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MAYO CLINIC

ELECTROMYOGRAPHY (EMG), ELECTROENCEPHALOGRAPHY (EEG), AND NEUROPHYSIOLOGY IN CLINICAL PRACTICE

February 19-25, 2023
Ritz-Carlton Amelia Island
Amelia Island, FL

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NUTS & BOLTS OF EEG

Keith Starnes

DISCLOSURE OF RELEVANT FINANCIAL RELATIONSHIP(S) WITH INELIGIBLE COMPANIES

- Nothing to disclose

REFERENCES TO OFF-LABEL USAGE(S) OF PHARMACEUTICALS OR INSTRUMENTS

- Nothing to disclose

All relevant financial relationships have been mitigated.

LEARNING OBJECTIVES

- Review the physics and physiological basis of EEG
- Explore the concepts of polarity, montages, filters, and digitization
- Develop a basic understanding of the electricity of EEG and brain waves

OUTLINE

1. EEG basics
2. Physics
3. Montages
4. Filters & Digitization

Ohm's Law

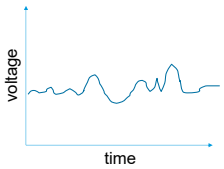
AMP Flow

VOLT Pressure

OHM Resistance

EEG BASIC PRINCIPLES

- Excellent temporal resolution
- Voltage vs time
- Scalp EEG signal generated by cerebral neurons
- Signal modified by properties of tissues between source and recorder
- Volume conduction
- Other biophysical signals (e.g. muscle) overwhelm EEG



Physics is much too hard for physicists.

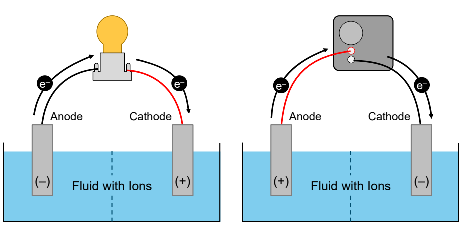
– David Hilbert –

EEG IS DIGITAL

- Digitization
  - Quantization
  - Sampling
- Digital EEG has higher inter-rater agreement
  - Easy montage switching, filter application, reformatting

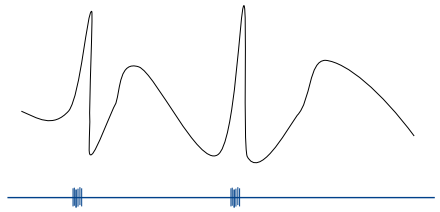
Levy et al, J Clin Neurophysiol, 1998

POLARITY – CATHODE AND ANODE



Redrawn from: https://chem.libretexts.org/Bookshelves/Analytical_Chemistry/Supplemental_Modules_(Analytical_Chemistry)/Electrochemistry/Electrolytic_Cells

POLARITY



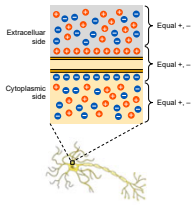
EEG

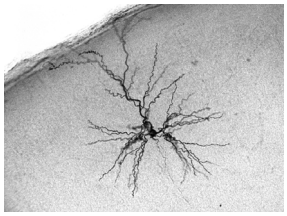
Single Units

Image courtesy of Brian Lundstrom

POLARITY

Nernst Equation $E = \frac{RT}{zF} \ln \frac{[\text{ion outside cell}]}{[\text{ion inside cell}]}$





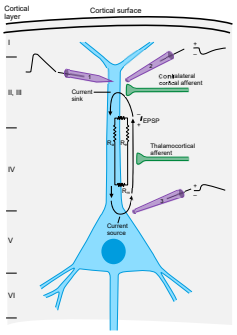
Redrawn from: Kandel et al, Principles of Neural Science, 5th Ed., 2013

POLARITY

Superficial Excitatory Post-synaptic Potentials (EPSP)

↓

Negative Surface Potential

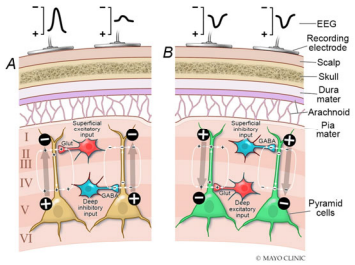


Redrawn from: Kandel et al, Principles of Neural Science, 5th Ed., 2013, Fig 50-2

