Studying the Human Brain: EEG and fMRI

The Challenges of Studying Human Brains

- Ethical limitations prohibit invasive studies of human brains
  - Except when they can be justified in a therapeutic context
- Limits of experiments of nature
  - Lesions follow things like blood vessels, and don't follow regions devoted to particular neural operations
- Even getting access to postmortem human brains for studying anatomy is difficult
- Challenges:
  - What signals from the brain can be detected from outside?
  - How should these signals be interpreted?

Discussion Question

Why not just ask people to report (introspect) on how they think

- People cannot tell you how they carry out cognitive tasks
- When people try to report on their cognitive activities, they make up stories (metaphors)
- People might know how they reason through problems, but they don't have any knowledge about where these activities occur in the brain
- Other

Psychology, Especially Cognitive

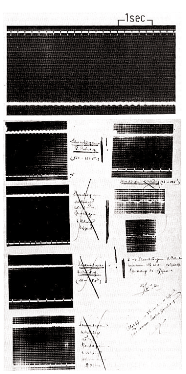
- Traditionally, psychologists did not have any direct access to what is occurring in the brain
  - Instead, they focused on behavior
    - Behaviorism: Explanations should focus primarily on behavior or at least be in behavioral terms
- The Cognitive Revolution (1960s) challenged the explanatory limits
  - OK to posit theories about internal operations—operations that operated on information/representations
  - But evidence still came from behavior
    - Errors in performance
    - Reaction times
- For psychology to link its accounts to the human brain, some means of getting a relevant signal from the brain was required

Hans Berger

- A psychiatrist with a long interest in psychic phenomena (e.g., extrasensory communication), Berger developed a technique for recording electrical activity from the surface of the skull
- Early in his career he was drawn into the 19th century fascination with energy, especially energy conservation, and mental phenomena
  - Energy originated from metabolism, so he developed techniques to measure blood flow in patients with craniotomies and correlated it with mental activities the patients performed
  - Subsequently, theorized about transformation of energy into heat, electrical activity, and psychic energy
- For the most part, kept these interests separate from his day job as psychiatrist and physician-in-chief at the University of Jena

Recording from the Skull

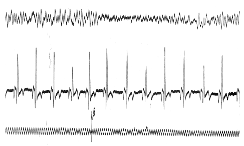
- Electrical activity at the skull initially reported by Caton in 1875 and Berger periodically tried to follow up
  - In the wake of numerous failed attempts, Berger pursued a project of electrical stimulation of the exposed brains of patients
  - But after stimulating one patient in 1924, he transferred the connectors from the electrode to a galvanometer used to measure heart rhythms to record current and got a very weak signal
    - Challenge: to enhance and interpret the signal
  - "Is it possible that I might fulfill the plan I have cherished for over 20 years and even still, to create a kind of brain mirror: the Elektrenkephalogramm!"



Electrophysiological Recordings

The first waves Berger (1930) distinguished and reported on were large in amplitude and relatively low frequency (8-12 Hz) while subjects were resting quietly

Then detected lower frequency, faster waves after providing stimulus to subject (12-30 Hz beta rhythms)



Discussion Question

How should we interpret the difference between alpha waves while resting and beta waves when responding to a stimulus

- The faster rhythms in beta waves indicates the brain must work faster when actually responding to a stimulus
- The higher amplitude during alpha waves indicates that resting allows deep relaxation in brain activity
- All you can tell is that the brain is in a different state, not how each state figures in activity
- Other

Establishing EEG as a Research Tool

Berger was an eccentric and not a major figure in brain research, so his work might not have had much uptake but for attracting the interest of a giant in the field, Lord Edgar Douglas Adrian

- Adrian has been a major force in recording action potentials, showing that action potentials were all-or-none affairs and successfully recording from a single nerve

Adrian replicated and began to extend Berger's findings, including in epilepsy

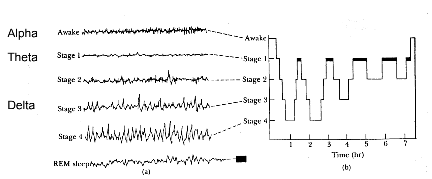
- Start of tradition of finding altered EEG rhythms in disease and turning these altered rhythms into a diagnostic tool

Extending EEG to Other Frequencies

- Gamma waves (>30 Hz)—could not be easily detected with analog devices so became focus of studies only much later
- Delta waves (1-4 Hz)
  - Found in sleep by Grey Walter, working in England
    - Common in deep or slow wave sleep
- Theta waves (4-7 Hz)—identified in the hippocampus by Jung and Kornmüller (1938)
  - Only much later, recognized as a timing signal to which activity in hippocampus was synced
  - Later oscillations in the same frequency range detected in progression to sleep

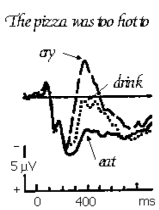
EEG and Sleep

- Initially it was difficult to link EEG to cognitive activities in a way that was informative
- But it was found to provide a useful measure of sleep
- Starting with Loomis in 1937, EEG has been used to distinguish sleep stages:
  - Slow wave sleep (delta rhythms: stages 3 and 4)
  - Rapid eye movement (stage REM) first discovered by Klaue in 1937 in cats—activity that more resembles the wake state



Evoked Response Potentials (ERPs)

- One solution to linking EEG to cognition was to time lock the EEG signal to the presentation of a stimulus and average over many trials
  - 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



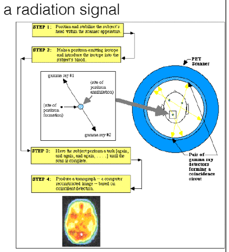
Clicker Question

What is directly measured in PET and fMRI studies

- The collective spiking of many neurons
- Blood flow in the brain
- Magnetic fields generating by neurons
- The binding of chemicals to the receptors on neurons

