Introduction to Electrophysiology

Dr. Kwangyeol Baek

Martinos Center for Biomedical Imaging

Massachusetts General Hospital

Harvard Medical School

2018-05-31s

Contents

Principles in Electrophysiology

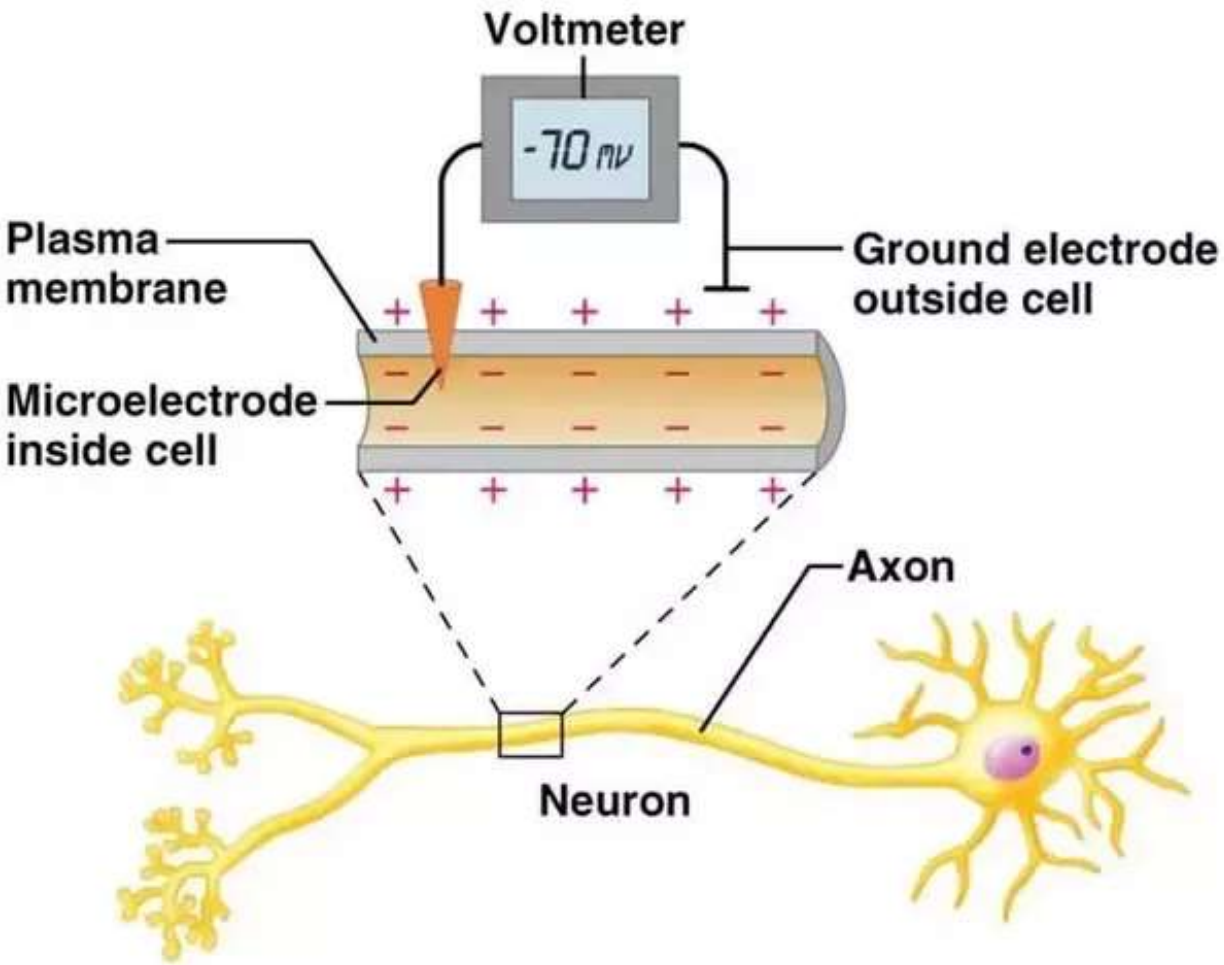
Electrophysiology

- To investigate the electrical properties of biological cells and tissues.
  - Nervous system, Heart (ECG), Muscle (EMG), etc.
  - Usually measuring electrical potential (in mV or μV).

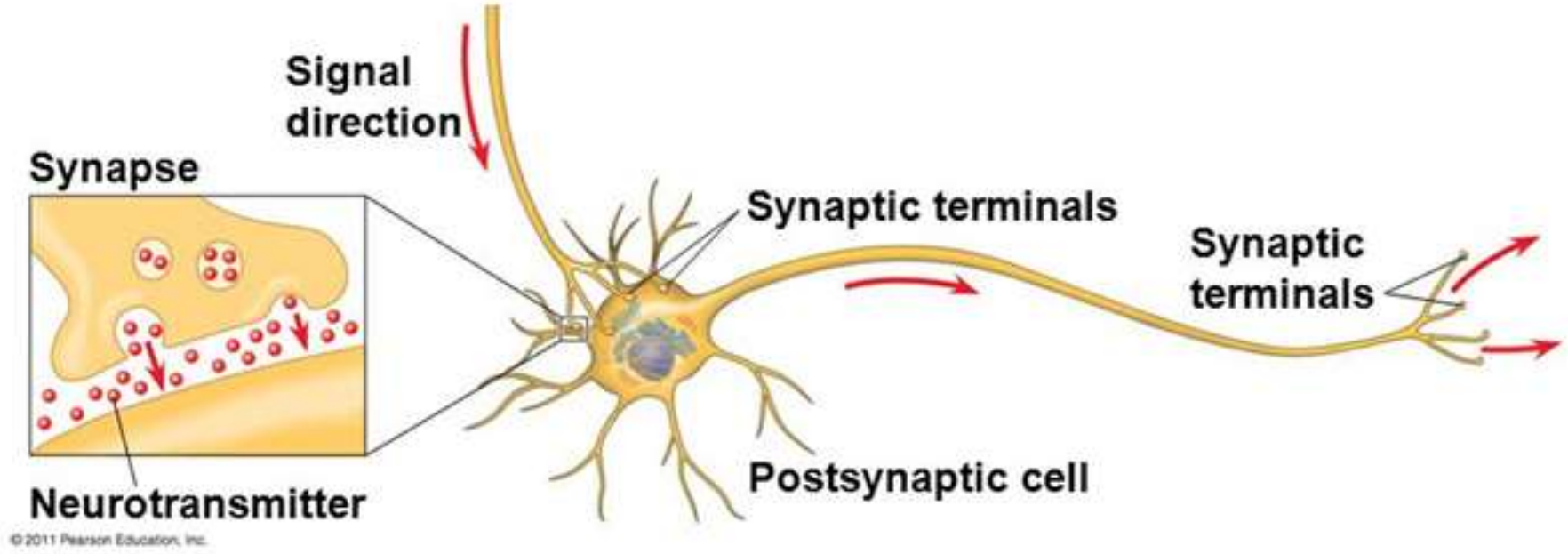
- Electrophysiology study in neuroscience
  - In vitro : cultured neurons or brain slice.
  - In vivo : living animal.

Electrophysiology of Neuron

- **Membrane potential**: Electrical potential difference across the cell membrane.



Electrophysiology of Neuron



Post-synaptic potential

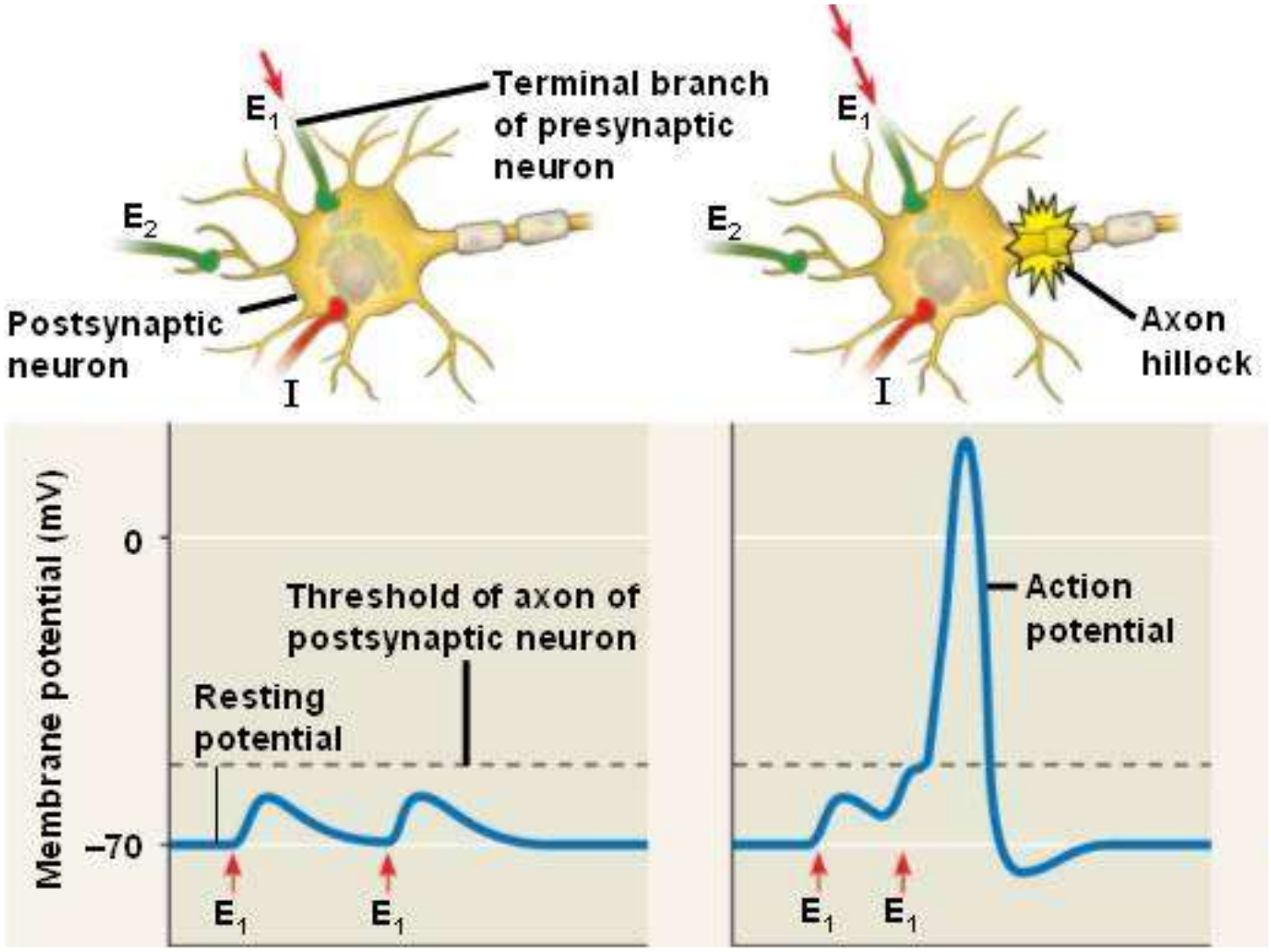
- Synaptic input
- Neurotransmitter-gated ion channels
- Varying amplitude and shape

Threshold

Action potential ("Spike")

