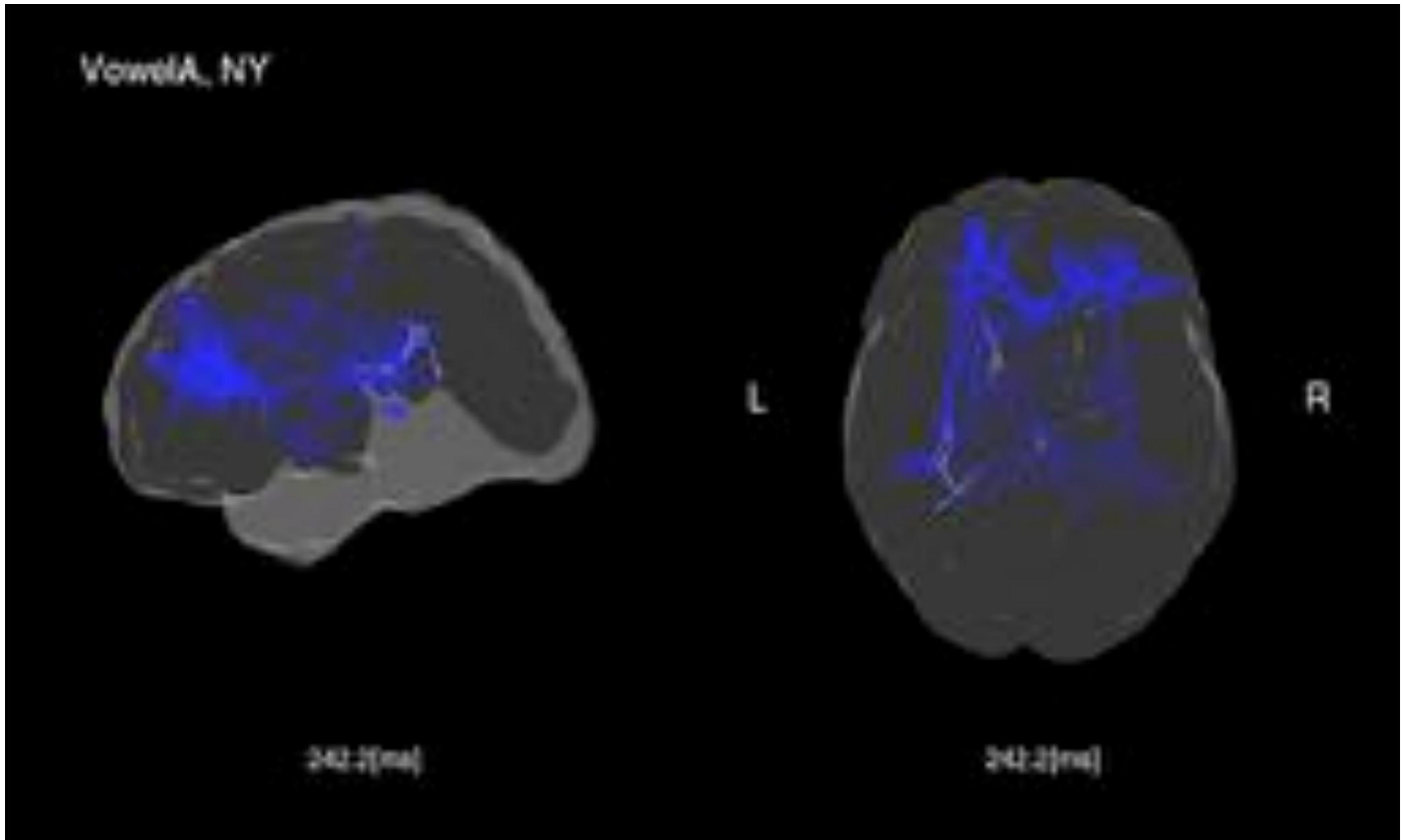


Emotion

Yoshimura et al.,
Acta IMEKO, 2017



Brain signaling visualization



EMG based
Interface



Charles et al. 2004



Choi et al 2006

