Introduction to Electrophysiology

Dr. Kwangyeol Baek
Martinos Center for Biomedical Imaging
Massachusetts General Hospital
Harvard Medical School

2018-05-31s
Contents

• Principles in Electrophysiology

• Techniques in Electrophysiology

• Electrophysiological basis of Functional MRI
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.

![Membrane Potential Diagram]

- **Plasma membrane**
- **Ground electrode outside cell**
- **Microelectrode inside cell**
- **Voltmeter (-70 mV)**
- **Axon**
- **Neuron**
Electrophysiology of Neuron

Post-synaptic potential
- Synaptic input
- Neurotransmitter-gated ion channels
- Varying amplitude and shape

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.
Intracellular vs. Extracellular recording

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

- **Extracellular 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
- Extracellular recording
  - Single unit activity
  - Multi-unit activity (MUA)
  - Local field potential (LFP)
- EEG / EcoG
Intracellular recording

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

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

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

  - **Spike activity**: 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 cellular 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.

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

![Image of a tetrode with a scale of 10 µm]
Single unit activity

- Data: Spike trains from multiple neurons.
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
  - 1\textsuperscript{st} spatial derivative: current flow density
  - 2\textsuperscript{nd} spatial derivative: current source density
  - Current sink: excitatory synaptic input
• 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 electrophysiological 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