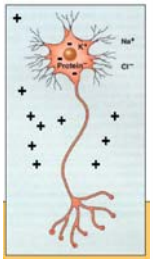
Neural Basis & Technical Details

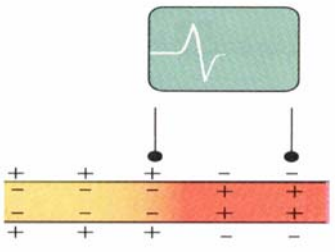
What are ERPs?



Could that work?

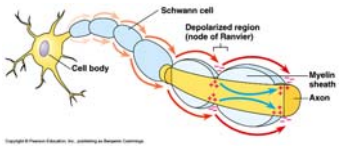

Neurons communicate with electrical signals

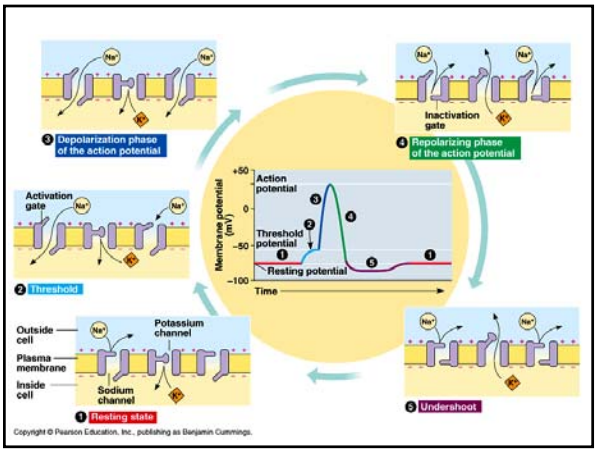




Action Potential

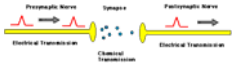
- "All-or-none" change in voltage
- Begins in the axon hillock
- Actively propagated down the axon
- Involves voltage-gated channels





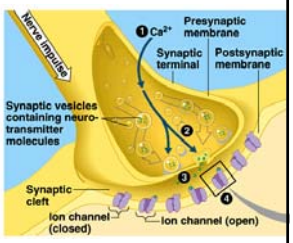
Synapse

- Neural "communication" requires chemical transfer
- Synapse



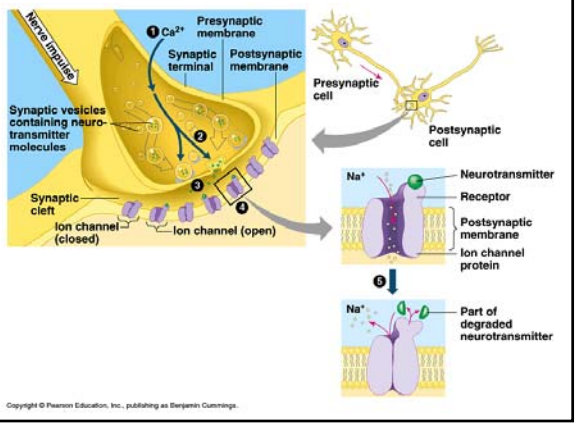
Synapse

- The action potential moves down the axon until it reaches the terminal (synapse)
- Its wave of depolarization opens *voltage-activated Ca^{2+} channels*
- Influx of Ca^{2+} causes *vesicles* to fuse with presynaptic cell membrane
- Transmitter diffuses across synaptic cleft and binds to receptors on post-synaptic cell

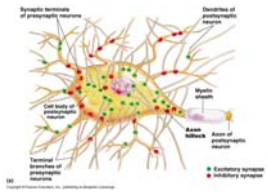


Post-Synaptic Potentials

- When transmitter bins to receptor, ion channels open
- Ions rush into postsynaptic cell
- Excitatory Post-Synaptic Potentials
  - Ions flow into the cell
  - Ions depolarize the cell
- Inhibitory Post-Synaptic Potentials
  - Make post-synaptic membrane more negative
  - Ions flow out of the cell
- Both excitatory & inhibitory nerves coming into most synapses

