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 binds 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

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”
• electroencephalography is device
  – telegraph
• electroencephalogram is record
  – telegram

Electrical Potentials in the Brain
• Ion flow in the dendrites causes a non-homogeneous distribution of electrical charges
  – An electrical potential
• Electrical field is dipolar
  – Source
  – Sink
Generators & Fields in Volume Conductors

- 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

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!

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

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