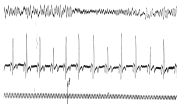
Studying the Brain: Recording Studies

Getting Evidence About How the Brain Works

- Both lesion and stimulation studies investigate the brain by trying to alter one or more of its components and determining what effects that has
  - Infer from the effect when altered what the component of the brain does
- Alternative strategy
  - Record from parts of the brain as it is working
    - to determine what parts are involved in specific tasks
    - and from that information, infer what they do

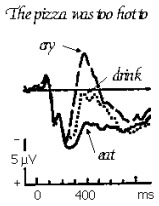
Recording Electrical Activity At the Surface of the Brain



- Electroencephalogram (EEG): Electrodes placed on the skull detect ongoing electrical signal
  - Berger (1930) distinguished large amplitude, slower waves during rest (8-12 Hz alpha rhythms) and lower-frequency, faster waves after stimulation (12-30 Hz beta rhythms)
  - Subsequent discovery of both higher-frequency (>30 Hz gamma rhythms) and lower-frequency (4-7 Hz theta and 0.1-4 Hz delta rhythms) oscillations
    - Much of the focus directed at the lower-frequency rhythms associated with stages of sleep
- Challenge—figure out what these rhythms mean about underlying brain activity

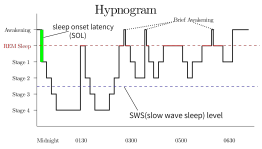
Evoked Response Potentials (ERPs)

- By time-locking the EEG signal to the presentation of a stimulus and averaging over many trials, researchers could extract a detectable signal
  - Thought to reflect the brain's processing of that stimulus
    - N400 (discovered at UCSD by Marta Kutas) thought to reflect violations of semantic expectations
- ERP studies can provide high resolution information about timing of activity
  - But little information about where the signal is coming from
    - As there is no general solution to the inverse problem--inferring from what is recorded at different electrodes to the source of the signal



What Do the Ongoing Brain Rhythms Represent?

- Challenge: how to link different rhythms (alpha, beta, gamma, etc.) with different mental activities
  - The one clear case: Slow wave rhythms (theta and delta) correlate with the transition to and actual sleep
    - Allow researchers to differentiate distinct sleep stages
    - Including one which was more like rhythms while awake during which individuals exhibit rapid eye movement

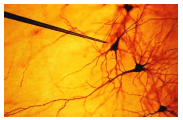


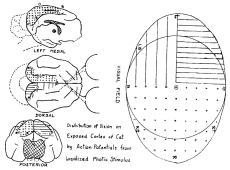
Using EEG to study brain dynamics

- The electrical activity detected by EEG originate not from action potentials
  - but from changes in the resting potential of populations of neurons
- Neurons are more likely to produce action potentials when stimulated when they are hypopolarized than when hyper polarized
  - by analyzing relations between oscillations in different brain regions (e.g., when they are temporarily synchronized with each other), researchers can investigate how information is passed between brain regions
- Recent observations of waves of sub-threshold activity moving across the neocortex, which have been interpreted as regulating processing in different cortical regions

Recording From Neurons

- The recognition that neurons transmit an electrical signal motivated the search for ways to record the electrical activity of individual neurons, finally achieved in the 1930s by inserting electrodes near neurons
  - Researchers could then investigate what stimuli would generate activity in specific neurons
- Talbot and Marshall mapped the receptive fields of individual neurons by correlating locations of stimuli with individual neural response
  - Confirming the idea of topological maps developed from lesion studies

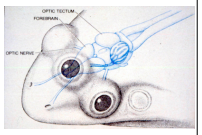




Frogs Lead the Way to Understanding What Visual Neurons Do

- In the 1930s Haldan Hartline differentiated cells in the frog's optic nerve that responded to light in their receptive fields
  - *on cells* responded when a light was on
  - *on-off cells* responded when a light switched from on to off or vice versa
  - *off-only* cells responded only when a light was off

  and correlated responses with intensity of light
- Following up, Horace Barlow demonstrated that with *on-off cells*, the response was less if the stimulus exceeded the receptive field
  - Conclusion: neurons are tuned to spots of light



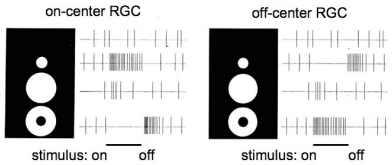
Discussion Question

Pretend you are a frog equipped with the ability to detect small spots moving across your visual field. How could this be useful to you?

