Week 5

- KW Chapter 6 : Neuroimaging
- KW Chapter 10 : Neocortex

Chapter 6 : Imaging The Brain

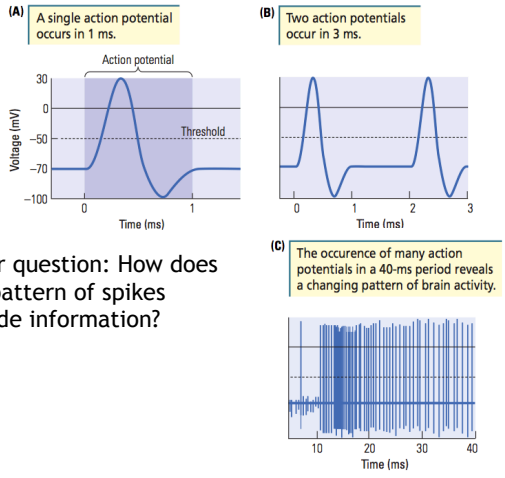
Brain Imaging Techniques : Overview

- Electrical
  - Recording
    - Single Cell, Multiple Cell
      - EEG, ERP
  - Stimulation
- Magnetic
  - Recording - MEG
  - Stimulation - TMS
- Structural
  - X-ray, MRI
- Dynamic / Functional electrical activity
  - metabolism / glucose
  - blood flow, other

Single-Cell recording

- Typically done in non-human animals
- Single electrode recording
- Arrays of electrodes
  - record from multiple cells

Action potential trains



- Major question: How does the pattern of spikes encode information?

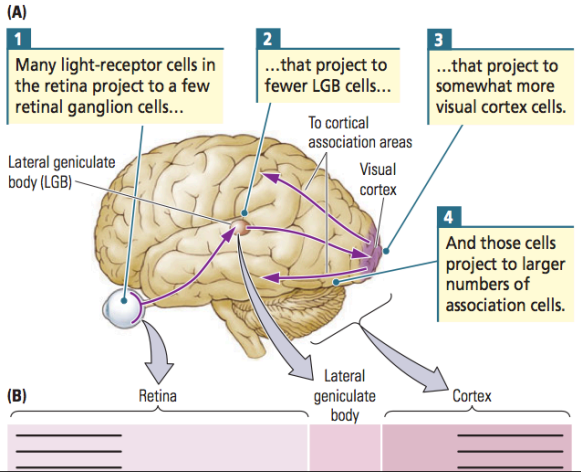
Neuronal Code

- Patterns of neuronal firing
  - steady rate (e.g. “heartbeat” or time counter)
  - bursts, associated with behavior
  - rarely fire at all
  - daily, monthly, or yearly patterns
- How does the pattern of action potentials encode information?
- Example: Pain fibers in the PNS use frequency encoding:
  - low frequency : mild pain
  - high frequency : severe pain
- Example: color sensitive neurons
  - medium frequency : no color
  - low frequency : green
  - high frequency : red

Findings re: Neuronal Code

- Cortical neurons
  - fire about 3x/minute, up to 10x/minute when excited
- Adjacent Neurons may have completely different function
  - e.g. Broca's area: neuron for word perception next to one for word production
- Learning :
  - Newly learned information/skills - requires lots of neurons
  - Old information : more sparsely encoded

Levels of Processing / # of neurons



Levels of Processing / # of neurons

- Sensory input - few to many to few neurons
  - Retina
    - photo-sensitive cells : many, capture low level features (Light & Dark)

      -->
    - ganglion cells : fewer

      -->
    - LGB cells : even fewer

      -->
    - A17 (V1) Primary visual cortex : more cells, respond to visual features (line oreientation)

      -->
    - association cortex : many more cells

      "Grandmother!"