- Cellular output
- Voltage-gated ion channels
- Fixed response

Electrophysiology of Neuron

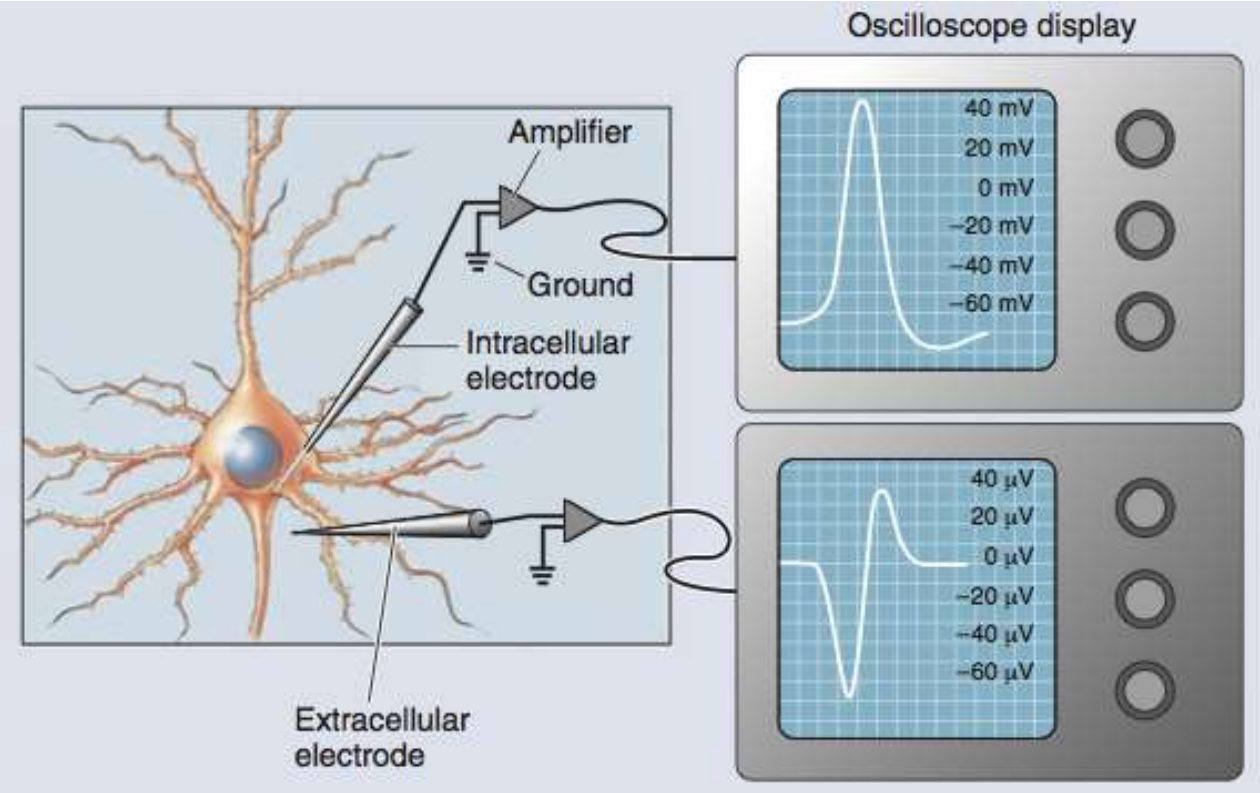


- **Synaptic inputs** are summed at cell body (axon hillock).
- **Action potential** occurs when the membrane potential reached the threshold. (All-or-nothing behavior)
- Action potential propagated to axon terminal, and then neurotransmitter is released to next neurons.

Intracelluar vs. Extracelluar recording

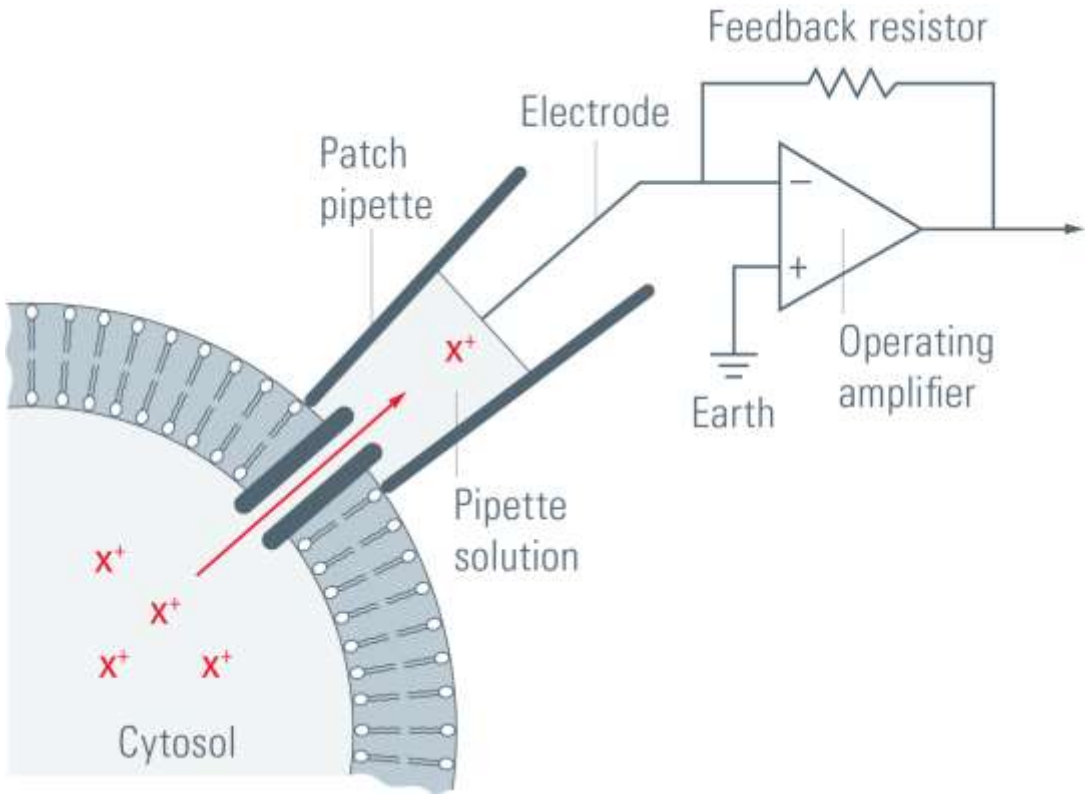
- **Intracelluar recording**
  - Electrode is placed into a single cell.
  - Measuring voltage or current across the membrane of a cell.

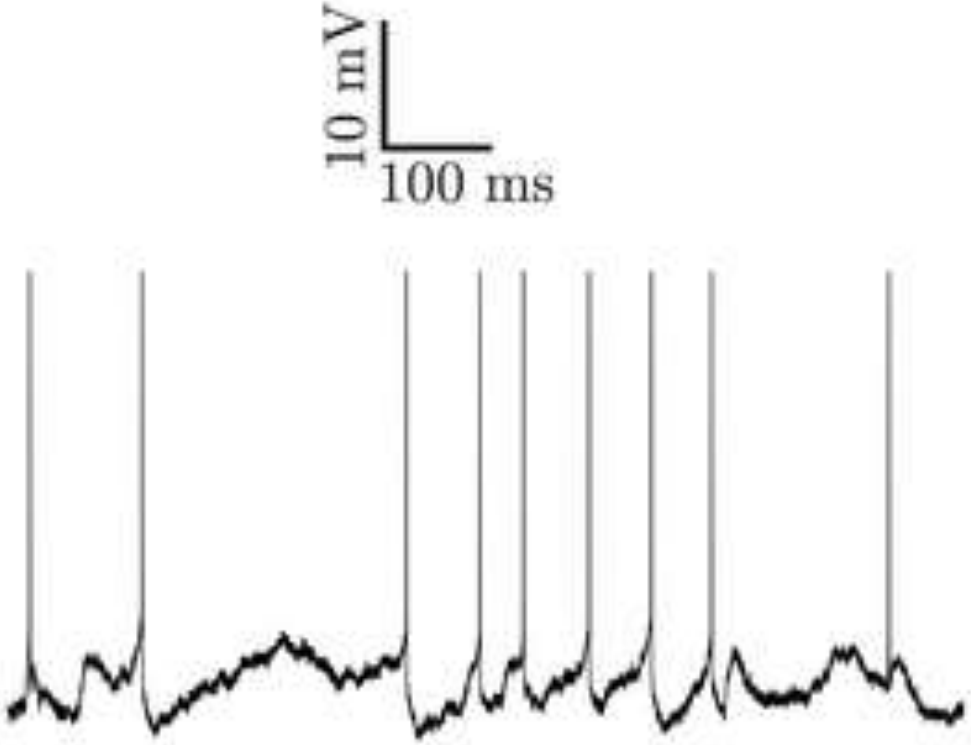
- **Extracelluar recording**
  - Measuring ionic current and voltage in extracellular space.
  - Summed activity from many neurons.



Intracellular recording

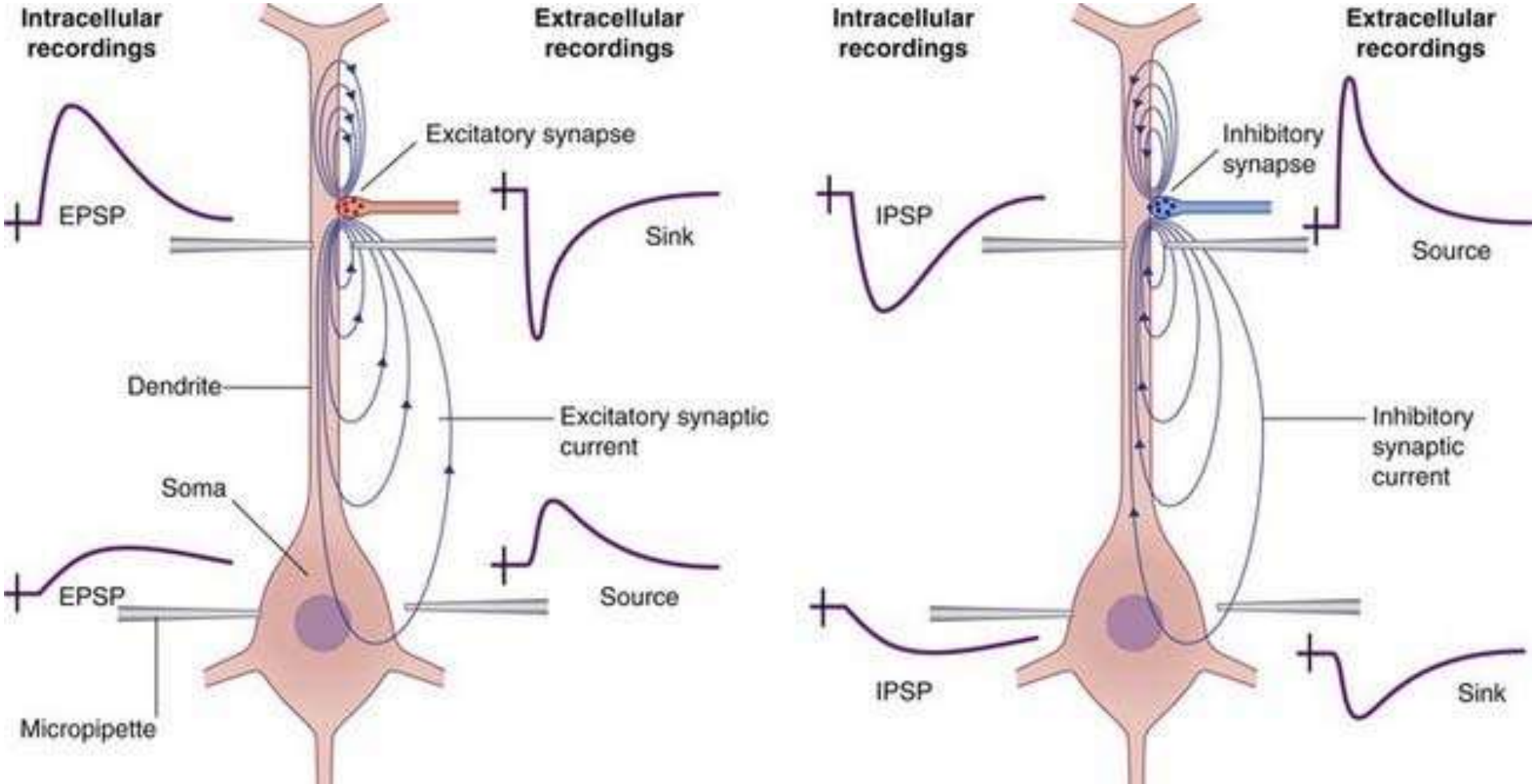
- Placing the electrode into a single cell.
- Direct measurement of the membrane potential.





Extracellular recording

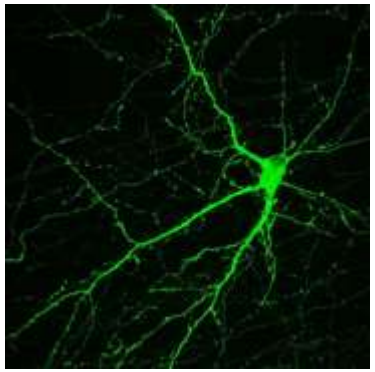
- Measuring electrical potential or current around the cell.