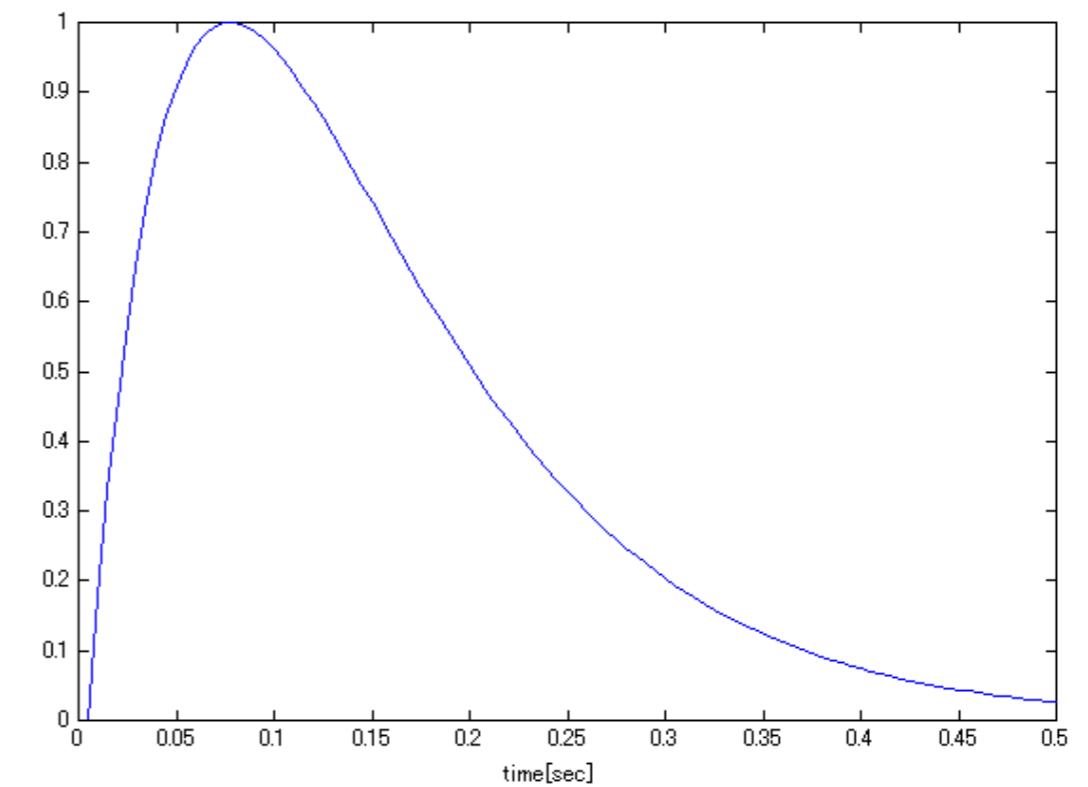
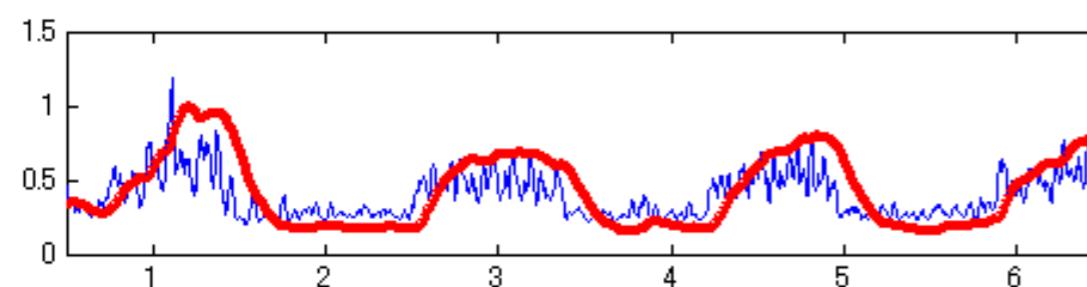
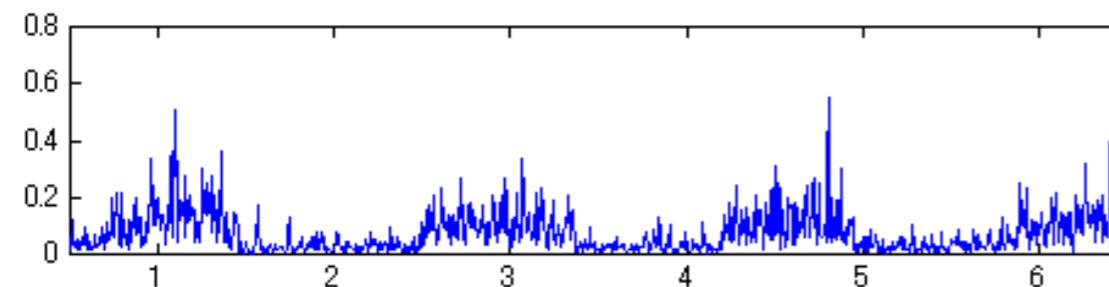
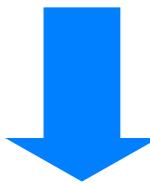
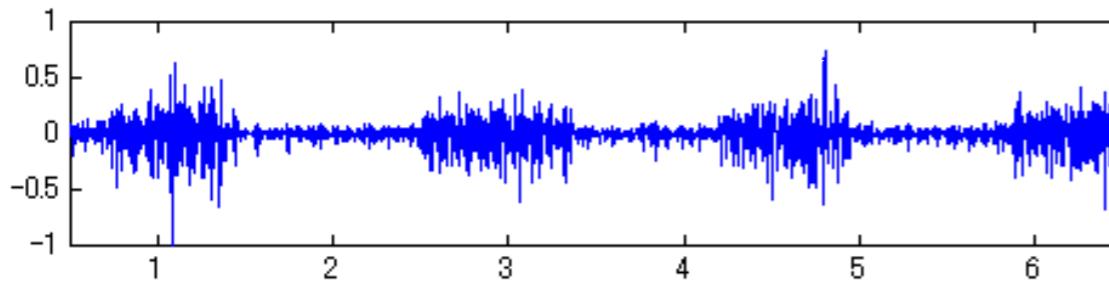