A. It provides a way to detect potential mates when they are moving near you
B. It provides a way of detecting insects that might make a nice meal
C. It provides a way for investigators to figure out how your vision system works
D. It provides a way to detect potentially dangerous projectiles so that you can duck to avoid them

Center-Surround Cells in Retina

- Turning to retinal ganglion cells in cats, Steven Kuffler found that in when the cat was in darkness or diffuse light the neurons fired at a basal rate (1-20 Hz)
  - Some cells exhibited an increased firing rate when a light spot was surrounded by darkness (*on-center*)
  - Others exhibited an increased firing rate when a dark spot was surrounded by light (*off-center*)
- Same response properties of neurons in the lateral geniculate nucleus (LGN) of the thalamus



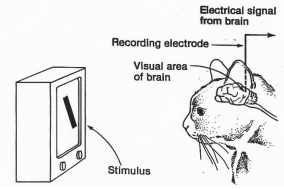
Discussion Question

Center-surrround cells register the difference in light levels, not the actual amount of light. What functional significance could this have?

A. It allows organisms to detect boundaries between objects
B. It allows the visual system to work at varying light levels
C. It reflects the fact that our senses aren't there to paint a picture of the world, but to detect what is important in it
D. Probably none. It is a crazy way to set up a visual system

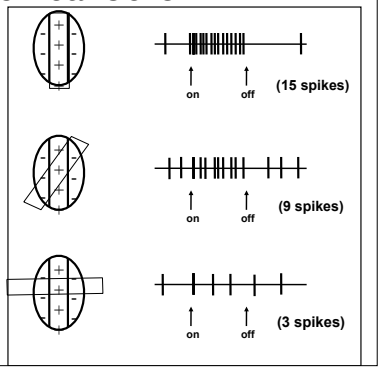
Turning to Cortex

- When a technique works once, it makes sense to try it again
  - David Hubel and Thorsten Wiesel, working in Kuffler's lab, tried to replicate his achievement in the striate cortex
    - But failed, and failed, and FAILED
- One day while they were inserting a glass slide into their projecting ophthalmoscope, it stuck, creating a bar of light on the screen
- Hubel reports that "over the audiomonitor the cell went off like a machine gun"
- Bars of light (edges), not dots, activate cells in striate cortex



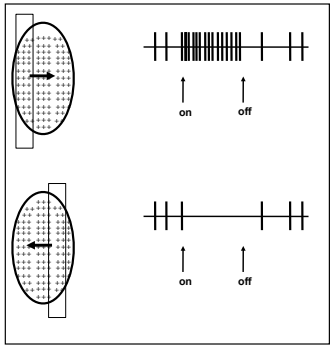
Hubel and Wiesel's Simple Cortical Cells

- Many of the cells Hubel and Wiesel tested in occipital lobe responded to bars of light
- But only if they were properly oriented



Hubel and Wiesel's complex cells

- Some cells Hubel and Wiesel tested responded to bars of light anywhere in the receptive field of the cell
- Or, if they were moving in a preferred direction across the field



Single-Cell Recording

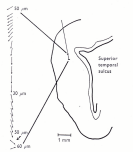
- Once the technique of inserting an electrode next to a neuron and recording its electrical behavior was developed it became the workhorse of sensory (especially visual) neuroscience
- Challenge 1: Finding the full set of stimuli that elicit response in a given neuron
- Challenge 2: Determining what that neuron is contributing to the processing of a given stimulus
- Challenge 3: It might not be the activity of individual cells but of multiple cells acting together that is the relevant brain activity

Lesion vs. Recording Studies

- Lesion studies show what ability is lost when a particular component of the mechanism is destroyed
  - But cannot show that the component is itself responsible for the ability
- Recording studies (single-cell recording, PET/fMRI) show what areas of the brain are active during a task
  - If a brain area is involved in a task, it should be active when the task is performed
    - But again, the converse is not necessarily true
- Neither type of evidence is alone conclusive, but for both types of evidence to be found by chance seems increasingly less plausible
  - Hence, when both are found, inhances the probative power of the evidence

Motion Processing

- In 1974 Zeki identified a cortical area (V5/MT) in which cells were responsive to the direction in which a stimulus was moving
  - Some cells responded to complex patterns such as opposite direction of movement in each eye
    - What would that tell you?
- At the time there were no reports of patients unable to detect motion, but Zihl et al., 1983 described a patient who lacked motion perception
  - MT lesion could explain her deficit



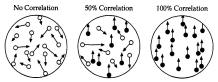
Discussion Question

What would it be like to have a lesion in MT destroying motion perception?