Techniques in Electrophysiology

Techniques in Electrophysiology

- Intracellular recording



single cell

- Extracellular recording
  - Single unit activity
  - Multi-unit activity (MUA)
  - Local field potential (LFP)

neuronal population

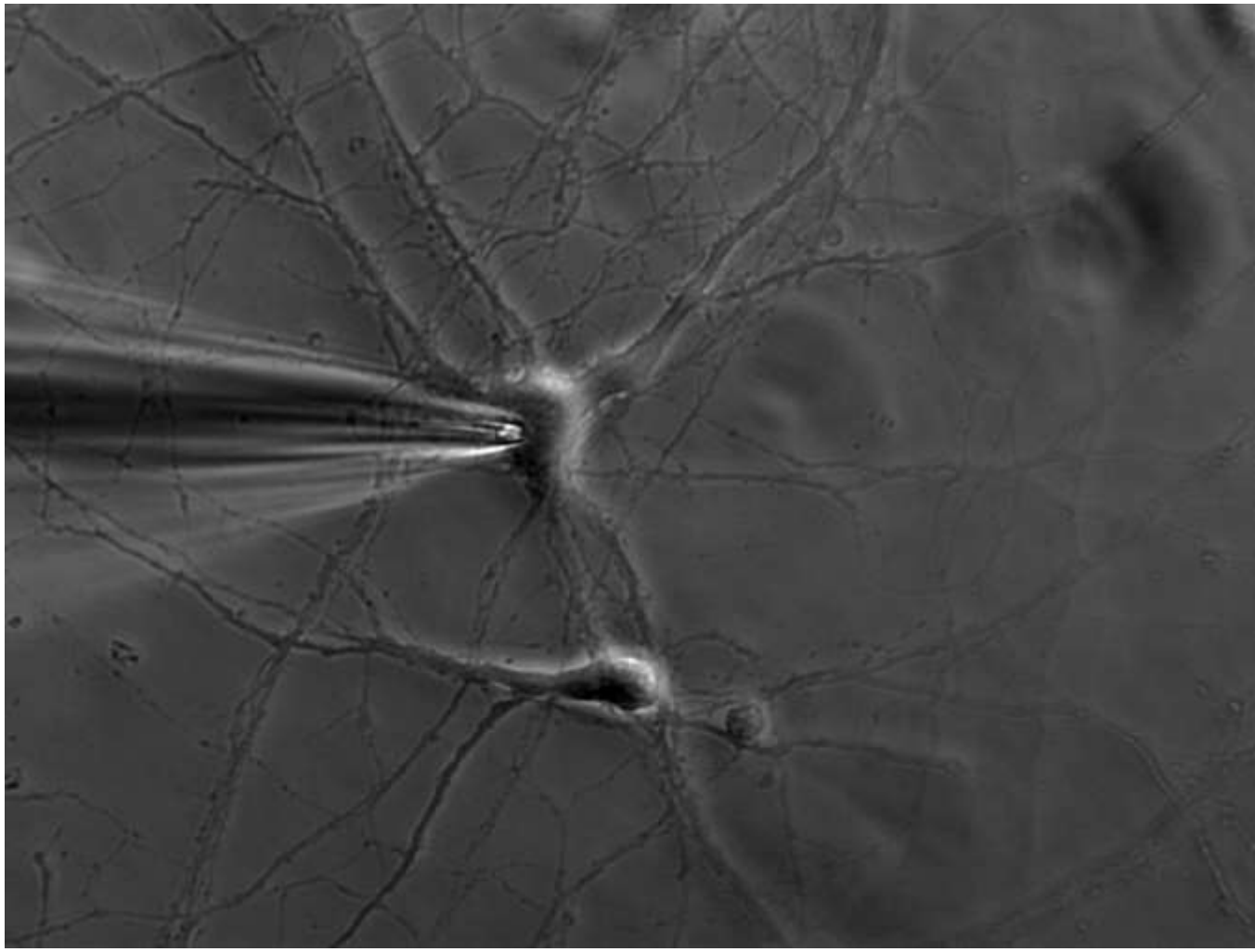
- EEG / EcoG

l areas

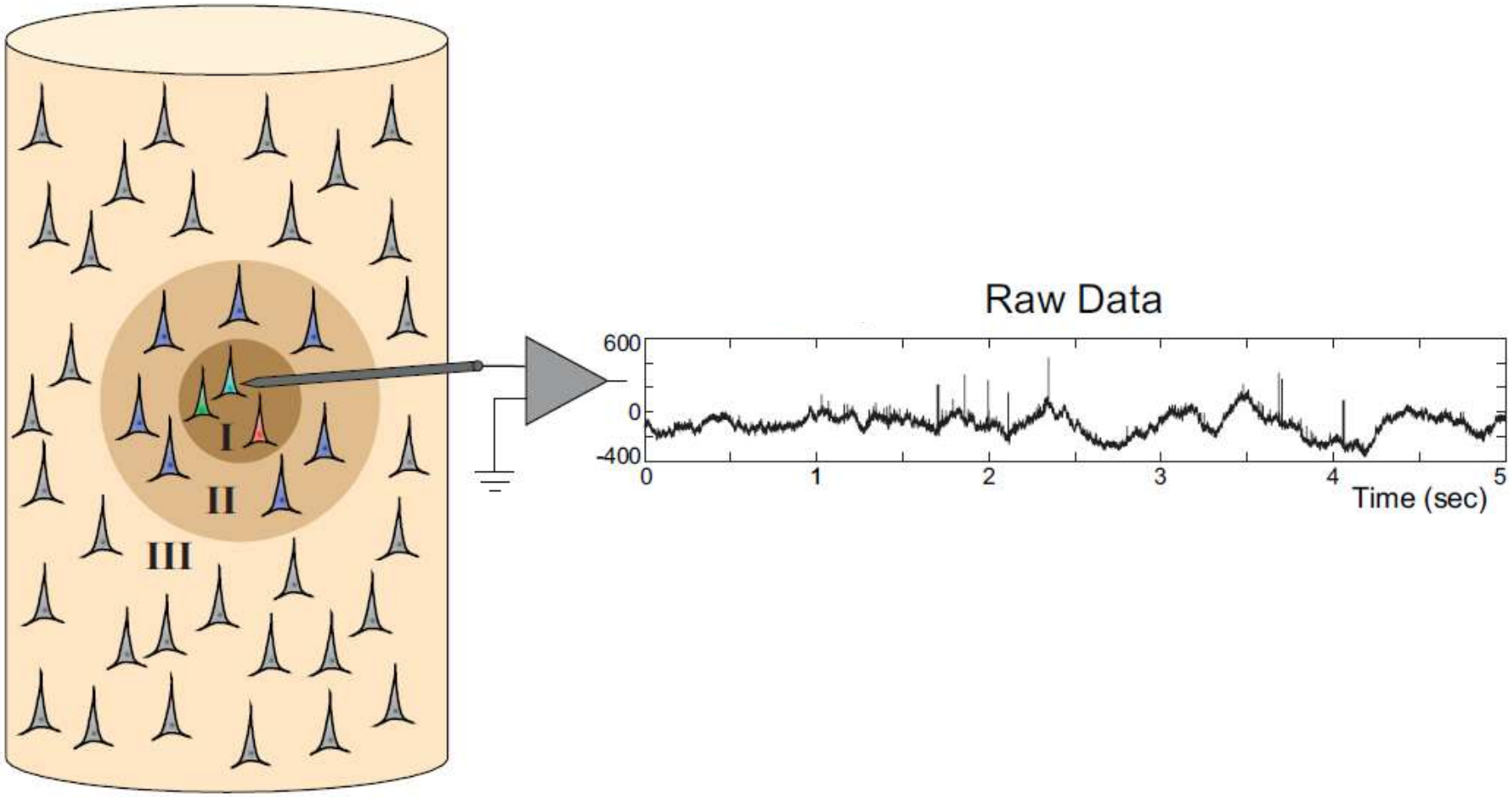
Intracellular recording

- Glass micropippet
  - Tip diameter of 50~500 nm
  - Impedence of 10~500 MΩ

- Intracellular amplifier
  - DC-amplifier with a large input resistance (~10^{11} Ω)



Extracellular recording



Extracellular recording

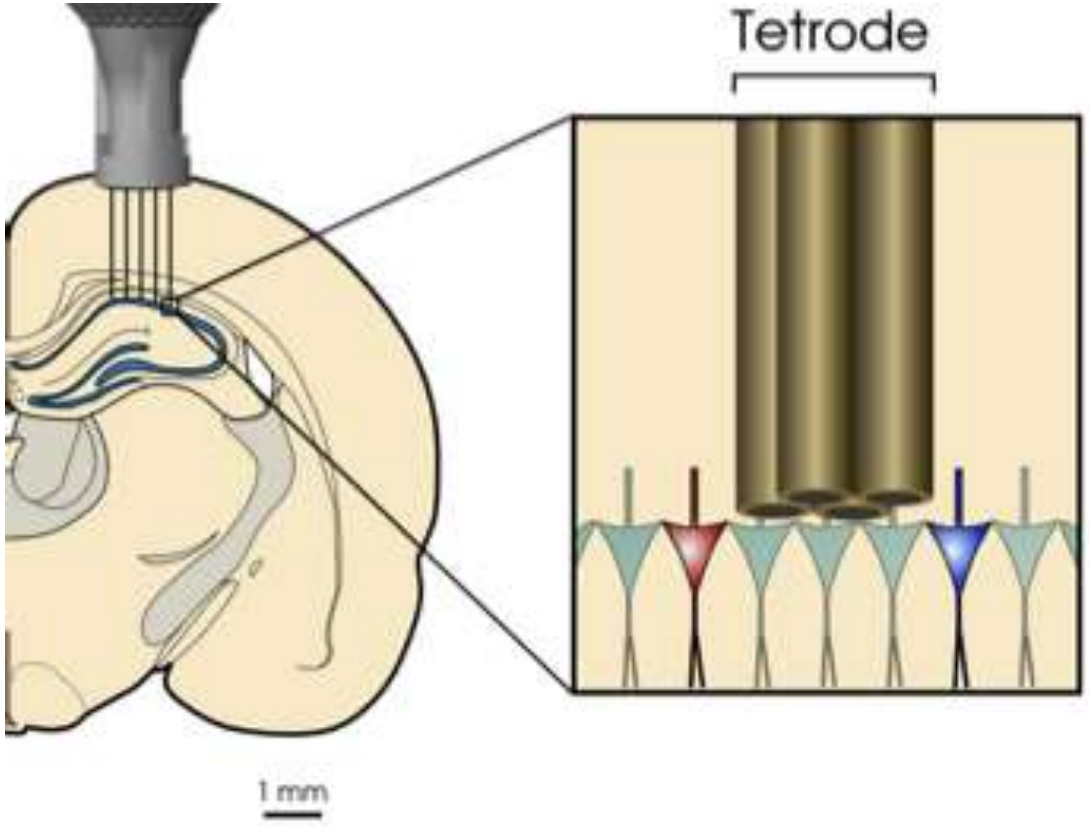
- Extracellular recording = (fast) spike acivity + (slow) field potential
  - Both types of activity were simulataneoulsy acquired and separated with bandpass filters.

