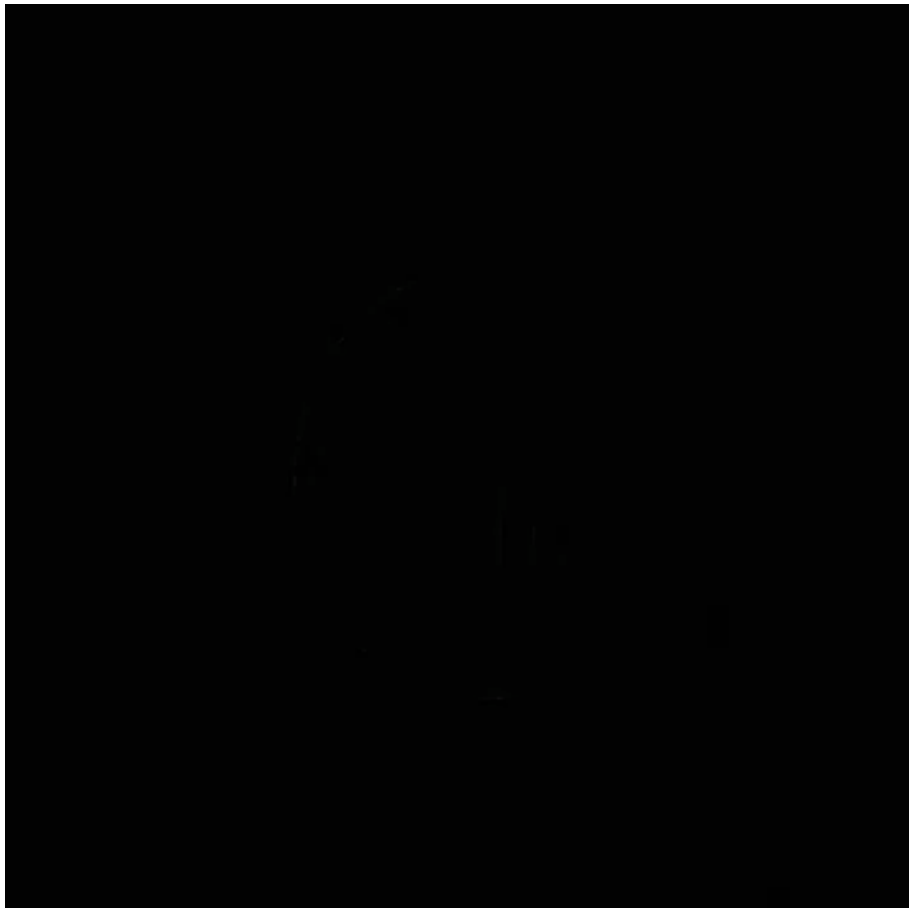
Methods of Cognitive Neuroscience: Part I



Participate in the Human Subject Pool (up to 2% bonus points!)

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HSP Identification Number

Completed during the pre-testing

- First four digits of student ID number
- Two digits of birth month
- Two digits of birth day
- If your student ID is 1234567, and your birthday is August 1, your ID will be:
- 1234+08+01 = 12340801

UBC Psychology

Participate in the Human Subject Pool (up to 2% bonus points!)

Critical Information Available Online

Did you know. . .

- Many students will miss the end of term deadline and not be able to earn full bonus credits!
- To find out more about critical information, like when the HSP system closes to participants, ***please read the handbook available online***:

https://psych.ubc.ca/undergraduate/opportunities/human-subject-pool/

UBCPsychology

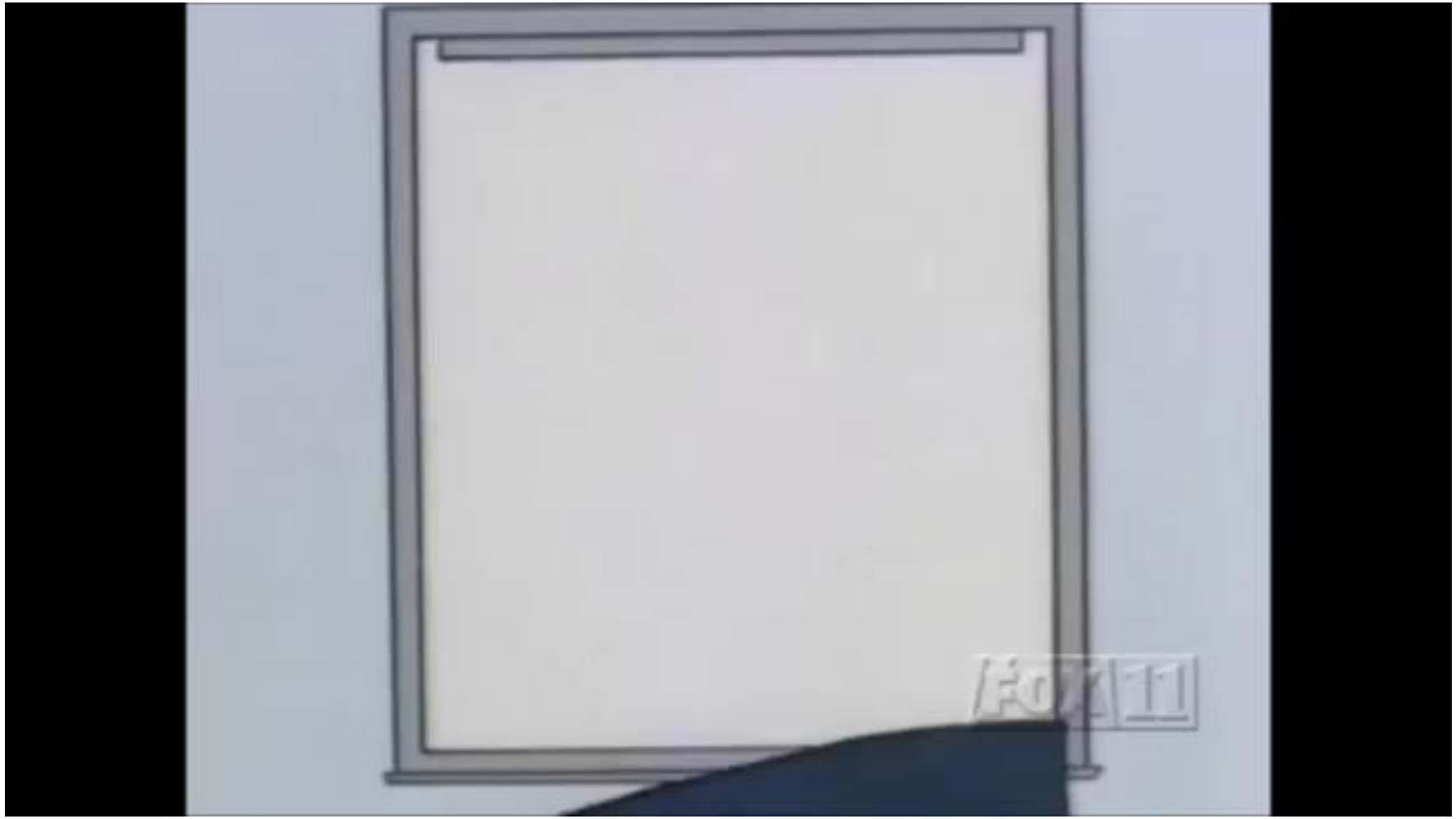
Housekeeping

- If you are new to the class:
  - Be sure to look over slides and watch the recordings of classes 1 and 2
- Upcoming deadline:
  - Complete the Neuroanatomy module and the 2 quizzes (for 2% of your grade) by Jan 23
  - No extensions!

Who's in this class: Week 2

Road map for next 3 classes

- **Class 3 (today):** Cognitive Neuroscience Methods Pt 1
  - Reading assignment: Poldrack & Farah, 2015 and tips
- **Class 4 (Thursday):** Methods Pt II: fMRI
  - Reading assignment: Dimsdale-Zucker et al., 2018: Section 1 (RSA)
- **Class 5 (Tuesday, Jan. 23rd):** Recognizing objects
  - Reading assignment: Passingham Chapter 2 up to Classifying Objects p. 58
    - Class time will be optional discussion!



Methods of Cognitive Neuroscience

> The way that we conceptualize brain function has always been constrained by the methods available to study it.
> -Poldrack and Farah, 2015

- What can we measure?
- What conclusions can we draw?
- What are the strengths and weaknesses of each approach?