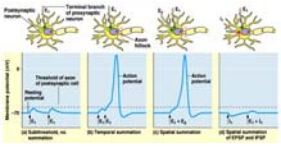


Potentials



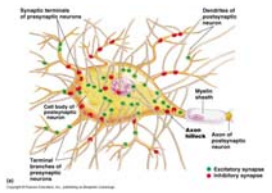
- Action Potentials occur in axons
- Synapses form on axon hillock, cell body, and especially on dendrites

Summation of Post-Synaptic Potentials



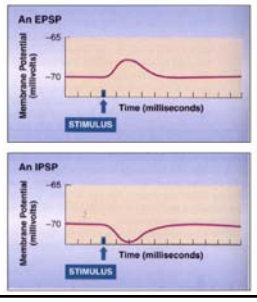
- Temporal Summation
  - If PSPs occur close in time, they summate
- Spatial Summation
  - If PSPs occur in close proximity, they summate
- EPSPs and IPSPs summate (and cancel)

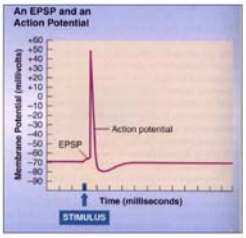
- The way a neuron's EPSPs and IPSPs summate to cause or prevent a spike is a computation
- The impact of a dendritic potential depends on its distance from the axon hillock



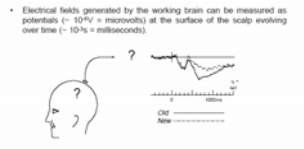
What does EEG record?

- Mostly EPSPs and IPSPs



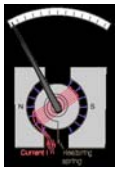


EEG



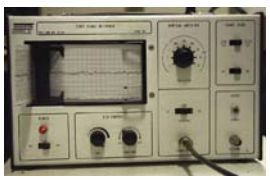
Measuring Voltage

- Galvanometer
  - When a current is passed thru a coil in a magnetic field, the coil experiences a torque proportional to the current
- Voltmeter
  - Connected in parallel to measure voltage change across a circuit element
- What's the difference between current and voltage?

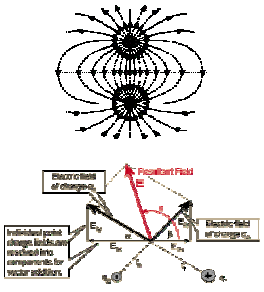


Electroencephalograph

- Instead of moving a needle, the voltmeter moves a pen
- If voltage frequently changes, the voltmeter needle will move up and down leaving squiggles on the page
- EEG
  - Electro "electrical"
  - Encephalo "in the head"
  - Graphy "writing"
- electroencephaloGRAPH is device
  - telegraph
- electroecephaloGRAM is record
  - telegram



Electrical Potentials in the Brain



- Ion flow in the dendrites causes a non-homogeneus distribution of electrical charges
  - An electrical potential
- Electrical field is dipolar
  - Source
  - Sink

Generators & Fields in Volume Conductors

- Potential field Φ generated by point current source has a scalar value at each point in space (x,y,z)

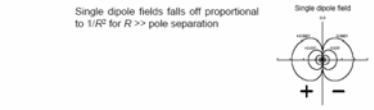
$$\Phi(x,y,z) = \frac{I}{4\pi\sigma R(x,y,z)}$$

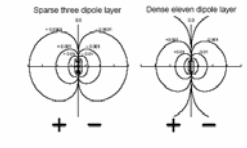
- Value of $\Phi(x,y,z)$ ...
  - *Increases as current I increases*
  - *Decreases as distance R(x,y,z) increases*
  - *varys with conductivity of medium σ*

- Possibility of recording a potential depends on
- Sensitivity of measuring device
- Size of signal
  - Current density
  - Conductivity of medium
- Distance between the source and the measuring device

Fields from multiple generators sum linearly

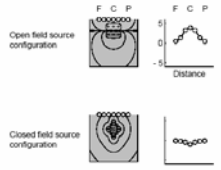
Single dipole fields falls off proportional to $1/R^2$ for $R >>$ pole separation



