Neurophysiology and Basics of EEG

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Disclosures:

• Most hated topic by faculty/fellows/techs

• Tedious to grasp and requires constant attention and repetition to understand

• If I can convey only 50% with 25 % retention: Success

• If you do not pay attention to first 15 minutes, nothing will make sense.
Rules of Polarity on EEG:

- Input 1: negative at time $t$
- Input 2: positive at time $t$
- Input 1: positive at time $t$
- Input 2: negative at time $t$

**Negative wave**

**Positive wave**
Objectives

1. A brief review of the neuronal physiology
2. Physiological basis of EEG recording
3. Physiological basis of epileptiform discharges and seizures
4. Physiological and Electrical factors affecting EEG waveforms
Objective:

1. A brief review of the neuronal physiology
Neurons are the primary functional units of the brain.

Neurons are excitable cells and use electrical impulses to communicate with each other.
1. A brief review of the neuronal physiology

• Terms:

1. Membrane Potential (MP)
2. Action Potential (AP)
3. Post Synaptic Potential (PSP - EPSP and IPSP)
4. Field Potential (FP)
1. Membrane Potential:

- When a neuron is impaled by a microelectrode, a membrane potential of approximately -70 mV with negative polarity in the intracellular space becomes apparent.

- This resting membrane potential, existing in the soma and all its fibers, is based mainly on a potassium outward current through leakage channels.

- Membrane potential varies with:
  - Activation of voltage-gated channels - AP
  - Activation of ligand-gated channels - PSP

1. A brief review of the neuronal physiology

• Terms:

1. Membrane Potential (MP)
2. **Action Potential (AP)**
3. Post Synaptic Potential (PSP - EPSP and IPSP)
4. Field Potential (FP)
2. Action Potential:

- **Sodium Channel**
  - Closed
  - Open
  - Refractory
  - Reset

- **Sodium Ions Enter**

- **Membrane Potential (mV)**
  - +40
  - 0
  - -70

- **Na+ Channels**
  - Become refractory, no more Na+ enters cell

- **K+ Channels**
  - Open, K+ begins to leave cell
  - Continues to leave cell, causes membrane potential to return to resting level

- **Threshold of Excitation**

- **Extra K+ Outside**
  - Diffuses away
1. A brief review of the neuronal physiology

• Terms:

1. Membrane Potential (MP)
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3. Post Synaptic Potential (PSP - EPSP and IPSP)
4. Field Potential (FP)
3. Post Synaptic Potentials

- APs are conducted along the axons to the terminations, where they lead to a release of transmitter substances at the chemical synapse.

- These neurotransmitters open ligand gated membrane channels in the postsynaptic neuron.
3. Post Synaptic Potentials (PSP): EPSP/ IPSP

**EPSP (Glutamate)**
- Excitatory Postsynaptic Potential
- Positive ions flow intracellularly (inward current flow)
- Local extracellular potential is negative

**IPSP (GABA)**
- Inhibitory Postsynaptic Potential
- Negative ions flow intracellularly (outward current flow)
- Local extracellular potential is positive
3. Post Synaptic Potentials (PSP): Properties

**Spatial summation** occurs when increasing numbers of nerve terminals release more neurotransmitter to produce larger EPSPs.

**Temporal summation** occurs when a single terminal discharges repetitively more rapidly to produce larger EPSPs.
EPSP: Excitatory synapse

• Intracellularly: A dendritic EPSP generates a rapid depolarization at the synaptic site and a slower and smaller depolarization at the soma.

• Extracellularly: the same EPSP generates a sink (negative) near the synapse and a simultaneous source (positive) at a distance along the core conductor (cell body).
IPSP: Inhibitory synapse

- Intracellularly: A dendritic IPSP generates a hyperpolarization at the dendritic and somatic levels.

- Extracellularly: the dendritic IPSP generates a source (positive) at the synapse & a simultaneous sink (negative) along the core conductor
Summary: Post Synaptic Potentials – EPSP/IPSP

• Nonpropagating potentials caused by neurotransmitter-induced opening or closing of channels.