Koike et al. 2006



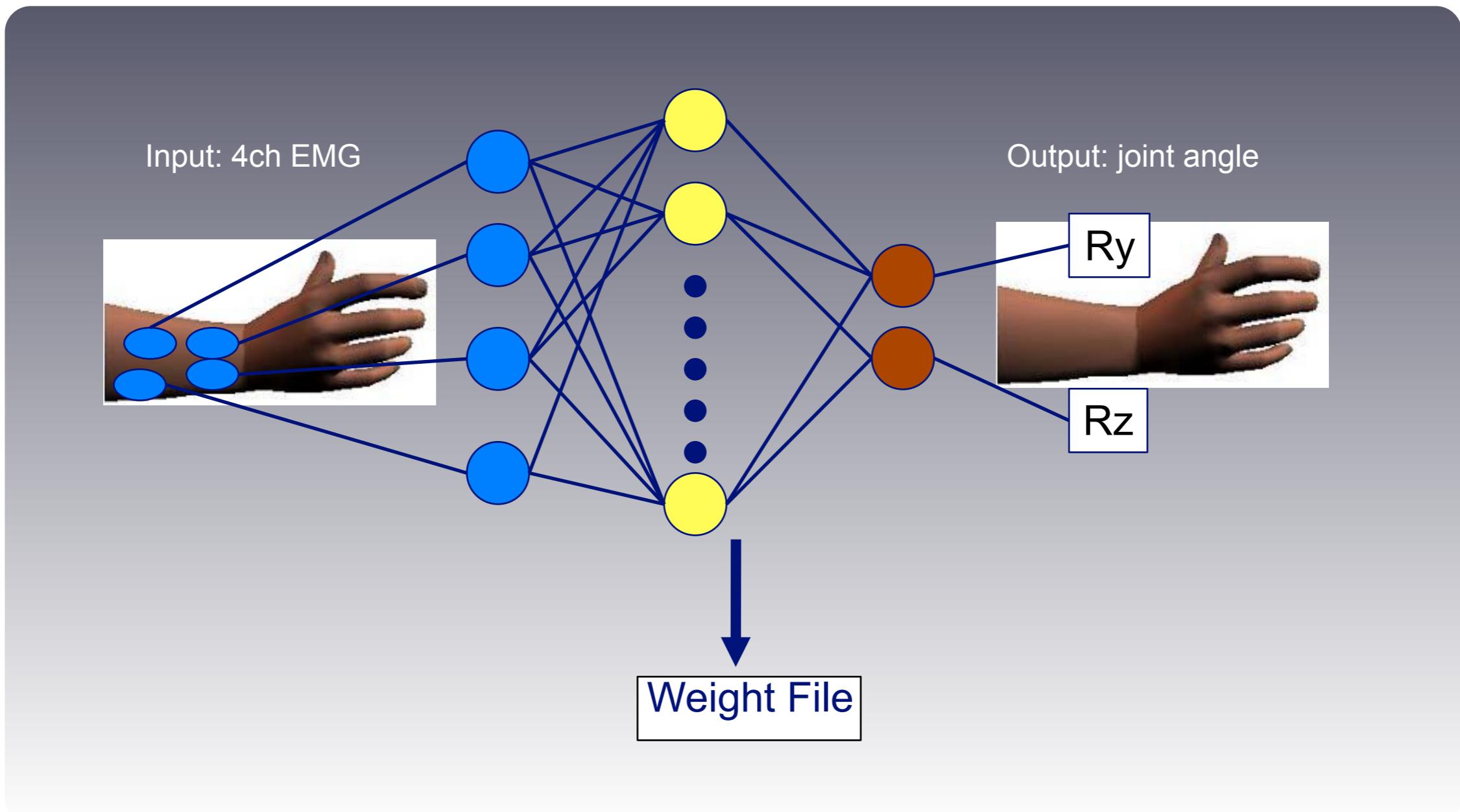
Shin et al. 2006

Signal Processing



Impulse response

Artificial Neural Network



Summary

- Spatial resolution of EEG are computationally increased by cortical current estimation method based on variational Bayesian algorithm (VBMEG)
- Muscle activity time-series were successfully reconstructed from EEG cortical current signals, and the reconstructed signals were able to control EMG-based exoskeleton robots.
- The cortical current estimation method can be applied to decode other brain information e.g. speech, emotion...
- Network analysis of the cortical current signals will provide us interesting insights to understand information processing in the brain (Thursday's topic)