Multiple Neuron Recording : EEG

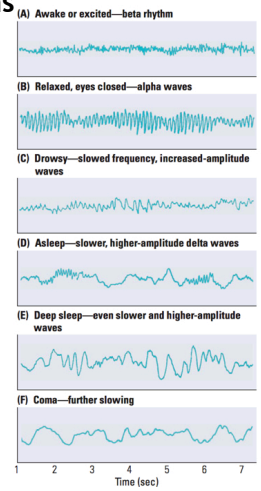
- Neurons fire in synchrony
- Tiny voltages + many many neurons = measurable voltage on the scalp
- EEG : Electroencepha logram

1 Electrodes are attached to the skull, corresponding to specific areas of the brain.

2 Polygraph electrodes are connected to magnets, which are connected to pens...

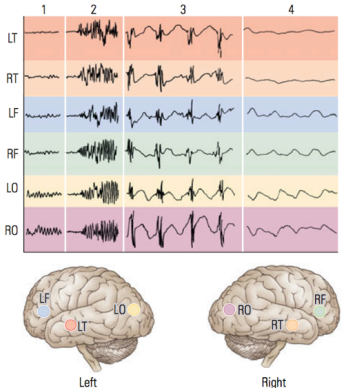
EEG Patterns

- Majority of EEG signal comes from neurons in Layers V and VI
- Pacemaker cells keep these cells synchronized
- Frequency & pattern :
- Faster, smaller, & more complicated with increasing arousal
- Slower & larger amplitude in sleep, coma



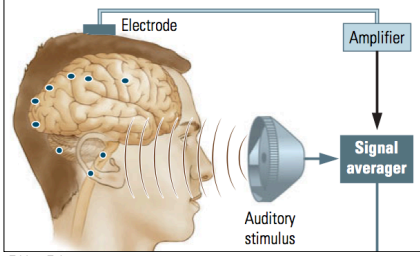
Epilepsy

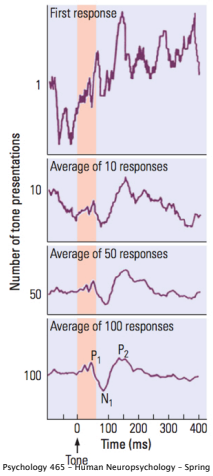
- Seizure
  - large groups of neurons firing all at once
  - out of control
  - pattern spreads
  - can involve entire brain
- Key
  - 1=pre
  - 2=onset
  - 3=clonic
  - 4=coma
- Note largest spikes in RO area - source of seizure?



ERP - Event-Related-Potentials

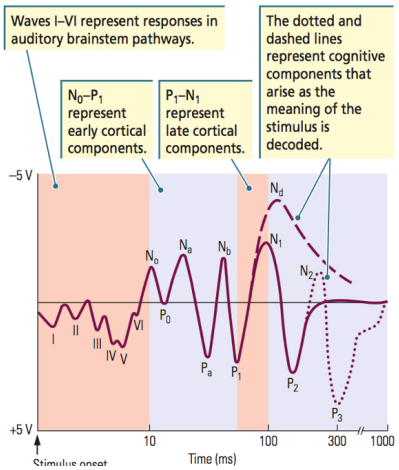
- Can you see "thinking" by watching EEG?
- In a single recording: No, it's too noisy
- By statistically averaging multiple events, a pattern emerges





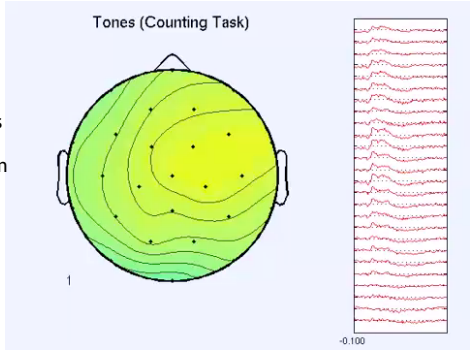
Common ERP patterns

- (P)ositive and (N)egative waves
- Early waves in brainstem (I, II, III, IV, V, VI)
- Later waves in cortex (N0, P0...N3, P3)
- Image: ERP in Parietal Cortex in response to spoken word



Multi-electrode ERP

- An individual's event-related potentials (ERPs) to tones in a simple tone counting task. Right column plots ERPs at 26 scalp electrodes (negative is up). Voltage is represented in color on the cartoon head (cool=negative, warm=positive). Time (in seconds) is printed at the bottom of the column of ERPs. Most prominent ERP deflection is the auditory N1 that peaks around 100 ms post-stimulus.