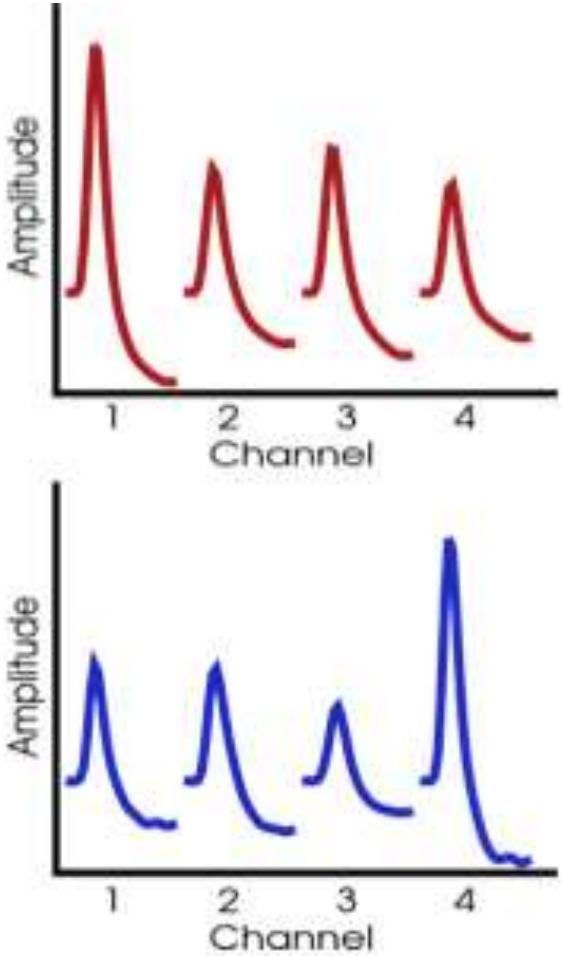
- **Spike acitivity**: Action potential in neurons (~ 1 ms = 1000 Hz)
  - **Single unit activity**: Identification of individual neurons with features in the spike shape.
  - **Multi-unit activity**: Unidentified sum of spike activity from nearby population of neurons.

- **Local field potential**: Synchronized synaptic inputs (< 300 Hz)
  - Electrical field potential in local extracellular celluar space generated by slow synchronized currents (mostly from post-synaptic current)

Single unit activity

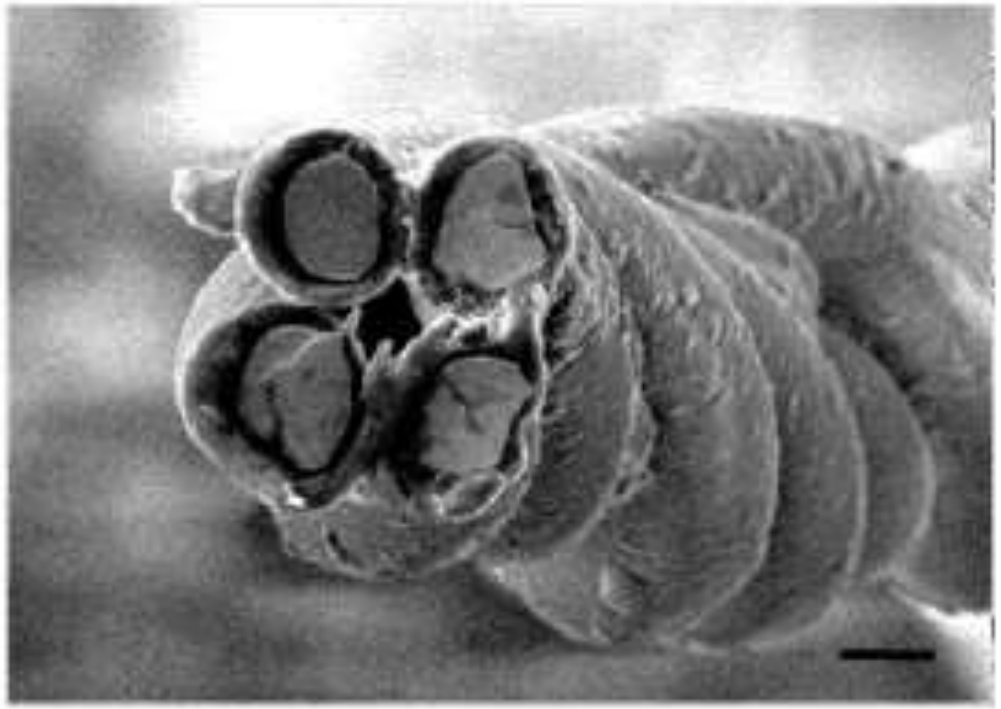
- Identifying individual neurons: Tetrode + Spike sorting





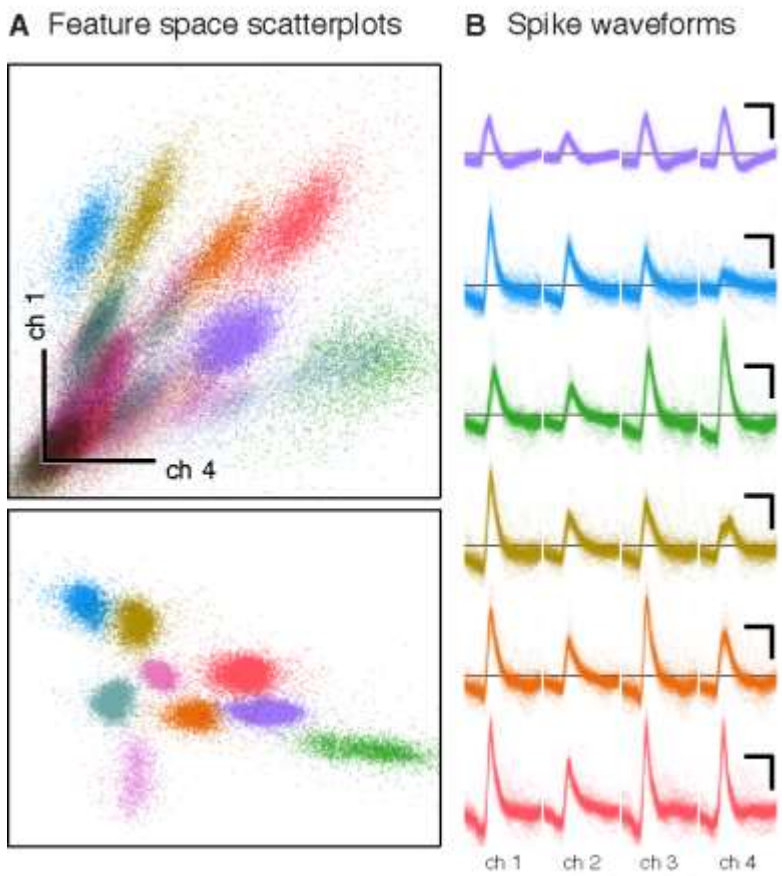
Single unit recording

- Tetrode
  - a bundle of four microwire electrodes.
  - Impedence of 50-500 kΩ.



10 µm

- Spike sorting
  - Size and shape of the spike events are depending on relative position of neurons.

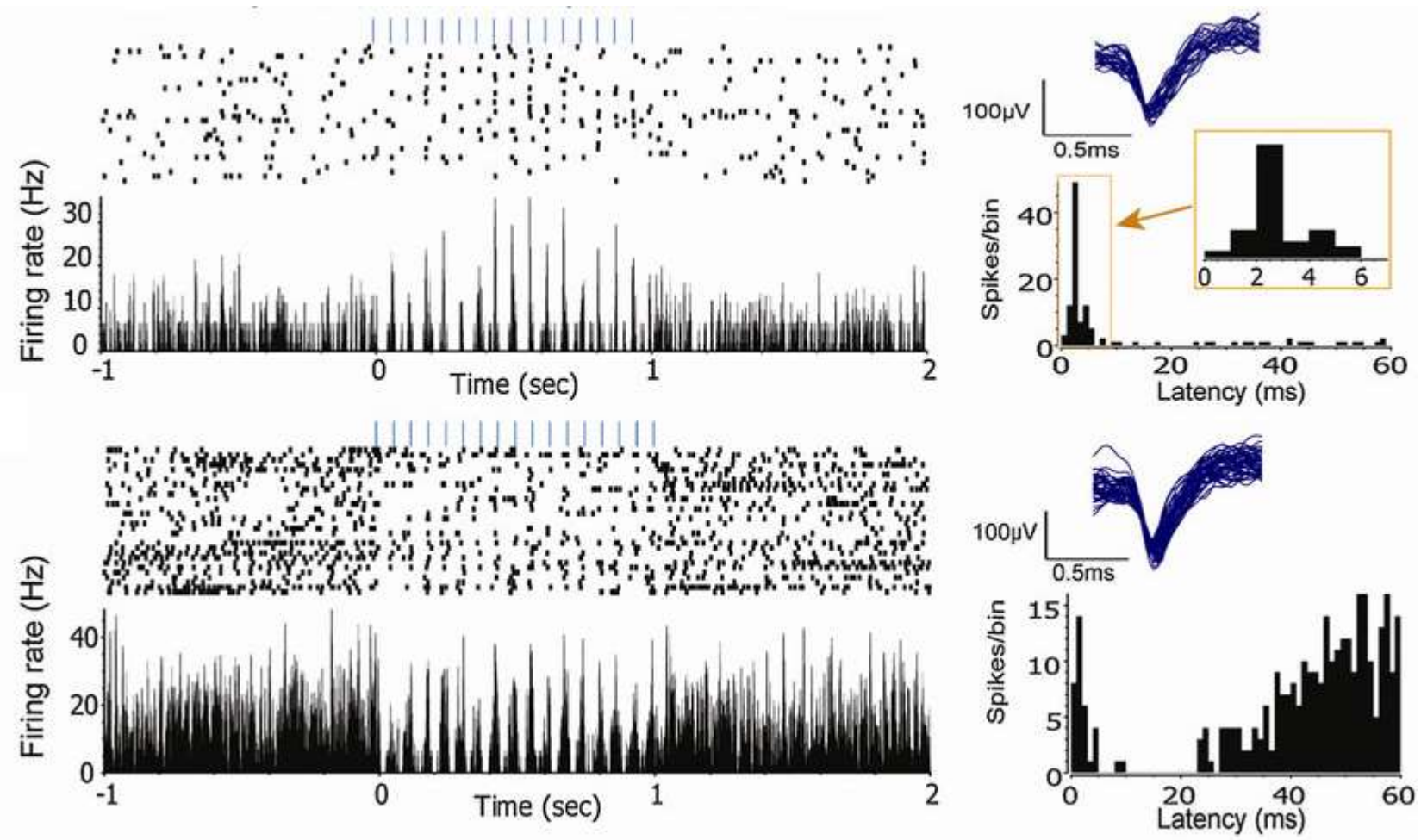


Single unit activity

- Data: Spike trains from multiple neurons.