POLARITY

Negative potential
- Superficial EPSP
- Deep IPSP

Positive potential
- Deep EPSP
- Superficial IPSP



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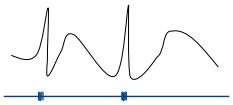
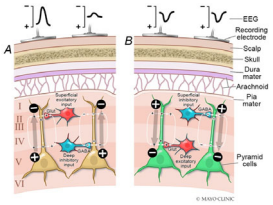


EEG

Single Units



POLARITY

1. Polarity is relative
2. Upward is negative by convention

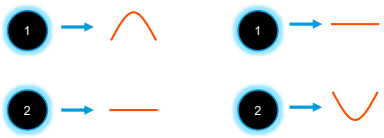
20 uV – 10 uV?
90 uV – 80 uV?
-5 uV – (-15) uV?

All = +10 uV

POLARITY

1. Upward negative
2. Polarity relative

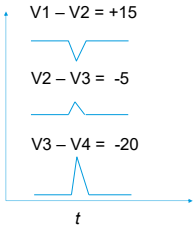
Contact 1 minus Contact 2 gives same result in both



POLARITY

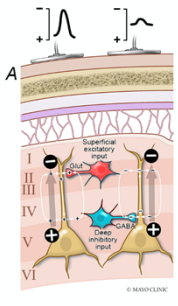
At time point *t*, V1, V2, V3, and V4 have the following values:

V1 = 10
V2 = -5
V3 = 0
V4 = 20



POLARITY

- Amplitude depends on the solid angle
- Amplitude can be higher for more distant sources



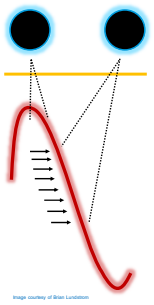
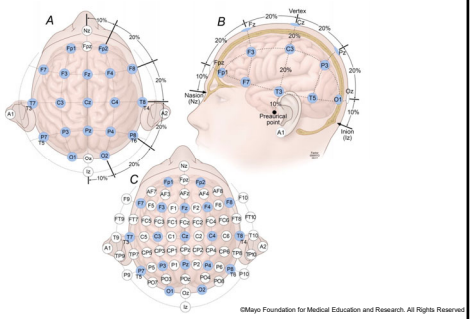
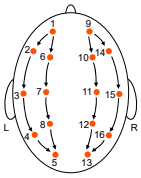


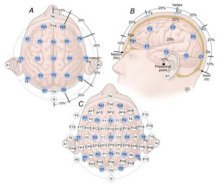
Image courtesy of Brian Lundstrom

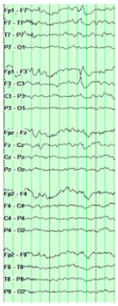
MONTAGES



MONTAGES







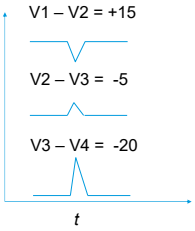
Redrawn from: Kandel et al, Principles of Neural Science, 5th Ed., 2013

MONTAGES

- Referencial: elevation – v
- Bipolar: slope – $\frac{dv}{dx}$
- Laplacian: curvature – $\frac{d^2v}{dx^2}$

MONTAGES

- Definition – arrangement of electrodes to display brain activity
- Types
  - Referential – single reference
  - Bipolar – comparison of one to the next
  - Laplacian – combination of nearby electrodes as reference

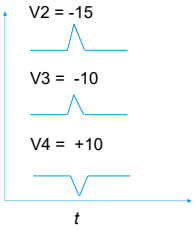


MONTAGES

REFERENTIAL MONTAGE – to V1

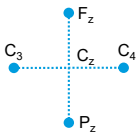
At time point *t*, V1, V2, V3, and V4 have the following values:

V1 = 10
V2 = -5
V3 = 0
V4 = 20



MONTAGES

LAPLACIAN APPROXIMATION – AVERAGE OF SURROUNDING ELECTRODES

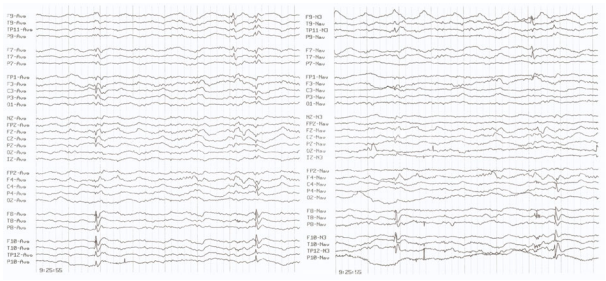


$$LC_z = C_z - \frac{F_z + P_z + C_3 + C_4}{4}$$

MONTAGES – LAPLACIAN CHARACTERISTICS

- Independent of reference (like bipolar)
- Calculated near 1 electrode (like referential)
- Locates local maxima by amplitude (like referential)
- Sensitivity to generators
  - Near-field sensitivity: Laplacian > bipolar > referential
  - Far-field sensitivity: referential > bipolar > Laplacian