MEG : magnetoencephalography

- Maxwell-Faraday equation - relates change in Electrical potential (voltage) "E-field" to change in magnetic field "B-field"

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

- Electrical voltages : can be measured with cheap equipment
- Magnetic fields : measured with fancy equipment
  - SQUIDs : Superconducting quantum interference device
  - Requires liquid helium
  - $$$
- Pro: higher resolution

Brain Stimulation

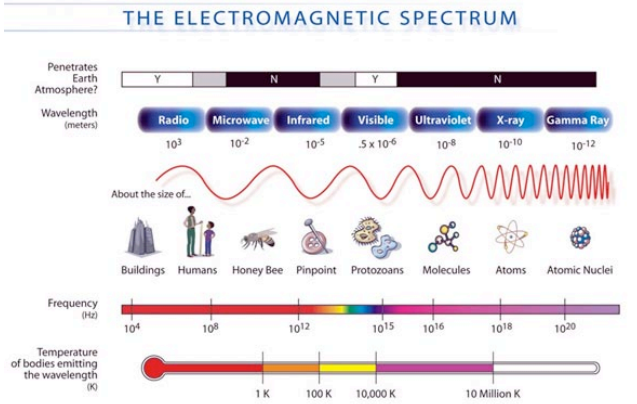
- Electrical
  - Surface
    - often used in brain surgery
  - Intracranial
    - DBS - Deep Brain Stimulation - mostly experimental, used for Parkinson's treatment
    - Very invasive - risks of infection, etc.
- Magnetic
  - TMS : transcranial magnetic stimulation

Transcranial Magnetic Stimulation

- TMS - new, still being researched
- very strong magnetic fields are created in the brain
- magnetic fields cause electrical currents in brain tissue
- mechanism - unknown

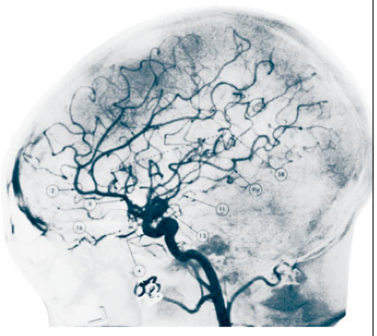
X-Ray techniques

- X-rays : very high frequency (small wavelength) waves
- Ionizing!



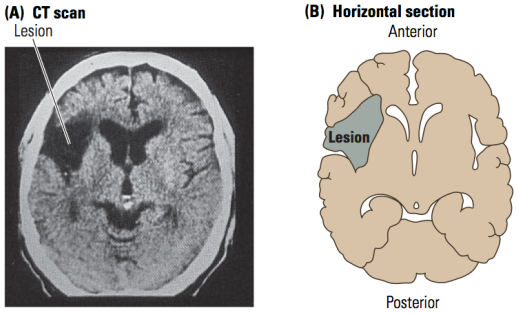
X-Ray Procedures

- Conventional - simple xray of the skull - shows gross features
- Contrast techniques
  - Pneumoencephalography - *air-brain-graph* - inject air into CSF for contrast
  - Angiography - inject material into blood which blocks xrays
- CT



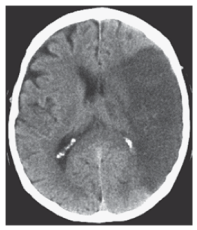
CT : Computed Tomography

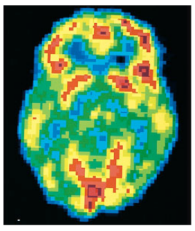
- Xrays are sent through head from all angles
- Computer reconstructs data into 3-D image
- Aka "Computed Axial Tomography" or CAT scan



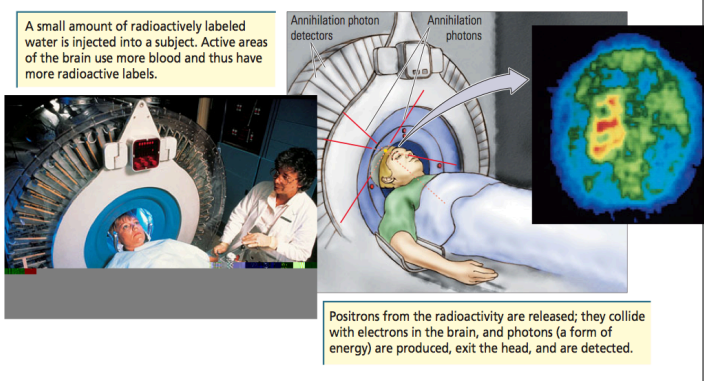
Neuroimaging

- Visualizing the brain *in vivo*
- CT : Computed Tomography
  - xray
  - cheap(er), quick
  - low resolution
- PET : Positron Emission Tomography
  - radioactive injection
  - tag chemicals to image