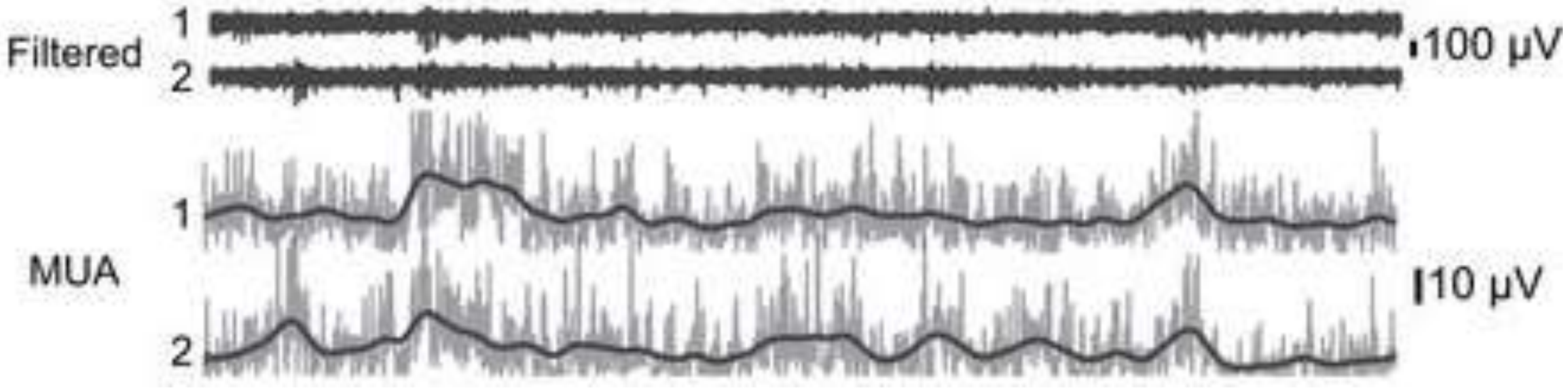
Neuron 1

Neuron 2



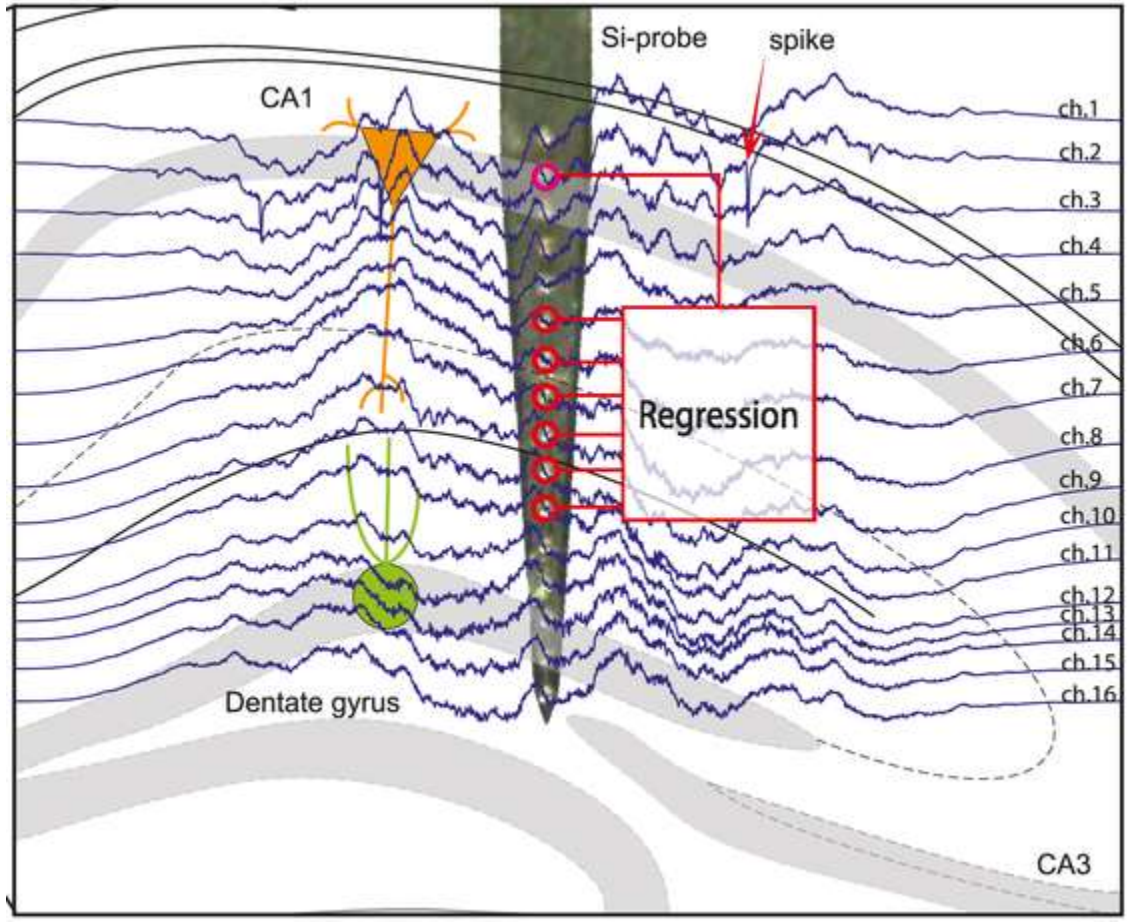
Multi-unit activity (MUA)

- Spike activity from many unidentified neurons.
- level of spiking rate in local neuronal population (neural output).
  - Rectification and downsampling of the bandpass-filtered signal.



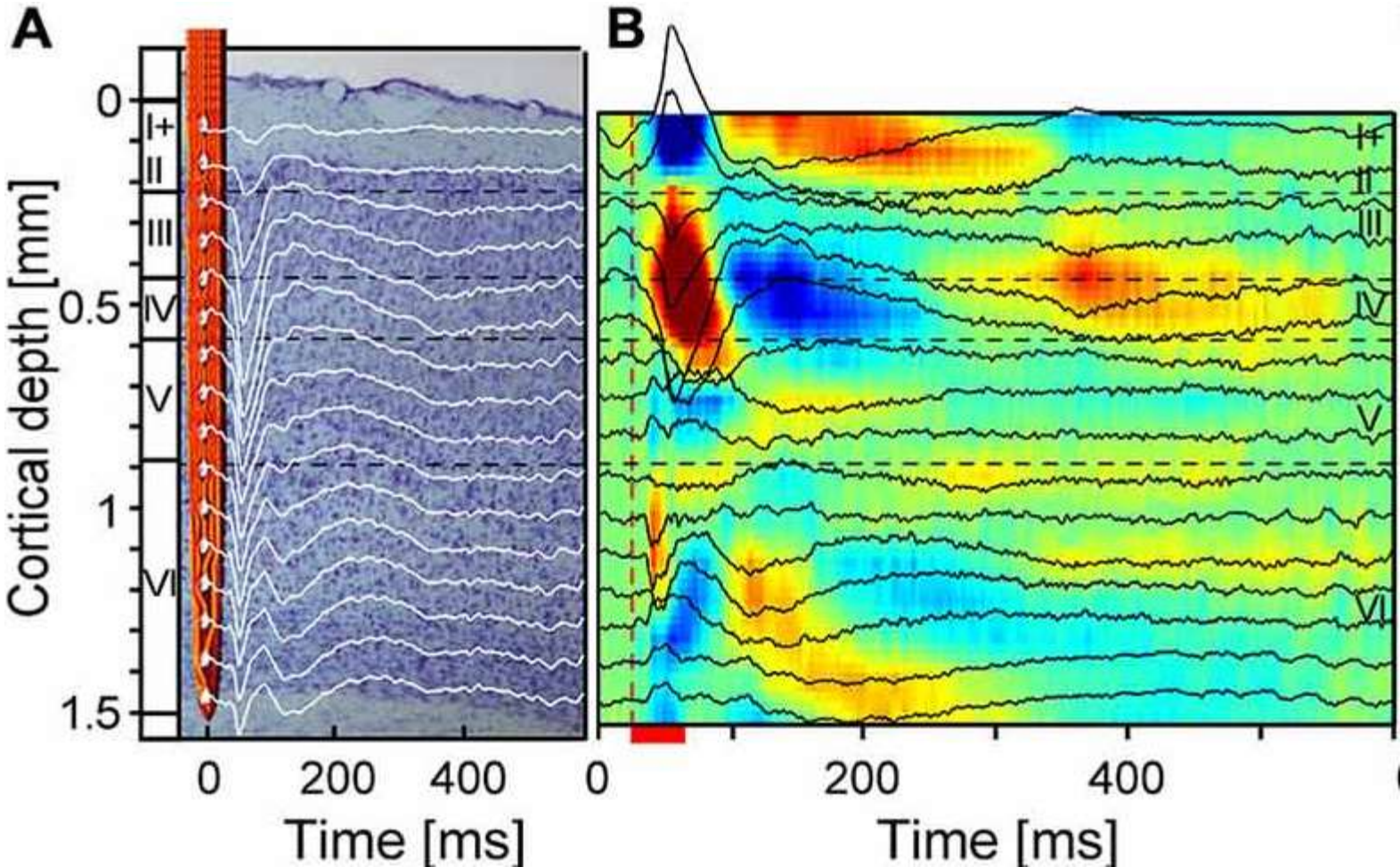
Local field potential (LFP)

- Slower frequency bands in extracellular recording (0.5~200 Hz): micro EEG
- synchronized synaptic input (postsynaptic current) in local area is a major source of LFP.
- Data is analyzed as spectral power (bands) or evoked potential.



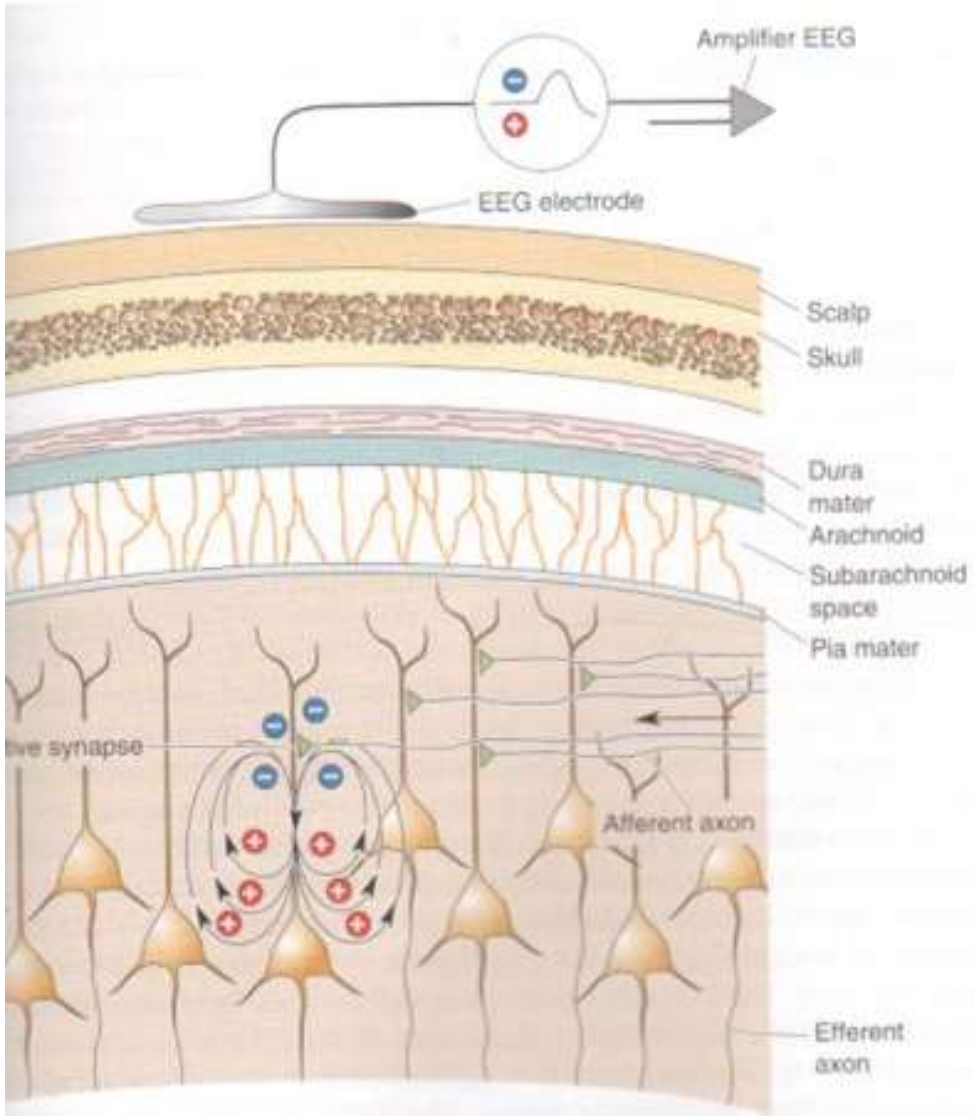
Local field potential (LFP)

- Linear electrode array recording of LFP
  - 1st spatial derivative: current flow density
  - 2nd spatial derivative: current source density
  - Current sink: excitatory synaptic input