Neuroimaging: PET

- Positron emission tomography (PET)
  - Employs a radioactive compound to provide a radiation signal
    - 2-deoxyglucose is transported to cells like glucose but not metabolized
      - Builds up in cells as they recruit glucose for energy
    - Water labeled with ^{15}O is carried by the bloodstream
      - Increasing with the increased blood flow as energy is needed
  - The products of the radioactive decay (gamma rays generated as an emitted positron collides with an electron) are detected by a scanner when they arrive simultaneously
    - Computerized tomography is used to generate a three-dimensional image from which slices in any direction can be viewed



Neuroimaging: MRI and fMRI

- Magnetic Resonance Imaging (MRI)
  - In a strong magnetic field, hydrogen nuclei align the axes of their spin
    - The energy from a radiowave pulse perturbs this alignment
    - When the pulse ends, nuclei return to the low-energy aligned state
      - And release radiowaves with a specific frequency
- 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
- The question of why blood flow exceeds that required to provide oxygen to neurons is still a matter of serious dispute

Neuroimaging: Relating Signal to Cognition

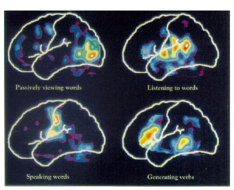
- Just as with single-cell recording, what one can infer from the results of a PET or fMRI scan depends on the input stimulus/task
- Researchers must find a means of relating inputs/task to the signal
  - During any task there will be activity throughout the brain (it is not dead when no task is presented)
- 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

Clicker Question

What is the assumption of "pure insertion"?

- The radioactivity used in PET is cleanly inserted into individual neurons as they fire
- Inserting an additional task activates a responsible area with affecting other cognitive activities
- Inserting more blood into a brain region causes it to increase its activity
- Other

Neuroimaging: The Verb-Generate Task

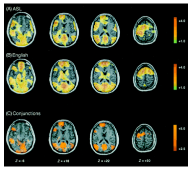


- Four subtraction conditions
  - Passively viewing words - resting
  - Passively listening to words - resting
  - Speaking viewed words - passively viewing words
  - Generating and speaking verb in response to viewed words - speaking viewed words
- Last subtraction resulted in increased activity in 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

Assessing the Credibility of Neuroimaging

Roskies: Are neuroimages comparable to photographs?

Why do we treat photographs as more reliable than paintings?



fMRI during spontaneous production of a narrative in A: ASL and B: English. C: conjunction (Braun et al., 2001)

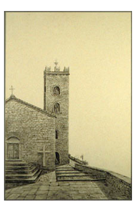
Bedroom in Arles

Joshua Louis Simon Van Gogh

Painting from Memory vs. Photograph

Frank Magnani left his childhood home of Pontito, Italy in 1958 never to return. He took up painting after moving to San Francisco and painted from memory scenes from his childhood. In 1987 Susan Schwartzenberg photographed the same scenes as they appeared at that time

Painting from Memory vs. Photograph



Discussion Question

In what way are photographs more reliable than paintings?

- They aren't
- The image in the photograph directly reflects what is before the lens
- The image in the photograph is partially determined by what is before the lens
- Other

Roskies: Downplaying the Similarities of Neuroimages to Photographs

- Photograph and what is photographed share visual properties
  - Not true of neuroimages
- Photographs are causally dependent on their referents in a straightforward way
  - We do not understand how neuroimages are dependent on brain activity
- Photographs are independent of the beliefs of the photographer
  - Neuroimages are dependent on
    - Way the task is designed
    - Subtraction performed
    - Choice of statistical analysis

Klein: Challenges in Using Neuroimages as Evidence

Two Directions to Consider:

- From Psychology to the Brain (forward inference): appeal to cognitive psychology to interpret neuroimages
- From the Brain to Psychology (reverse inference): appeal to neuroimages to test cognitive theories

From Psychology to the Brain

- Host of challenges in adapting a psychological theory to interpret brain data
  - What do brain areas represent?
    - Modules in a strong sense (relatively independent processing components) (recall pure insertion)
    - Hotspots in a highly integrated network
      - Klein: use neuroimaging as evidence in the debate How?
    - Do areas represent types of processing or types of information?
    - Common process versus multiplexing
      - Left posterior lateral fusiform area active in lots of tasks
        - Price and Friston: always performs the same task of integrating sensory cues with motor outputs
      - Cognitive ontology challenge: what are the basic cognitive activities?

From Brain to Psychology

- Reverse inference proper:

(P1) If a subject judges cognitively, there is activity in region R

(P2) Task T (contemplating action-vs.-inaction) cases causes <u>activity in region R.</u>

Therefore, task T is done via cognitive judgment

  - Invalid argument form
- What can one infer from brain data
  - A given cognitive theory is consistent with neural data
    - This is extremely weak
      - Cognitive theories make few predictions
      - Can easily be amended to handle recalcitrant data
- Cognitive theories made more likely by imaging data
  - Challenge of identifying the probabilities

Klein: Exploration, not Confirmation

- *Data-driven* versus *hypothesis-driven* research
  - Recognizing that science often involves testing (esp. falsifying) hypotheses doesn't tell us much about how to go about developing new hypotheses

- Traditional philosophy of science emphasized confirmation/ falsification and dismissed discovery as not a topic for philosophy
  - Mechanist philosophers of science have emphasized discovery
    - Seek to identify heuristics (fallible but useful strategies) to advance new hypotheses
  - Hope (is it more than a hope?) that detecting activity in neuroimaging might contribute to developing new hypotheses (a data-driven endeavor)