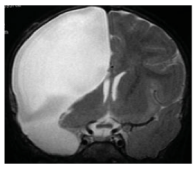


PET Scanner

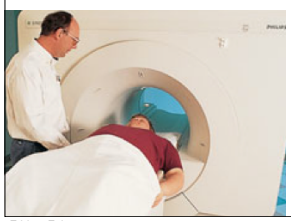


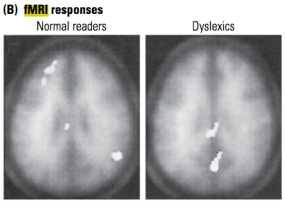
MRI

- MRI : Magnetic Resonance Imaging
  - magnetic fields
  - detailed
  - expensive



- fMRI : Functional MRI
  - metabolism in real time





MR - Spectroscopy

- MRI normally images hydrogen molecules in water (80% of the brain) - Can't see other 20%
- MR Spectroscopy - uses different RF frequency to image non-water chemicals
- Experimental
  - e.g. can detect choline (precursor to Acetylcholine)

MR - DTI - Diffusion Tensor Imaging

- measures directional movements of H_2O molecules
- in ventricles & cell bodies: water molecules are random
- in nerve fibers, water moves along axis of fiber

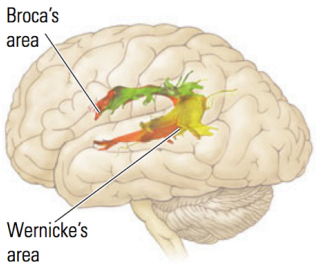
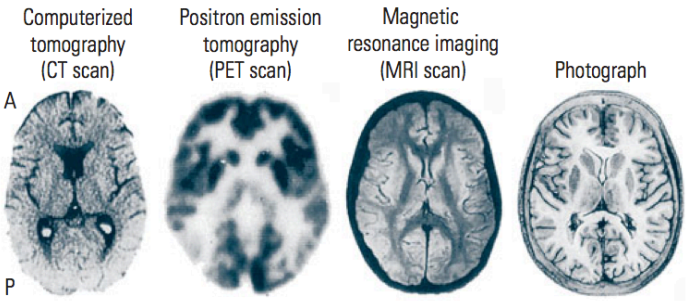


Figure 6.24

Diffusion Tensor Images of the Language Pathways Connecting Broca's and Wernicke's Regions

Comparison of Neuroimaging images



Imaging Comparison

Kind	Time	Resolution	Cost	Risk	Detect Function?
Xray - Conventional	fast	very low	$	☠	✘
Xray angiography	slow	high	$$	☠ ☠	✘
Xray - CAT	medium	medium	$$	☠ ☠	✘
PET	slow	low	$$$	☠ ☠	✔
MRI	slow	high	$$		✘
fMRI	slow	high	$$$		✔

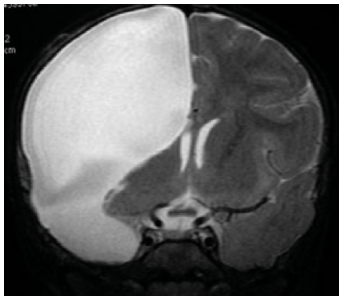
Chapter 10 : Neocortical Function

Case Report : Hemispherectomy

- AR, an 11 year old boy began developing seizures
  - right-sided weakness, difficulty talking (dysphasia)
- Over next six years, hospitalized many times
  - Right handed -> left handed
  - by age 15, IQ dropped 30 points (from 100 to 70)
  - by age 17, he was not testable due to emotional & language problems
- Dx : Rasmussen's Encephalitis
- Tx : removal of most of left hemisphere

Case Report : Hemispherectomy

- Note: image is from another patient with a Right-hemispherectomy



Case Report : Hemispherectomy

- Recover post hemispherectomy
- 10 years later
  - oral language skills : vastly improved (to average)
  - unable to read or write
  - motor skills : improved
    - could walk (with limp)
    - could raise right arm to shoulder level and grasp objects with right hand

How did AR recover?