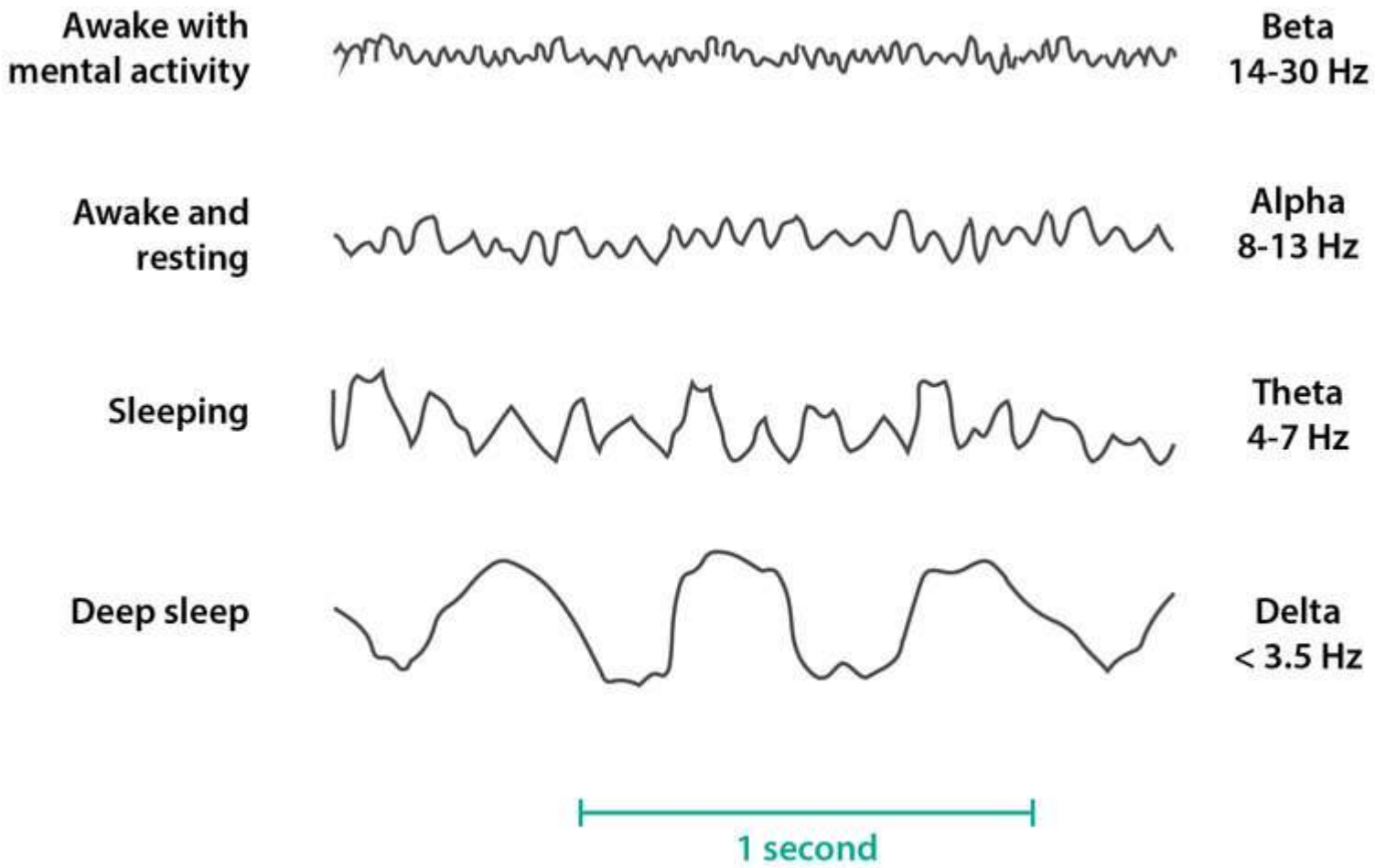
EEG/EcoG

- EEG records extracellular potential generated with synchronous synaptic inputs as same as LFP.
- Skull and dura matter work as volume conductor, and worsen spatial resolution. EcoG (electro-cortico-graphy) has a better sensitivity.
- Same data analysis scheme can be applied for both LFP and EEG



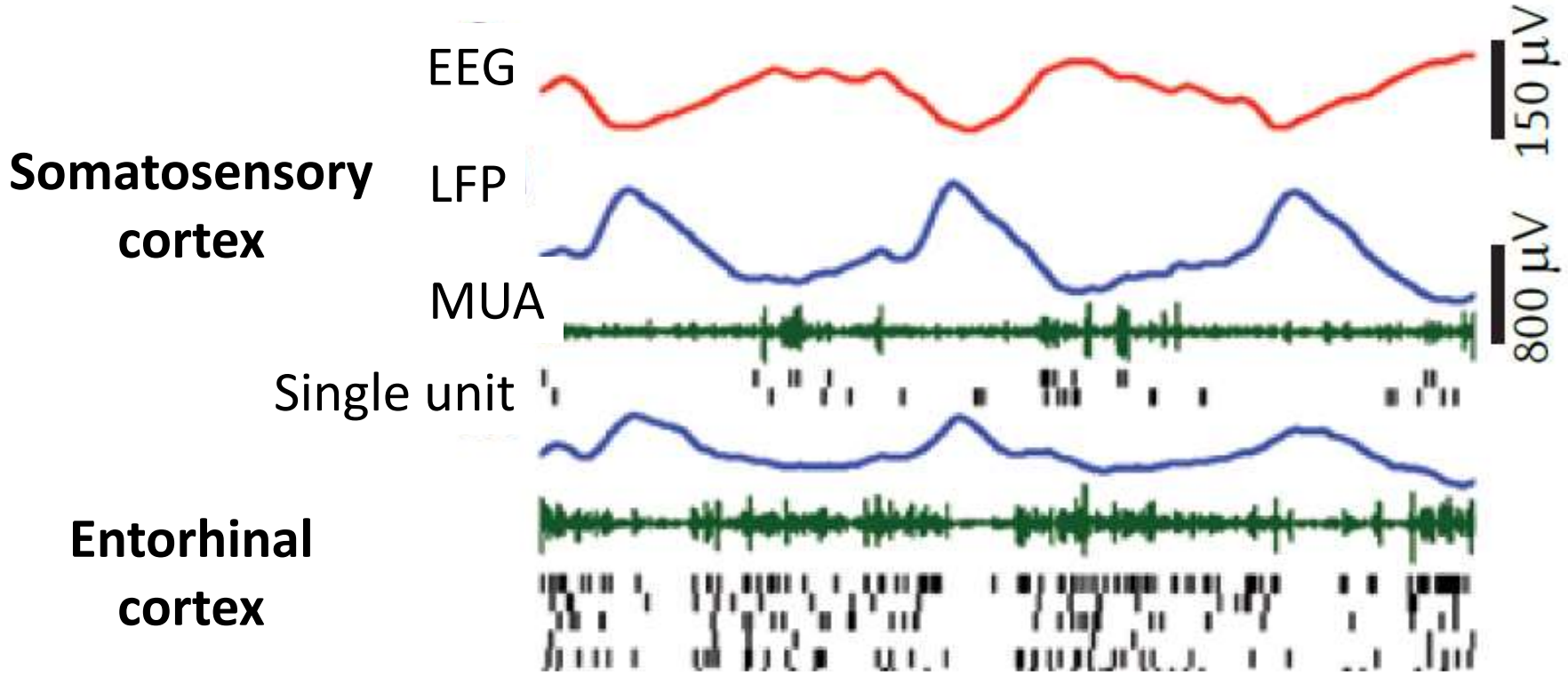
Neural oscillation in LFP/EEG

- Frequency bands in LFP/EEG
  - Delta wave (0.5~4 Hz)
  - Theta wave (4~8 Hz)
  - Alpha wave (8~13 Hz)
  - Beta wave (13~30 Hz)
  - Gamma wave (30~100 Hz)



Comparison of electrophysiological recording

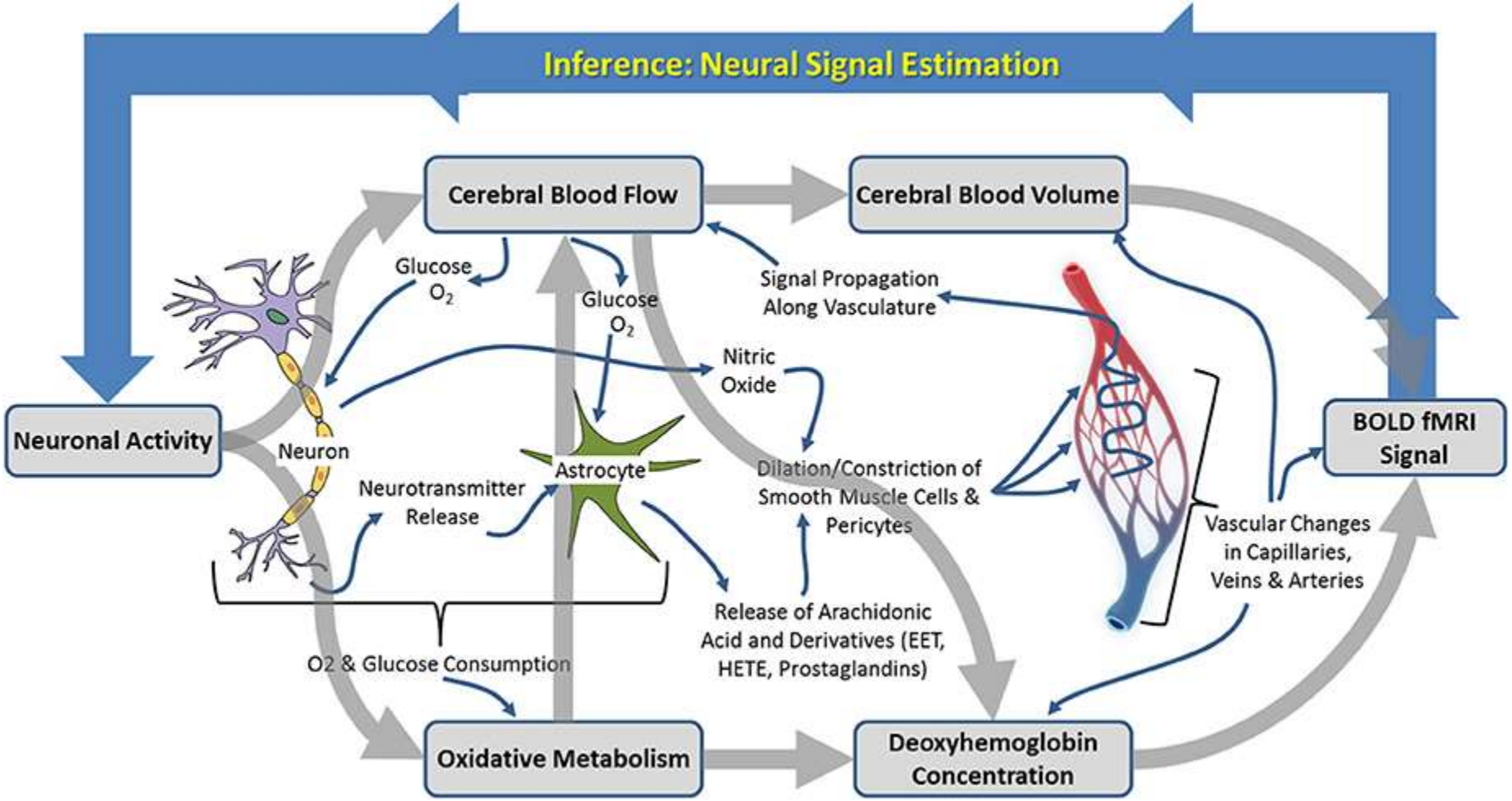
- EEG, LFP, MUA and single unit activity are closely interrelated.



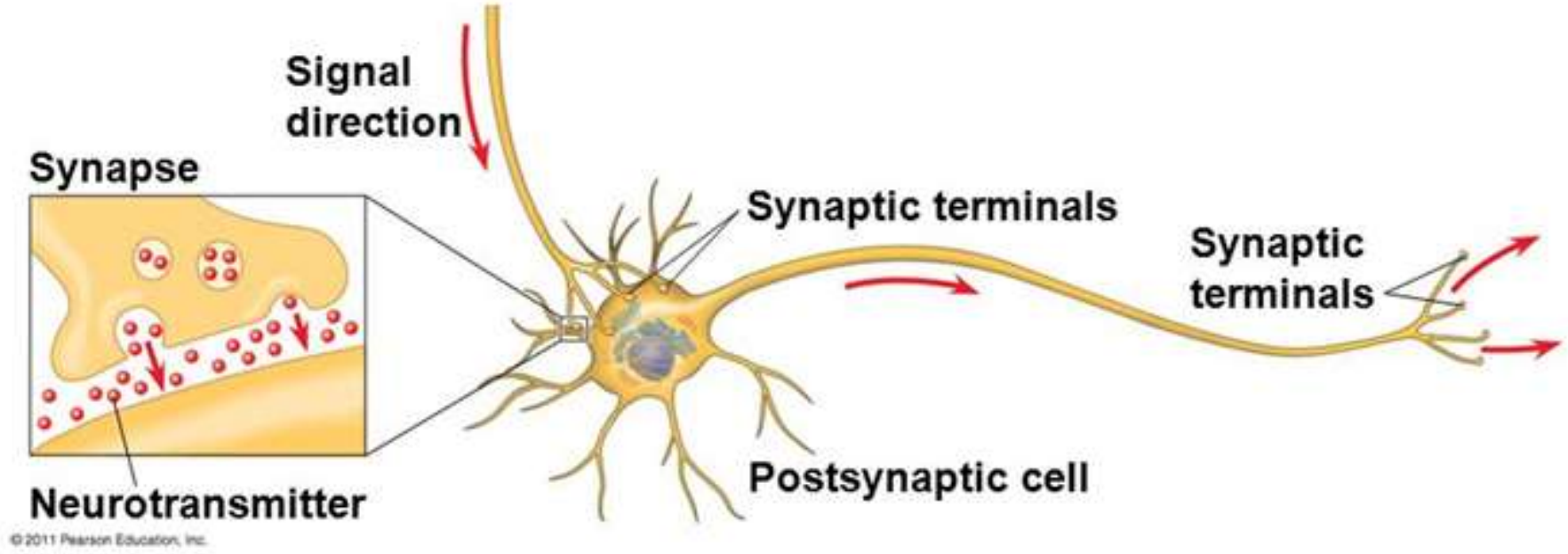
Electrophysiological basis of fMRI

Neurovascular coupling

- What type of electrophysiolgical activity explains BOLD fMRI?