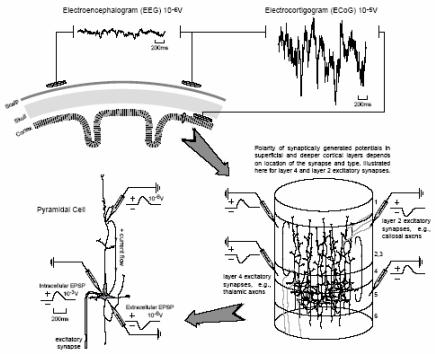


Open and closed field generator configurations

- Fields generated by parallel dipoles add up (open fields) and can be measurable at a distance
- Fields from other non-parallel dipoles tend to cancel (closed fields) and are neglible at a distance

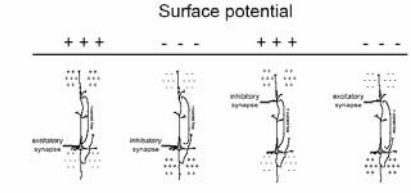


Biopotentials at different scales



Surface polarity depends on location and type of PSP

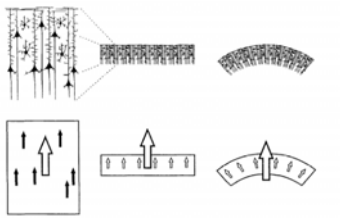
- Excitatory postsynaptic potentials result from ionic current (+ ions) flowing **into** the cell across the synaptic membrane and out elsewhere.
- Inhibitory postsynaptic potentials result from ionic current (+ ions) flowing **out** of the cell across the synaptic membrane and in elsewhere.



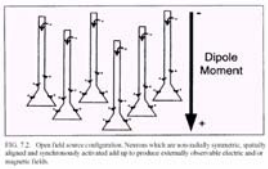
Preconditions

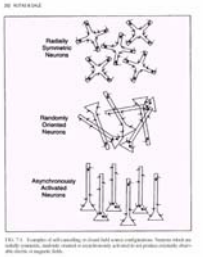
- What conditions are needed to record electrical brain potentials at the scalp?
  - Very sensitive voltmeter (bioamplifier)
  - Possibility of spatial summation
  - Possibility of temporal summation

All together now!



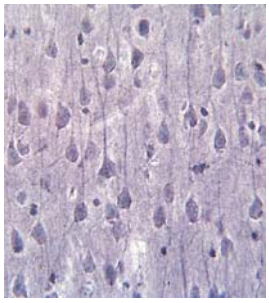
Summates Cancels out





Which brain areas?

- Pyramidal cells in the cortex
  - Open field arrangement
  - Synchronously active
  - Close to the scalp
- Hippocampal neurons
- Brainstem nuclei
- Many nuclei have closed field arrangement ☹
- Do you think we could record potentials from these cells (→) with electrodes on the scalp?



Non-brain areas?

- Eyes
- Muscles
- Heart

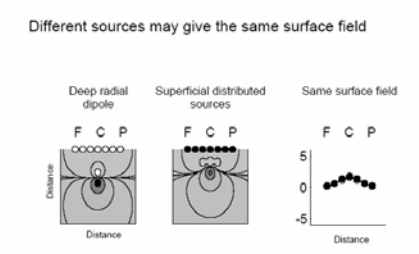
- "Artifactual activity"

Forward problem: Given the generators, determine surface potentials

- Given a set of current sources and sinks in a volume conductor, what field will they generate at the surface?
- Compare: what do 3, -6, and 7 add up to?
- Solution: Calculate the fields generated by each and add them up.
- Tricky, b.c. volume conduction depends on the type of media and its shape: cerebrospinal fluid, skull, scalp, and air have different conductivities. Bone conducts poorly and air not at all for practical purposes.
- But … possible in principle and approximations can be computed in practice. Structural MRI can provide geometry in real heads.