- Levels of Function
  - Subcortical areas manage, direct, and control cortical areas
- Brain Plasticity
  - brain can respond to injury / damage / dysfunction
  - in AR's case: dysfunctional LH blocking language functions in RH. With LH removed, RH could work better and grow back some functions.

Levels of Function

Level	Function
Cortex	**Control and Intention:** Sequences of voluntary movements. Cognitive maps, relationships between objects, emotional values, motivation, long term planning
Basal Ganglia	**Self Maintenance:** Coordinates voluntary and automatic movements for self-preservation (simple eating, drinking, sex)
Diencephalon hypothalamus thalamus	**Affect and Motivation:** Voluntary movements, but without purpose. Integrated emotional behavior, but mis-directed. Thermoregulation.
Midbrain	**Spontaneous Movement:** Simple motor responses to visual/ auditory stimuli. Automatic behavior (grooming). Stand, walk, turn, jump in response to stimuli.
Hindbrain	**Postural Support:** hiss, bite, growl, chew, lick in response to stimuli. Standing, postural reflexes, sleepwalking.
Spinal cord	**Reflexes:** stretch, withdraw, scratch in response to stimuli

Decorticate Rats

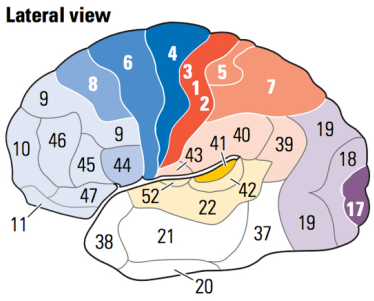
- Decorticate rats behave in many ways normally
  - eat, drink
  - can run simple mazes
- Untrained observers have difficulty telling them apart from a rat with a cortex
- Decorticate rats
  - don't build nests
  - do not hoard food
  - can't do skilled movements with tongue & mouth
  - can do simple learning

Cortex - what is it good for?

- Conclusions : Neocortex not necessary for basic survival
- Neocortex is a "new layer" evolutionarily developed
- Manages complex and new combinations of behavior

Cortical Mapping Ideas

- Brodmann's Map
- Primary/Secondary/ Tertiary
- Developmental
- Primordial zone
  - myelinates early : part of motor & somatosensory cortex
- Secondary zone (borders primordial zone)
  - myelinates next
- Tertiary zone (association)



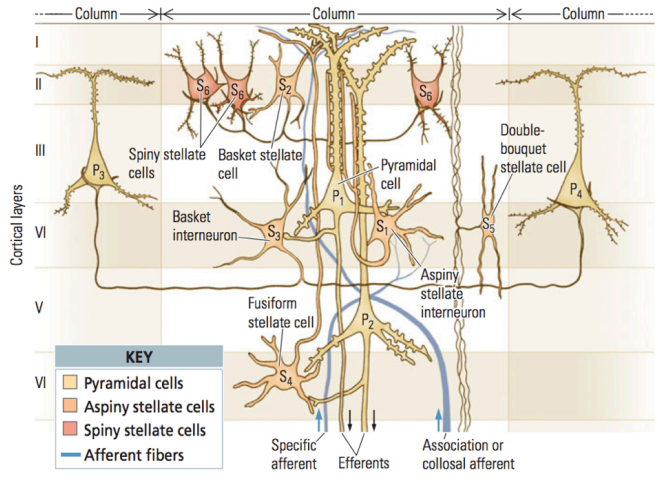
Cortical Neuron Types

- Spiny
  - has dendritic spines
  - Examples:
    - Pyramidal cells
      - pyramid-shaped
      - 75% of all neurons
      - efferent (project out of brain, e.g. motor neurons)
    - Stellate cells
      - star-shaped