• These excitatory or inhibitory potentials constitute normal synaptic transmission.

• Postsynaptic potentials creates reciprocal changes in local extracellular potential / Field Potential.
1. A brief review of the neuronal physiology

- Terms:
  1. Membrane Potential (MP)
  2. Action Potential (AP)
  3. Post Synaptic Potential (PSP - EPSP and IPSP)
  4. Field Potential (FP)
4. Field Potentials

- Field potentials appear and are detectable in the space surrounding cellular elements of the nervous system.

- They comprise rapid waves and baseline shifts; the former correspond to the conventional electroencephalogram (EEG), and both phenomena are included in the so-called direct current (DC) potential.

- Field potentials are essential in the diagnosis and classification of epileptic seizures.

- This is the most important contributor of the EEG potential: -
  - Longer lasting (10-100 ms)
  - Occur over a larger area of the membrane
  - Occur almost simultaneously in thousands of pyramidal cells
A. DIAGRAM: FIELD POTENTIAL GENERATION

An excitatory synaptic contact at the superficial aspect of the apical dendrite
Wave Generation (Conventional Electroencephalogram)
Objective:

2. Physiological basis of EEG recording
Neocortex

- Six cellular layers
- Layer I- superficial, VI- deep
- Relative thickness of the cell layers varies according to the main function of that area of cortex.
  - Sensory cortex- Layer IV most developed
  - Motor cortex- Layer V most developed
Generation of Field Potential in Neocortex
Two principal types of neuronal arrangements can be identified.

In the parallel type, the soma are in one layer and the dendrites are in opposite layers.

In the other type, the soma are in the center of a pool and the dendrites extend to its periphery.

The first arrangement is realized in the cortex and the second in brainstem nuclei.
Objective:

3. Physiological basis of epileptiform discharges and generalized seizures
BASIS OF EPILEPTIFORM ACTIVITY

- Focal epileptic activity was induced by local penicillin application.

- Simultaneous establishment of paroxysmal depolarizations of a neuron in superficial cortical layers and of sharp waves in the electroencephalogram at the cortical surface during development of an epileptic focus.

- Graphic superposition of 30 successive potentials with the commencement of focal epileptic activity is shown.

Epileptic foci can induce evoked potentials (EP) in nonepileptic areas.

In Figure A, two cortical columns generate epileptic activity, as indicated by the neuronal paroxysmal depolarizations and the concomitant negative spikes in the EEG.

In Figure B, only one column is epileptically active. The epileptic discharges elicit synaptic potentials in the neighboring nonepileptic area.

The synchronized burst discharges induced in the nonepileptic column then give rise to “epileptic evoked potentials”.

Epileptic Evoked Potential
FIELD POTENTIALS WITH FOCAL EPILEPTIC ACTIVITY

- Dissociation in occurrence of epileptiform potentials on the surface EEG and of spinal field potentials (SFPs).
- Focal epileptiform activity was restricted to motor cortical layers.
- A: Simultaneous appearance of cortical and spinal activity is indicated.
- B: Presence of cortical activity and failure of spinal activity are shown.
- C: Failure of cortical activity and presence of spinal activity are shown.

FIELD POTENTIALS WITH FOCAL EPILEPTIC ACTIVITY

- Epicortical (electroencephalogram), intracortical, and spinal field potentials during focal epileptiform activity.

- The occurrence of synchronized spinal field potentials is linked to the appearance of negative field potentials in lamina V (C).

Myoclonic jerks with spike and wave activity
FIELD POTENTIALS WITH GENERALIZED TONIC–CLONIC ACTIVITY

Experimental animal model of generalized tonic–clonic seizures elicited by repeated systemic administration of pentylenetetrazol.

A: The recording arrangement is shown.

B: Simultaneous recordings of the epicortical direct current (DC) potential from the motor regions of both hemispheres and from an occipital area are presented.

