Electroencephalography (EEG)

Practical 3 – Nervous System Physiology
2nd year English Module

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What is EEG

- EEG noninvasively records the continuous electrical activity in the brain using surface electrodes placed over the scalp.

- Brain waves are the undulations in the recorded electrical potentials, with mixed and variable frequency.

- Brain waves recorded from the surface of the scalp range from 0 - 200mV, and their frequencies range from once every few sec. to 50 or more / sec.

- The character of the waves (intensity and patterns) is dependent on the degree of activity in respective parts of the cerebral cortex, and the waves change markedly between the states of wakefulness, sleep, epilepsy and coma.

- Much of the time, the brain waves are irregular, and no specific pattern can be discerned in the EEG. At other times, distinct patterns do appear, some of which are characteristic of specific abnormalities of the brain such as epilepsy.

- Brain electrical activity can be measured also on the surface of the cortex or dura mater (electrocorticogram) or in the depth of cerebral matter (electrogram)
EEG is done together with other electrophysiological recordings for sleep (polysomnography):

- Electromiogram (EMG)
- Electrooculogram (EOG)
- Electrocardiogram (ECG)
EEG - Historic

- 1875 Richard Caton – ECoG & EP on mouse and monkey
- 1924 **Hans Berger** – human EEG, cerebral electric activity
- 1934 Adrian and Matthews – cerebral waves, alfa rhythm
- After 1945 – EEG as a clinical inspection
- 1953 - Aserinsky and Kleitman describe REM sleep
The first human EEG recording obtained by Hans Berger in 1924. The upper tracing is EEG, and the lower is a 10 Hz timing signal.

Berger was the first to describe the different waves or rhythms which were present in the normal and abnormal brain, such as the alpha wave rhythm (8–12 Hz), also known as "Berger's wave"; and its suppression (substitution by the faster beta waves) when the subject opens the eyes (the so-called alpha blockade).

He also studied and described for the first time the nature of EEG alterations in brain diseases such as epilepsy.
EEG

- During synaptic excitation of the cortical pyramidal neurons there is a difference in potential created between the neuron and its apical dendrite determining electric current which can be recorded by EEG.
- These recordings are called brain waves
EEG principles
Dipoles

- A dipole source occurs when equal amounts of negative and positive charge are separated over a short distance.

- Assume synaptic currents occur in a vertically oriented neuron with a deep cell soma and superficial apical dendrite.
Electroencephalography (EEG)

EEG can’t measure activity of a single cells from outside the skull. Instead EEG records synchronized activity of large populations of cells.
The brainstem reticular formation and reticular activating system. Ascending sensory tracts send axon collateral fibers to the reticular formation. These give rise to fibers synapsing in the intralaminar nuclei of the thalamus. From there, these nonspecific thalamic projections influence widespread areas of the cerebral cortex and limbic system.
Currents due to:
1) the parallel array of pyramidal cells
2) synaptic currents, lasting 10-100’s of milliseconds.

By convention, downward deflections of the EEG are positive. Generally speaking, depolarization (excitation) of deeper layers of the cortex and hyperpolarization of superficial layers cause downward deflection (+) and vice versa.
EEG recording technique

- Electrodes with conductive media
- Amplifications and filters
- Digital convertor
- Recording machine
EEG recording technique
EEG recording technique

- **Pairs of electrodes** are connected to separate **channels** of an **amplifying** and **recording** device – **electroencephalograph**

- Most EEG machines have 8 to 16 channels, but high number of electrodes can be used for high-density scalp recording (128-256).

- **Electrodes placement** over the scalp:
  - **10-20 system** using 21 active electrodes (standardized, 1958)
  - method advantage: there is an anatomic correlate for each electrode, which is consistent from patient to patient

- Three types of electrodes:
  - Active electrode
  - Reference electrode
  - Ground electrode

- **Electrode derivations**:
  1. **bipolar method**: each channels is connected to 2 recording electrodes
  2. **common reference method** (one common electrode for all channels – usually ear lobe, mastoid – with minimal potential)
  3. **average reference derivation**: all electrodes connected through equal resistors to a single point, used then as the common reference
EEG recording technique

Standard 10-20

High density EEG

Maximal configuration: “multi-channel” 128-256 active electrodes
10-20 electrodes placement scheme

Three distances are measured:
1. between two preauricular points, 2. between the nasion (nose bridge) and inion (the occipital bone mount), both across vertex, 3. the circumference between nasion and inion. These distances are divided in proportion of 10-20-20-20-20-10% in both orthogonal axes and in circumference, and a net of imaging quadrates is built on head surface. The electrodes are placed in a quadrates angles.