Neural basis of BOLD fMRI



Synaptic input

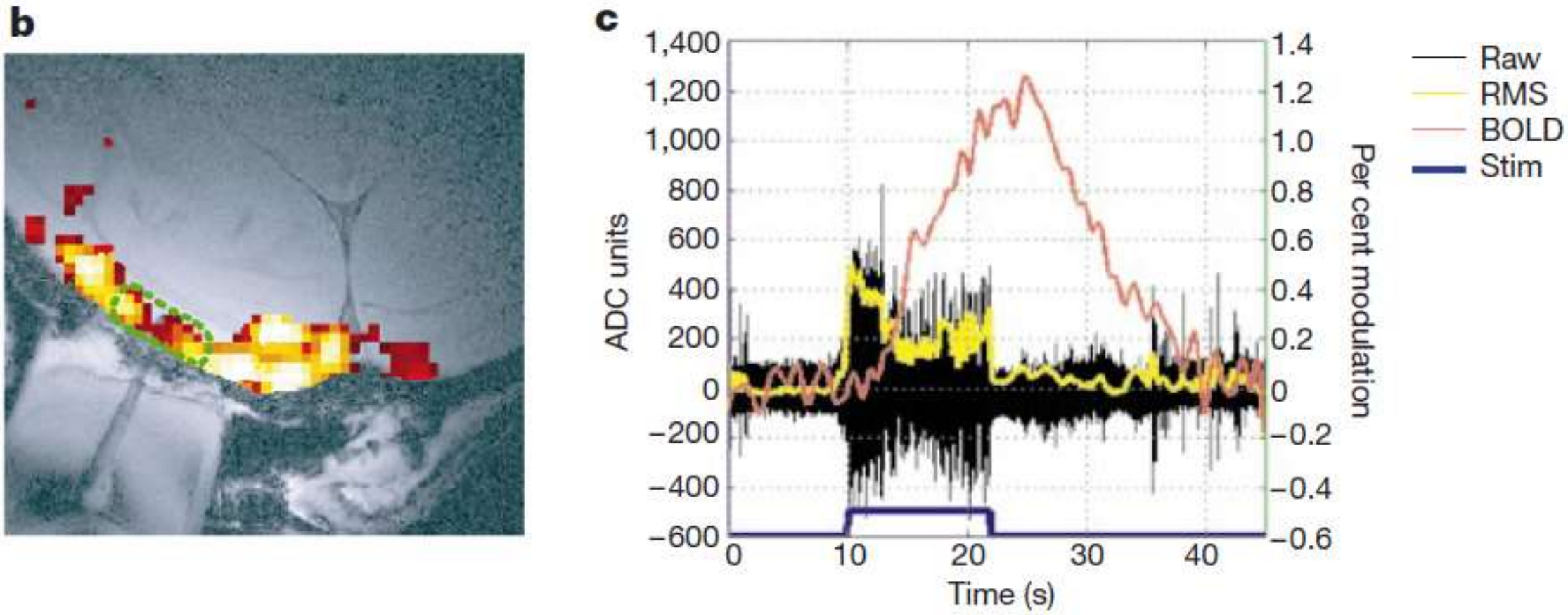
- Local Field Potential (LFP)

Neuronal output ("Spikes")

- Multi-unit activity (MUA)
- Single unit activity

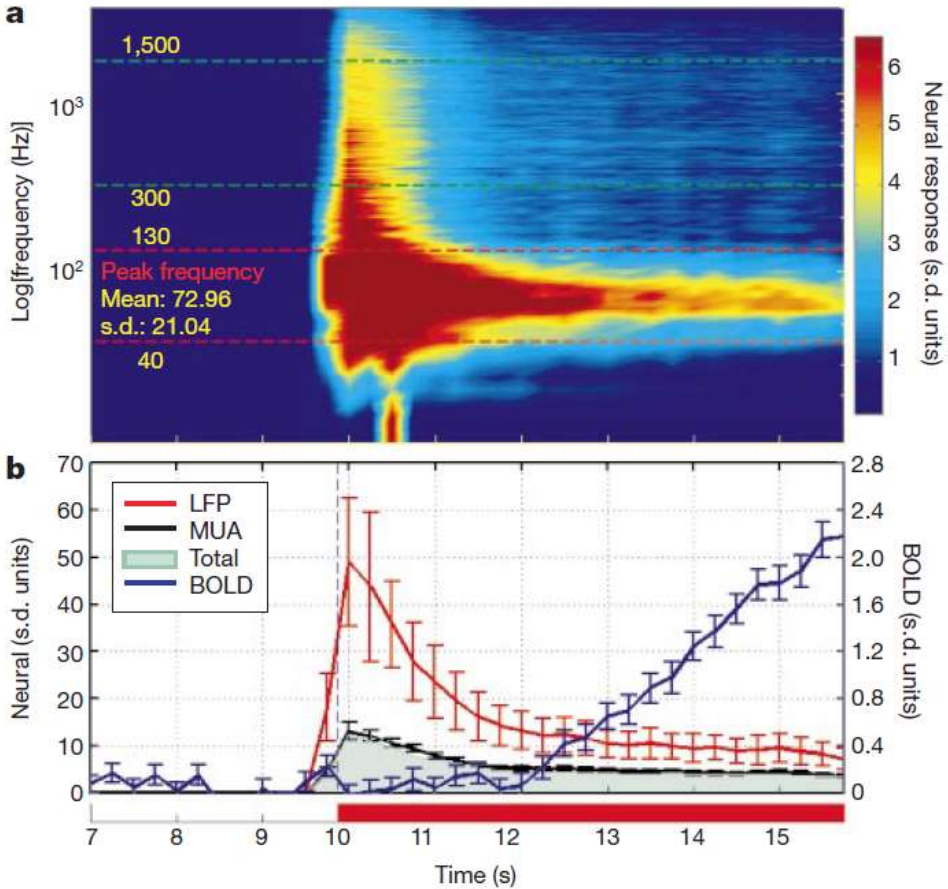
Neural basis of BOLD fMRI

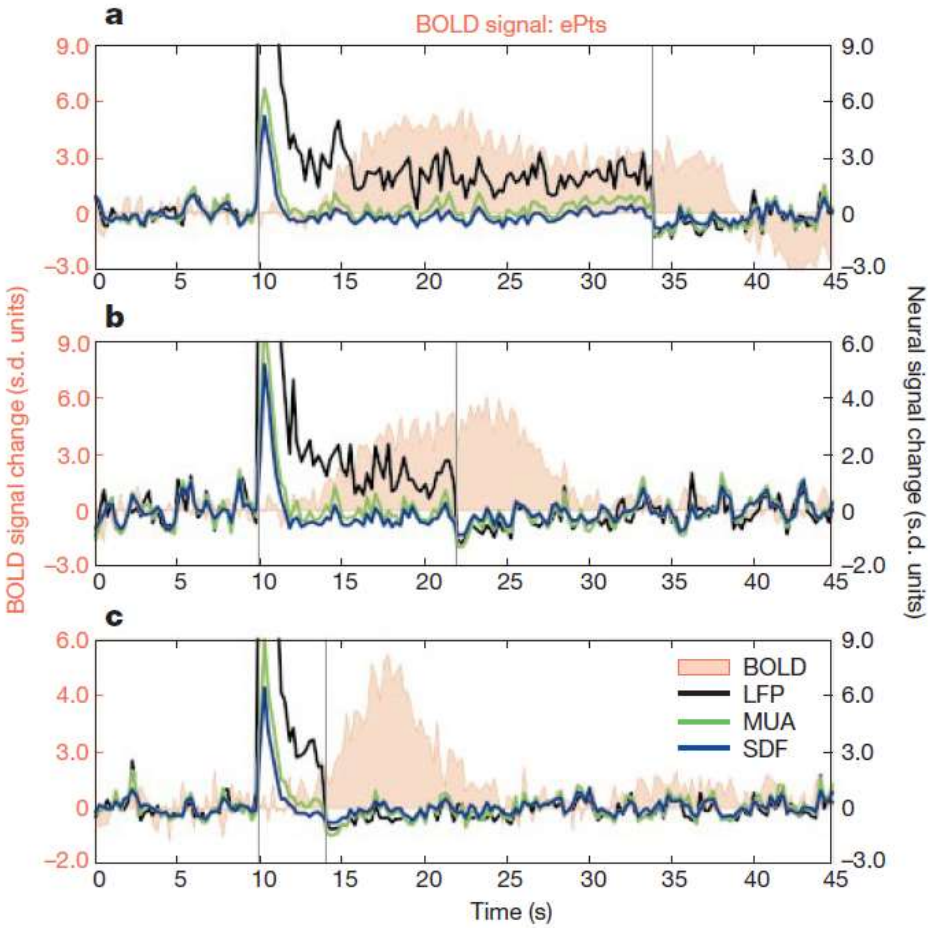
- Logothetis et al. (2001)
  - Simultaneous electrophysiological recording with BOLD fMRI. (Monkey visual cortex)