Average Reference **Laplacian**



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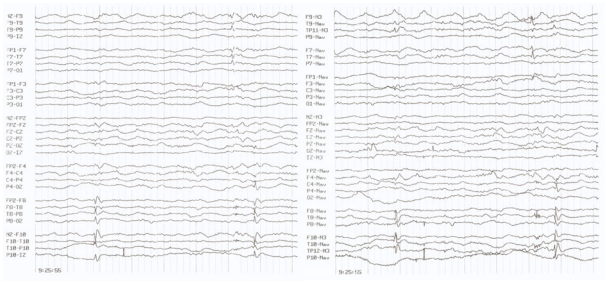
Bipolar **Laplacian**



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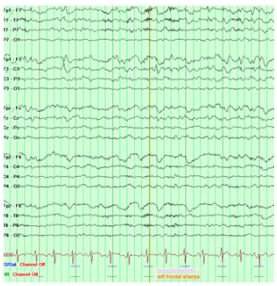
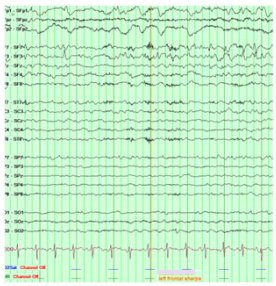
Bipolar

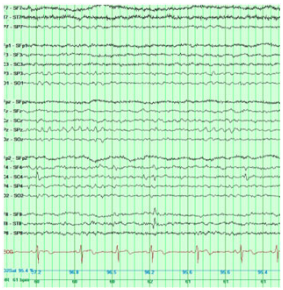


Laplacian

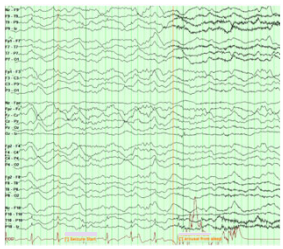


Bipolar

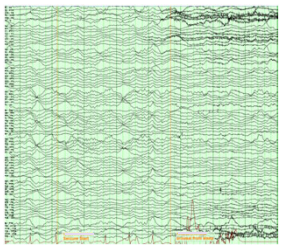
Laplacian



Bipolar 32

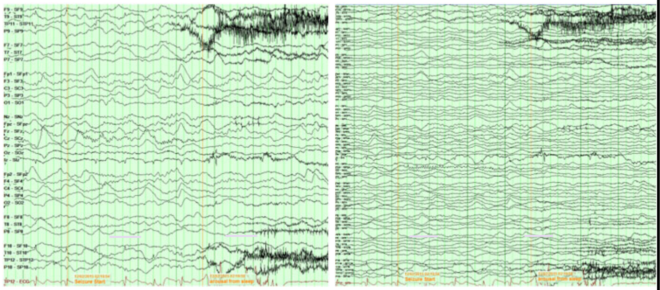


Bipolar 76



Laplacian 32

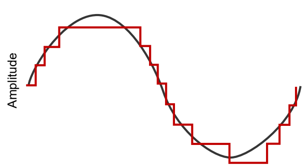
Laplacian 76



FILTERS & DIGITIZATION

FILTERS

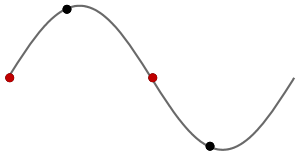
- Analog to Digital Converter (ADC)
- Bits describe the quantum size



FILTERS

Nyquist-Shannon sampling theorem

- Sampling frequency should be at least twice as much as the highest frequency in the signal