A = Ear lobe, C = central, Pg = nasopharyngeal, P = parietal, F = frontal, Fp = frontal polar, O = occipital.
EEG montages:

Patterns of connections between electrodes (8 channels usually)

Longitudinal bipolar montage

Common referential montage referred to the ipsilateral ear lobule
Amplification and filtration of EEG signal

- Amplification 100-100000x:
  - Signal must be amplified in order to be visualized, recorded and digitally converted
  - Must be selective in filtering the signal from the “background noise”

- Filtering of the signal from:
  - “background noise” (e.g. signals from the electrical network 50-60Hz)
  - low frequency signals determined by physiological biopotentials (respiration)
EEG application

- Monitoring the wake state and sleep stages
- Testing afferent pathways (VEP, AEP)
- Monitoring of cerebral development;
- Control of anesthesia
- Monitoring coma; diagnosing cerebral death
- Localization of cerebral lesions like: cerebral tumors, stroke, cerebral ischemia, trauma;
- Investigation of epilepsy; testing the effects of antiepileptic medication;
- Investigating sleep disorders and associated diseases
- Neurofeedback…
Normal EEG
EEG interpreting

- Background activity
- Frequency
- Amplitude
- Wave morphology
- Symmetry
- Synchronisation – coherence
- Localisation
- Continuity
- Reactivity
EEG interpreting

Change in background activity
Note frequency and amplitude

Wave morphology

Synchronous activity

Compare symmetry left vs. right

Localisation Parieto-occipital

Reactivity

Continuity
Normal EEG rhythms

- Frequency between 0.5-30 Hz, divided into 4 types based on frequency:
  - delta (0-3 Hz),
  - theta (3-8 Hz),
  - alpha (8-13 Hz),
  - beta (>13-30 Hz).
- Amplitude varies with every type.
EEG Rhythms – Frequency spectre

EEG waves

<table>
<thead>
<tr>
<th>Normal</th>
<th>Frequency</th>
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</thead>
<tbody>
<tr>
<td>α</td>
<td>8 – 13 Hz</td>
</tr>
<tr>
<td>β</td>
<td>14 – 30 Hz</td>
</tr>
<tr>
<td>θ</td>
<td>4 – 7 Hz</td>
</tr>
<tr>
<td>δ</td>
<td>0.5 – 3 Hz</td>
</tr>
</tbody>
</table>

Paroxysmal spikes
Paroxysmal waves
3 Hz spikes and waves

20-70 ms

→200 ms
**alfa and beta rhythms**

**alpha rhythm:**
- 8 – 13 Hz, 50-100 uV
- More prominent in posterior regions (parietooccipital area)
- Conditions: eyes closed (EC), subject awake and relaxed (EEG synchronization)
- Disappears on OE and attention → EEG desynchronization

**beta rhythm:**
- 13-30 Hz (>13 Hz), low voltage
- More prominent in frontal and parietal regions
- Conditions: mental activities (ex. calculus, thinking, open eyes)
- Rhythm of rapid activity (arousal), freq. and amplitude of beta vary greatly (desynchronization)
**delta and theta rhythms**

**Theta rhythm:**
-4 – 7 Hz
-Slow activity
-generalized distribution
-Normal: children under 13 (parietal & temporal) and adults in 2nd sleep stage
-Pathologic: focal in subcortical lesions and diffuse in profound lesions, diffuse cortical lesions or metabolic encephalopathies
-Exp. recorded from hippocampus

**Delta rhythm:**
-under 3-4 Hz
-Normal and dominant in 3 and 4 sleep stages and in infancy
-Occurs in the cortex indep. of lower brain regions activities
-Pathologic: focal in subcortical lesions and diffuse in profound lesions, diffuse cortical lesions or metabolic encephalopathies
alfa – beta – alfa transition
## EEG waves