Neural basis of BOLD fMRI

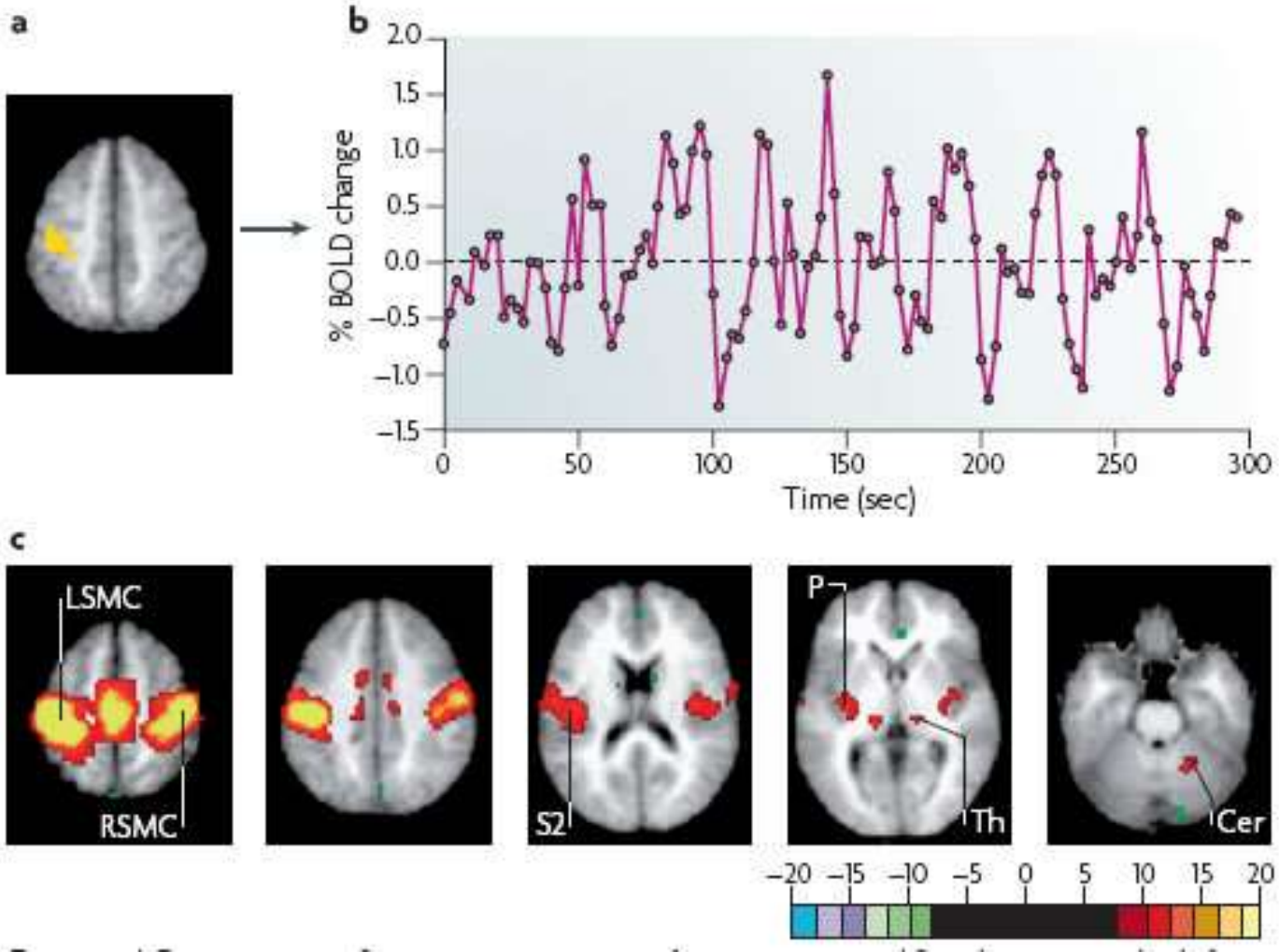
- Logothetis et al. (2001)
  - LFP was more well matched with BOLD fMRI than MUA.



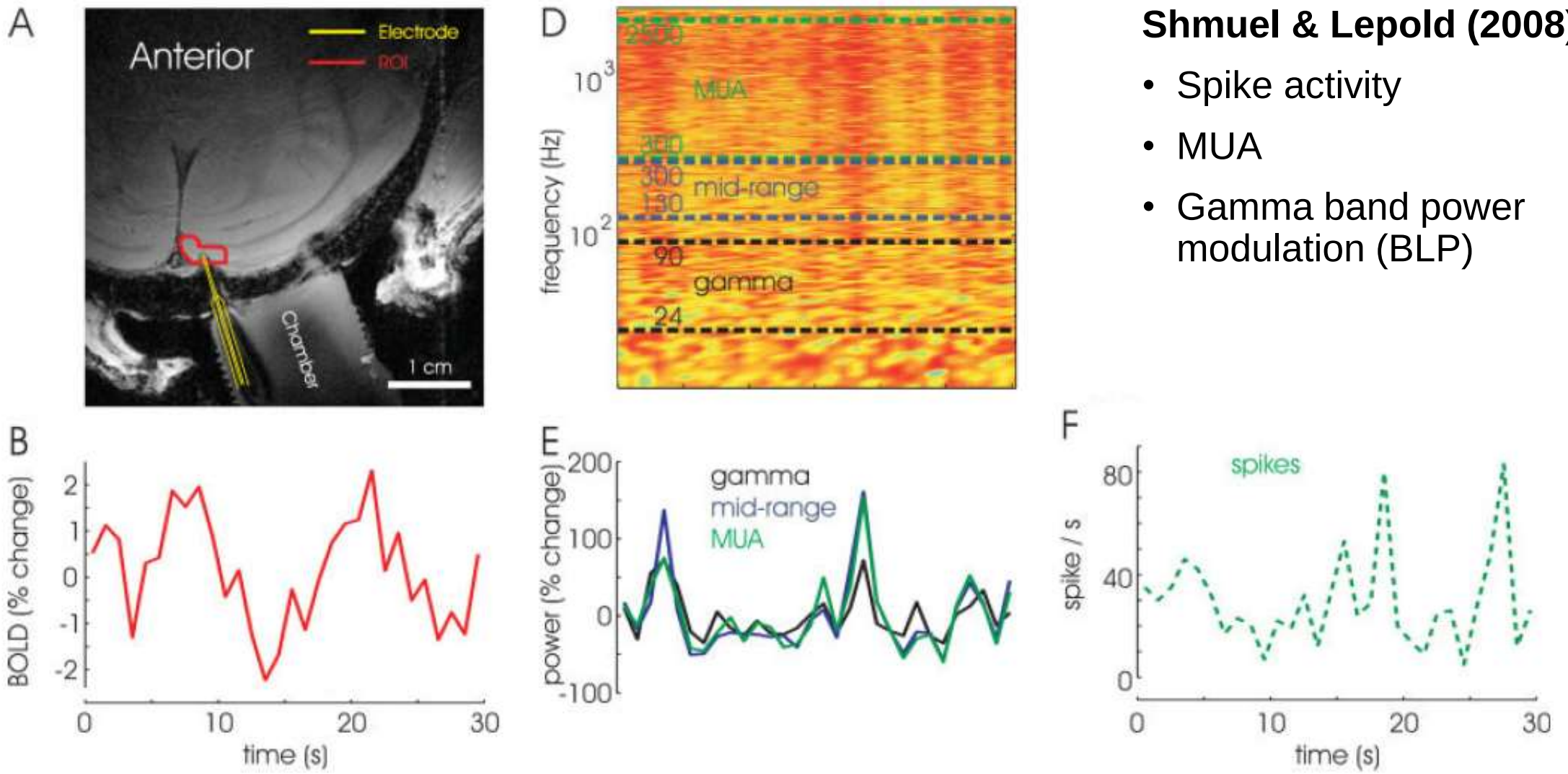


Neural basis of resting state fMRI

- Spontaneous BOLD fluctuation in fMRI: 0.01~0.1 Hz



Neural basis of resting state fMRI

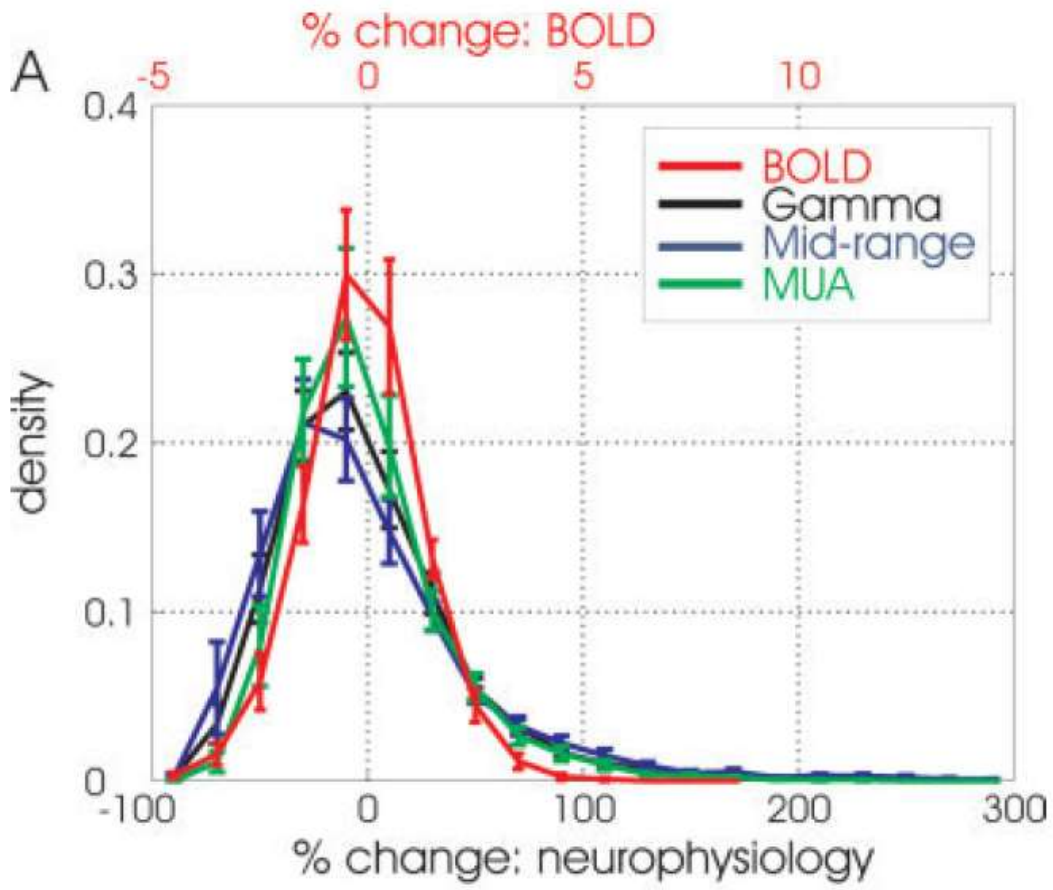


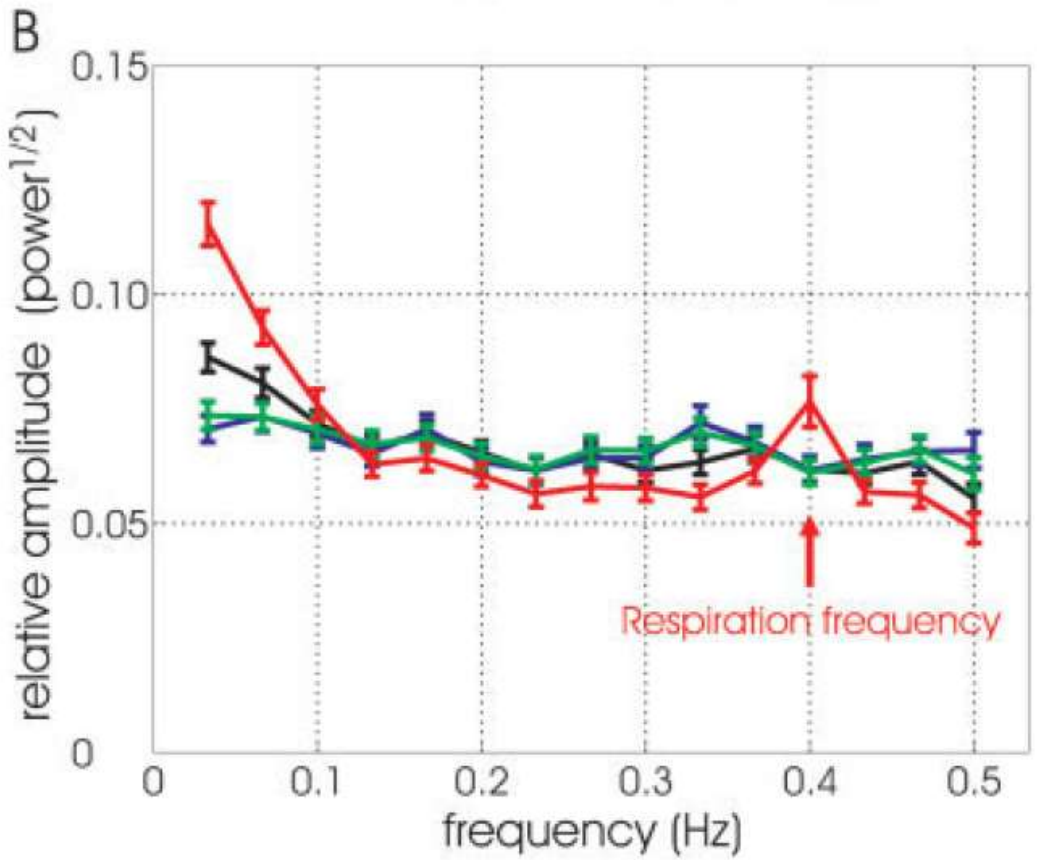
Shmuel & Lepold (2008)

- Spike activity
- MUA
- Gamma band power modulation (BLP)

Neural basis of resting state fMRI

- Hemodynamic response was conserved in resting state activity.





Thank you for listening!

kwangyeol.baek@gmail.com