A. I wouldn't be able to detect objects coming at me
B. It would be like seeing a series of still photographs projected rather slowly
C. It would be difficult to walk around since I wouldn't be able to pick up cues from the relative motion of objects round me
D. Other (be prepared to specify)

Combining Methods to Determine Function

- Movshon and Newsome combined lesion studies and recording studies with stimulating a brain area with a mild electrical charge
  - Trained monkeys to respond differently if stimuli were perceived as moving in the in same direction or randomly
  - Then presented the test case in which 50% of the stimuli were moving in the same direction
    - Monkeys responded with random answers
      - Recordings from MT cells predicted their answers
      - Microstimulation of MT cells biased their answers



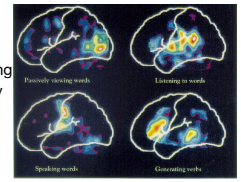
Neuroimaging

- Challenge: how to record brain activity non-invasively
- Positron emission tomography (PET)
  - Derives a signal from radioactive decay
- Magnetic Resonance Imaging (MRI)
  - Derives a signal from the altered electron spin in a magnetic field
- Structural MRI uses the difference in frequency from atoms in grey and white matter to construct an image
- Functional MRI (fMRI) detects changes in deoxyhemoglobin resulting from changes in blood flow that *exceed* oxygen required by neurons
  - Blood oxygen level-dependent (BOLD) signal
- From the signals received by receptors that surround the individual's head, use computerized tomography to generate a 3-D map indicating the activity at each location
  - Researchers often visualize the activity in slices through the brain

Neuroimaging: Relating Signal to Cognition

- Just as with single-cell recording, what one can infer from the results of a PET or fMRI scan depends on the input stimulus/task
- Researchers must find a means of relating inputs/task to the signal
  - During any task there will be activity throughout the brain (it is not dead when no task is presented)
- One of the most widely used strategies for relating task to detected activity is subtraction
  - An approach first developed by Donders in the 19th century for reaction time studies
    - Compare two different task conditions and subtract the time required for one from that required for the other
  - In neuroimaging, compare two tasks conditions and subtract blood flow produced by one task from that produced by another (baseline) task

Neuroimaging: The Verb-Generate Task



- Four subtraction conditions
  - Passively viewing words - resting
  - Passively listening to words - resting
  - Speaking viewed words - passively viewing words
  - Generating and speaking verb in response to viewed words - speaking viewed words
- Last subtraction resulted in increased activity in the left prefrontal cortex, anterior cingulate, right cerebellum
  - The researchers contended that the left prefrontal cortex reflected semantic processing
  - This was one of the first studies to highlight the anterior cingulate, but they and others assumed it was involved in executive control

Discussion Question

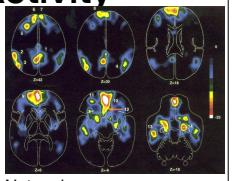
You are trying to determine how the temperature in a glass of water varies with time of day. While you see a pattern (warmer during the day, colder at night), you notice a great deal of variability in the measurements of the temperature. What do you make of this?

A. Ignore it. Compute the average per three-hour and use that in your study
B. Include all the measurements and try to figure out how amount of daylight corresponds to each temperature change
C. Assume that the average is due to daylight and search for some other source of heat else that explains the rest of the data
D. Assume that the average is due to daylight and search for something within the water and glass that explains the rest of the variability in the data

Signal vs. Noise

- Almost all measurements of variables exhibit variability
- Common to assume that much of it just represents noise
  - Averaging the measurements cancels out the noise and leaves the signal of interest
- Question: might the remaining variability constitute a signal
  - of the effects of other external causes
  - of ongoing activity in the system
- Can this *extra* variability be turned into a signal?

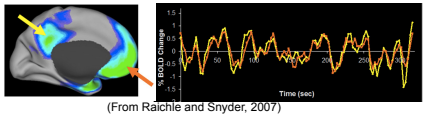
Using fMRI to Study Endogenous Activity



- Early PET and fMRI studies related blood flow (a proxy for brain activity) directly to a task condition
- In the mid-1990s Raichle and his colleagues identified brain regions that were consistently less active in task conditions
  - Leading to the idea of a *Default Mode Network*
  - "This consistency with which certain areas of the brain participate in these decreases made us wonder whether there might be an organized mode of brain function that is present as a baseline or default state and is suspended during specific goal-directed behaviors" (Raichle et al., 2001)

Using fMRI to Study Endogenous Activity

- Biswal et al. (1995) obtained BOLD values every 250 msec following hand movements and found synchronized oscillations (< 0.1 Hz) across motor areas bilaterally
  - Functional connectivity MRI (fcMRI)
- Greicius et al. (2003) applied this approach to the Default Mode Network: areas in the Default Mode Network were found to oscillate in synchrony



(From Raichle and Snyder, 2007)

Multiple Oscillating Brain Networks

- Other brain areas also exhibit synchronized oscillations in BOLD signal in the resting state, but these are uncorrelated with oscillations in the Default Network
  - Network of areas active in attention demanding tasks:
    - Includes intraparietal sulcus, frontal eye field, middle temporal region, supplementary motor areas, and the insula (Fox et al., 2005)
  - Mantini et al. (2007) identified six networks
    - Each anti-correlated with the others
- "A consistent finding is that regions with similar functionality—that is, regions that are similarly modulated by various task paradigms—tend to be correlated in their spontaneous BOLD activity" (Fox and Raichle, 2007).
- NOTE: These networks are identified in the resting state when they are not invoked by tasks
  - These networks are endogenously active and only modulated by tasks