<table>
<thead>
<tr>
<th>Designation</th>
<th>Morphology</th>
<th>Definition</th>
<th>9 Sharp waves (sharp potential)</th>
<th>10 Spike</th>
<th>11 Polyspikes</th>
<th>12 Spike–wave complex</th>
<th>13 Rhythmic spikes and waves</th>
<th>14 Sharp and slow waves</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 β rhythm</td>
<td>Regular sequence of waves at 14–30 Hz</td>
<td>Sharp and steep waves of 80–250 ms duration ascending phase usually steeper than descending phase</td>
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<tr>
<td>2 Spindles</td>
<td>Regularly waxing and waning waves at 14–30 Hz</td>
<td>Sharp and steep wave of duration &lt; 80 ms</td>
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<tr>
<td>3 α rhythm</td>
<td>Regular sequence of waves at 8–13.3 Hz</td>
<td>Compact series of spikes</td>
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<tr>
<td>4 θ rhythm</td>
<td>Regular sequence of waves at 4–7 Hz</td>
<td>Complex consisting of a spike and slow wave</td>
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<tr>
<td>5 δ rhythm</td>
<td>Regular sequence of waves at 1–3.5 Hz</td>
<td>Sequence of regular spike–wave complexes at about 3 Hz</td>
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<tr>
<td>6 δ activity</td>
<td>Irregular sequence of polymorphic waves at 1–3.5 Hz</td>
<td>Sequence of complexes of sharp waves and slow waves of 500–1000 ms duration, often rhythmic</td>
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<td>7 Subdelta wave</td>
<td>Wave with duration &gt; 1 s</td>
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<tr>
<td>8 Steep waves (steep potential)</td>
<td>Conspicuous, blunt, steep individual waves</td>
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Artifacts

- **patient related:**
  - Any body movement
  - Sweat
  - Pulse
  - ECG
  - Eye movement

- **technical:**
  - Displacement of the electrode
  - Too much paste or dry electrode
  - Battery discharged
Pathological morphology

- Alpha Coma – brainstem lesions, severe encefalopathies
- IRDA (Intermitent rhythmic delta activity) – metabolic, toxic, hipoxic encefalopathies
- Burst suppression
- Epileptiform discharges
Alpha Coma

Unresponsive
Intermitent Delta Rhythmic Activity
Burst suppression
Epileptiform EEG discharges

- **Epileptiform EEG discharges**, during epileptic attack, used in epilepsy diagnosis:
  1. spikes (20-70ms);
  2. sharp waves (70-200 ms);
  3. a spike and wave complex (spike or sharp wave followed by a slower wave).

- **Activation/trigger procedures** in a suspected case of epilepsy/ in the interictal period:
  - hyperventilation for 3-5 min (most used)
  - intermittent photic stimulation: bright light flashes (1-30/sec) delivered for 10 sec. (most effective)
3 Hz Discharges – Absence
Tonico-clonic generalised discharges
Cerebral Mapping
Sleep investigation methods

Electroencephalogram (EEG) = Brain Waves

Electrooculogram (EOG) = Eye Movements

Electromyogram (EMG) = Muscle Tension
Standard somnographic montage

- 3 EEG leads:
  C3-A2, C4-O1, O2-A1

- 2 EOG leads

- 2 EMG leads
Supplemental investigations

- ECG
- Pulsoximetry
- Breathing sensors, thoracic & abdominal
- Position sensor
- Limb movement sensor
- Microphone
- Temperature sensor
Awakefulness

AWAKE

EEG
EOG
EMG
Stage 1

- Brain activation level reduced: low voltage EEG, diminished alpha activity, reduced frequency activity (theta) 3-7 Hz
- EOG – Slow eye movement, low muscular activity
- EMG moderate – reduced
Stage 2

- low voltage EEG, mixed activity frequency, 12-14 Hz
- sleep spindles associated with K complexes (diphasic waves, > 0.5 s)
- EOG – slow, rare eye movements
- EMG moderate – reduced muscular activity
Stage 3

- EEG – delta waves, 0.5-2 Hz & amplitude >75mV; covering around 20-50% from the analyzed epoch.
- EOG – rare eye movements
- EMG moderate – reduced muscular activity
Stage 4

- EEG delta activity covering >50% from the epoch
- EOG – rare eye movements
- EMG moderate - reduced
REM Stage

- EEG low voltage, rhythm with rapid activity and mixed frequencies (desynchronized sleep), aspect close to stage 1
- EOG – REM, mirror aspect
- EMG – muscular activity absent
EEG Stages in Wakefulness and Sleep

**Awake**
- Alpha activity
- Beta activity

**Stage 1 sleep**
- Theta activity

**Stage 2 sleep**
- K complex
- Spindle

**Stage 3 sleep**
- Delta activity

**Stage 4 sleep**
- Delta activity

**REM sleep**
- Theta activity
- Beta activity
Aditional

- EEG ambulator (out-patients)
- Evoked potentials
  - Definition
  - Useful for neuronal coherence
  - Clinical implications
- Sleep apnea
- Cerebral death diagnostic