C: Displayed as a conventional electroencephalogram (EEG) and EEG/DC potential with an extended timescale.

Objective:

4. Physiological and Electrical factors affecting EEG waveforms
What changes the waveforms we record?

1. Distance of the recording electrode
2. Reference used (referential vs. bipolar)
3. Orientation of generator (perp. vs. parallel)
4. Volume conductor - what is between the discharge and the recording electrode
1. Distance from source

- **Monopole**
  - A single source or electric sink
  - Magnitude of current density *decreases inversely* with distance from source along concentric equipotential lines
1. Distance from source

- **Near-Field:**
  - Recording close to the source
  - More accurately depicts morphology, amplitude, and duration

- **Far-Field:**
  - Recording further from the source
  - Introduces distortion of morphology, decreased amplitude, and decreased duration
2. Reference used and 3. Orientation of generator

<table>
<thead>
<tr>
<th>Reference</th>
<th>Orientation to dipole</th>
<th>Waveform configuration</th>
<th>Nearer generator</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Distant</td>
<td>Perpendicular</td>
<td>Single peak</td>
</tr>
<tr>
<td>B</td>
<td>Bipolar</td>
<td>Perpendicular</td>
<td>Biphasic</td>
</tr>
<tr>
<td>C</td>
<td>Distant</td>
<td>Parallel</td>
<td>Biphasic</td>
</tr>
<tr>
<td>D</td>
<td>Bipolar</td>
<td>Parallel</td>
<td>Triphasic</td>
</tr>
</tbody>
</table>

[A diagram showing the orientation and waveform configuration for each reference.]

[A graph showing the waveform configuration for each reference.]

[B, C, D graphs showing the orientation and waveform configuration for each reference.]
• Because the dendrites of cortical pyramidal cells are perpendicular to the cortical/pial surface, dipoles are radial in direction (perpendicular to scalp)

• These generators are in the apex of cortical gyri.

• Generators in the wall of sulci create potential fields that result in a tangentially oriented dipole (e.g. potential field of the centro-temporal spike discharges often seen in BECTS)

• Spikes have a characteristic horizontal, anterior–posterior dipole, with maximal negativity in centrotemporal (inferior rolandic) and with positivity in frontal regions
Rolandic Spikes
4. Volume Conductor:

**Volume Conduction**: Bioelectric potentials’s flow from the source in the body to the recording electrodes.

**Breach effect**: Higher amplitudes recorded with high frequencies.
4. Volume Conductor: Breach Effect
Non cerebral waveforms

• Artifact: unwanted signals generated by sources other than those of interest and not of clinical value

• Physiologic

  • EKG – high amplitude, widely distributed
  • EMG
  • Potentials that occur with the movement of electrically charged structures (tongue, eye, blink)
  • Autonomic potentials (skin/sweat)
• Nonphysiologic – from technical sources

  • Movement of wires that connect the electrodes to the equipment or movement of the electrodes on the skin
  
  • Opening and closing of switches on the equipment
  
  • Poor connections of the recording electrodes, with high resistance
  
  • Use of dissimilar metals
  
  • External power sources (60-Hz signal from power lines, fluorescent lights; cautery and diathermic equipment; radio; MRI)
Objectives Discussed

1. A brief review of the neuronal physiology
2. Physiological basis of EEG recording
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“It is thus with regard to the disease called Sacred: it appears to me to be no wise more divine nor more sacred than other diseases, but has a natural cause from the originates like other affections. Men regard its nature and cause as divine from ignorance and wonder, because it is not at all like to other diseases. And this notion of its divinity is kept up by their inability to comprehend it, and the simplicity of the mode by which it is cured, for men are freed from it by purifications and incantations. But if it is reckoned divine because it is wonderful, instead of one there are many diseases which would be sacred; for, as I will show, there are others no less wonderful and prodigious, which nobody imagines to be sacred.”

Hippocrates 400 BC