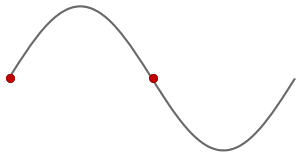


Sample rate / 2 = Nyquist frequency

FILTERS

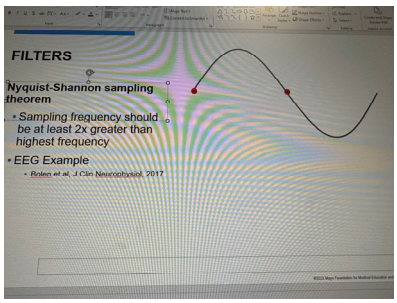
Nyquist-Shannon sampling theorem

- Sampling frequency should be at least 2x greater than highest frequency



FILTERS

- Aliasing: results when a signal frequency is incorrectly displayed because of inadequate sample rate
- For an EEG example, see Bolen et al, J Clin Neurophysiol, 2017:
  - 60 Hz artifact displayed as 4 Hz delta at 15 mm/sec

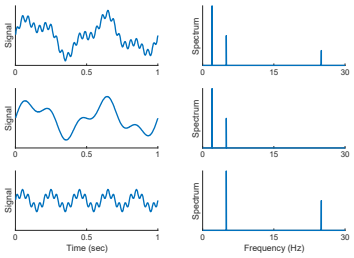


FILTERS

- Remove unwanted frequencies
- Effect easily seen in frequency domain

Low-pass filter

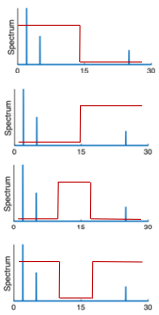
High-pass filter



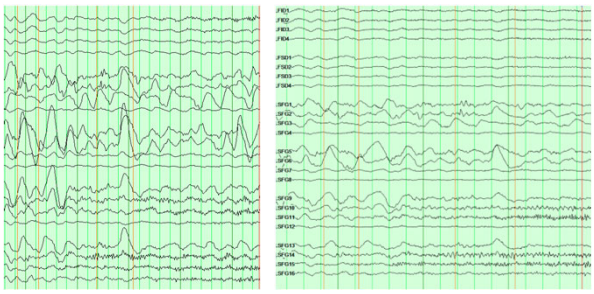
FILTERS

Types

- Low-pass
- High-pass
- Band-pass
- Notch



High Frequency Filter off

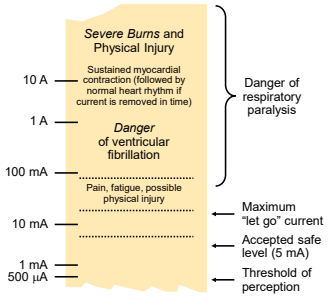


ELECTRICAL SAFETY

- Electricity from Source to Ground
  - Through heart → ventricular fibrillation
- Leakage currents are dangerous
- Goal: avoid unanticipated shocks
- Risks:
  - Susceptible patients – invasive devices, encephalopathy
  - Leakage currents – device chassis, long cords
  - Different ground potentials

CURRENT FOR VFIB

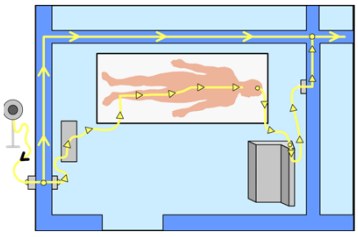
- 100 mA: external
- Direct to heart
  - 50 uA: humans
  - 20 uA: dogs
- Acceptable Leakage
  - 50-100 uA
  - 10 uA in electrically susceptible patients



Redrawn from: Clinical Neurophysiol, Oxford

ELECTRICAL SAFETY RECOMMENDATIONS

- 60 Hz artifact could indicate leakage current
- Do not use extension cords
- Choose outlet in same area as patient
- Use 3-pronged plugs
- Avoid direct connections of patient to ground
- Turn equipment on/off with patient disconnected



Redrawn from: Clinical Neurophysiol, Oxford

KEY POINTS

1. **Polarity**
   - Negative potential = Excitatory or Inhibitory
2. **Montages**
   - Near-field sensitivity: Laplacian > bipolar > referential
3. **Filters**
   - Nyquist: sample 2-5x greater than highest frequency
   - Far-field sensitivity: referential > bipolar > Laplacian
4. **Electrical safety**
   - Acceptable leakage current: 100uA or 10 uA (susceptible)

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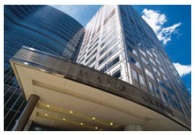
THANK YOU FOR JOINING US IN THIS COURSE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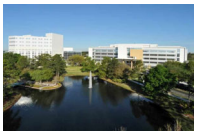
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