Cortical Neuron Types

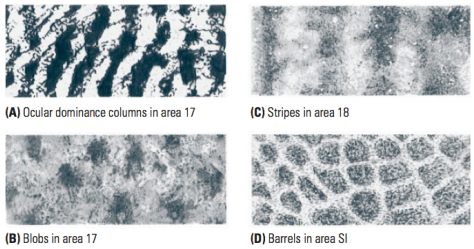
- Aspiny
  - no dendritic spines
  - Inhibitory, use GABA and also use other NTs
  - diverse shape & chemistry
  - Examples:
    - basket cell
- Columns:
  - cells in vertical arrangement mostly talk to each other

Cortical Columns



Cortical Columns, Spots & Stripes

- Cortical neurons function in narrow columns
- Up to 300 neurons in 1mm wide strip
- "Column" or "Module"
- How determined?
  - radioactive staining - inject tagged AA into eyeball
- Not widespread agreement on definition or function

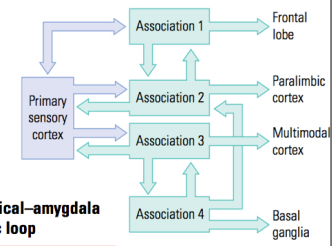


Representation & Mapping

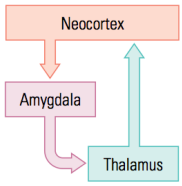
- Early views
  - brain areas have mapping to specific topics
  - e.g. motor cortex maps to body muscles
    - sensory cortex maps to skin receptors
- Later research
  - found multiple maps in many parts of the brain
    - e.g. monkeys: approx 30 areas mapping to vision
  - found multimodal / polymodal areas
    - combining sensory / motor information
  - found maps are widely distributed / general (not as localized as thought)
- Conclusion:
  - # of maps --> amount of "intelligence" ?

Cortical Systems & Subcortical Loops

- Cortex connections can be divided into 5 major areas



- Subcortical connections form loops between subcortical and cortex (6 major ones discovered)



The Binding Problem

- How does the brain integrate sensory perception into a *gestalt* (a "whole")
- Possible solutions
- 1. A top-level cortical area binds them together
  - problem - this doesn't seem to exist
- 2. All areas are interconnected and share information
  - problem - not all areas are connected
- 3. Intracortical networks among subsets of regions
  - may actually be how the brain works?
  - called "integration"

- Still not really solved

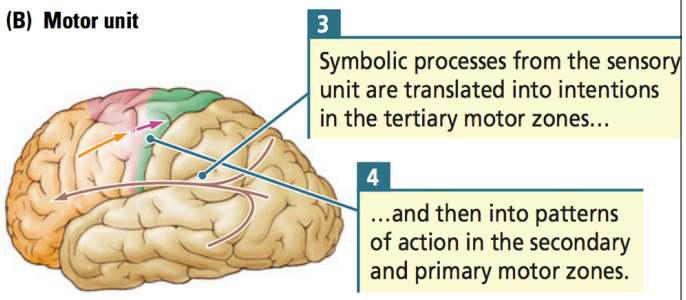
A Hierarchical Model : Structure

- Alexander Luria's model
- Cortex : two parts
  - posterior : sensory
  - anterior : motor

- Each part has 3 zones:
  - primary
  - secondary
  - tertiary (association)

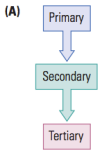
A Hierarchical Model : Function

- Processing is serial:
  - posterior (1,2,3) --> anterior (3,2,1)

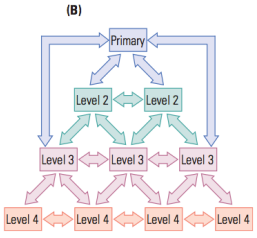


Luria's model : accurate?

- Problems
  - serial connections may not exist
  - subcortical connections bypass cortex



- Newer models:
  - still hierarchy, but some levels bypass each other
  - includes parallel processing.
- "Distributed Hierarchy"



Are Humans Special?

- Do Human brains have any unique properties?
- Biological, Psychological and Theological Question

- Human brains have
  - High density of neurons with fast conduction velocity
    - --> increased processing capability
  - Von Economo Neurons
    - large bipolar neurons in cingulate cortex (also seen in great apes, but to a lesser extent)
    - develop around age 4
      - might hold "theory of mind"?
      - defective in Autism?