Inverse problem: Given surface potentials, determine the generators

- Given a pattern of potentials on the surface of a volume conductor, where are the current sources are generating it?
- Compare: what numbers add up to make 7?
- Solution: In principle, no way to decide from the surface potentials alone. In a volume conductor (e.g., head), different combinations of sources and sinks can give exactly the same potential at the surface.
- Special case solutions of the inverse problem are possible if further constraints are added
  - requiring the sources to be a small number of dipoles
  - forcing the location of the sources to be in plausible locations, e.g., visual cortex for visual response

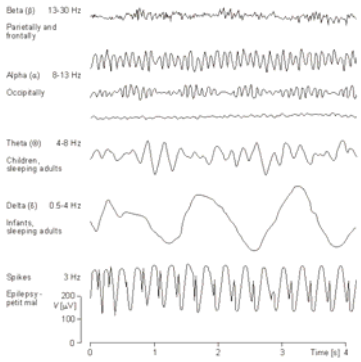


EEG invented 1928

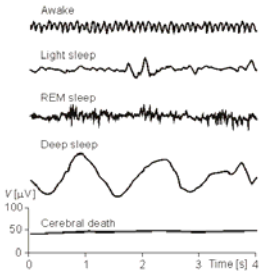
Hans Berger

Early recording set-up

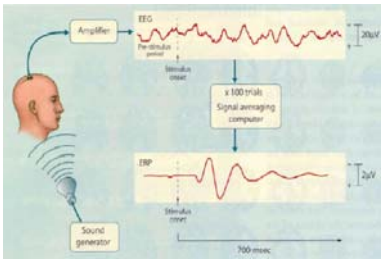
Human Subject



EEG monitors alertness

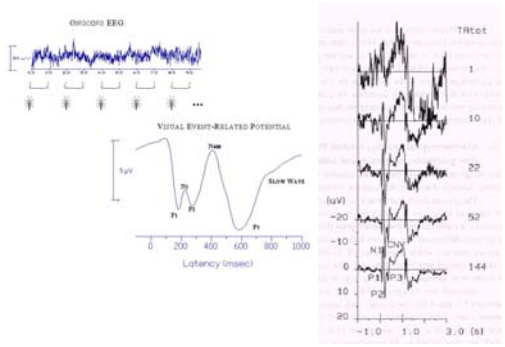


EEG and ERPs

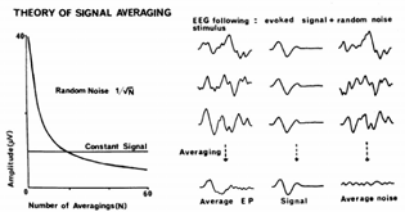


What are ERPs?

- ERPs formed by averaging EEG time-locked to the onset of stimuli that require cognitive processing
- ERPs represent electrical activity associated with the processing of the stimuli
- ERPs can be related to different kinds of cognitive tasks, e.g. attention, memory, & language comprehension



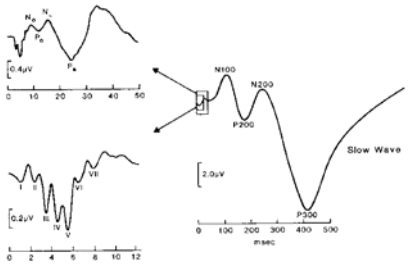
Why averaging works…



What do ERPs reflect?

- Sensory, motor, and/or cognitive events in the brain
- Synchronous activity of large populations of neurons engaged in information processing

ERP Components



Characteristics of ERP components

- Polarity
  - Is it a positive wave or a negative one?
- Latency
  - How long after stimulus presentation does it peak?
- Functional Significance
  - What cognitive (or perceptual) activity is it sensitive to?
  - What makes it bigger or smaller?

Early Components

- Waves I-VI represent evoked activity in auditory pathways in the brainstem
- Driven by sensory factors
  - What are the features of the stimulus?

Later components

- P300, N400
- Sensitive to changes in people
- Sensitive to the meaning of the stimulus
  - Not just its physical characteristics
- Sensitive to information processing demands