Learning objectives

> Our goal here is to review the current state of human neuroscience, focusing on what kinds of questions can and cannot be answered using current techniques and how those answers are relevant to real-world applications.
> -Poldrack and Farah, 2015

After this lecture you should be able to:

- Describe five methods of manipulating and measuring human brain activity, and their main strengths and weaknesses:
    1. Lesion studies
    2. Neuromodulation
    3. Electroencephalography (EEG)
    4. Magnetic Encephalography (MEG)
    5. Positron Emission Tomography (PET)

What's inside the black box?

Input (stimulus) →  → Output (response)

How do we probe the human brain?

Probing mechanisms of the brain

> To fully understand human brain function is to know the causal chains of events at the molecular, cellular, population, and network levels that give rise to psychological function. For this reason, the power to identify causal relationships is a crucial dimension of difference among methods.
> -Poldrack and Farah, 2015

- How do Poldrack and Farah define mechanisms?
- What methods do they say provide little insight into causal mechanisms? What is the value those methods have?

Examples of neurocognitive tools

Two kinds of mechanistic insight

Mechanistic insight: Insight into brain mechanisms

Strength of Causal Evidence	**Level of Mechanism**			
	Molecules	Cells	Populations	Networks
Purely observational (no causality)				
Manipulate psychological processes & observe brain				
Manipulate brain and observe psychological effects				

Probing the human brain: An array of methods

1. Study of brain lesion patients (Neuropsychology)
2. *Neuromodulation*, or transcranial brain stimulation
3. Electroencephalography (EEG)/Magnetoencephalography (MEG)
4. Positron Emission Tomography (PET)
5. Magnetic Resonance Imaging (MRI)/Diffusion Tensor Imaging (DTI)
6. Functional Magnetic Resonance Imaging (f)MRI

Patient studies: Using brain damage to learn about cognition

Neuropsychology & patient studies

- Lesion: Abnormality or injury to any part of the brain
- Causes:
  - Born with it
  - Epilepsy/surgery
  - Stroke
  - Injury
  - Disease…
- Neuropsychology: Use laboratory tasks to measure behaviour and see what people can and can't do
- You can infer causality. Can reveal brain regions *necessary* for healthy cognition

Example: Broca's area for speech production

Two kinds of mechanistic insight

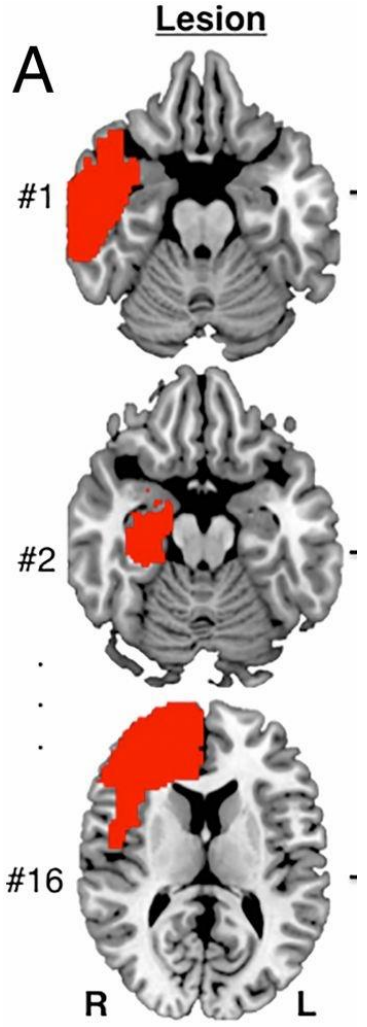
Mechanistic insight: Insight into brain mechanisms

Strength of Causal Evidence	**Level of Mechanism**			
	Molecules	Cells	Populations	Networks
Purely observational (no causality)				
Manipulate psychological processes & observe brain				
Manipulate brain and observe psychological effects			**Focal lesions**	

Lesion network mapping

- Find *different* lesion locations linked to problems with a given behaviour in *different* people
- Look for a single network they are all part of
- Suggests disruption of *network*, not single region, is key

Establishes a causal role for brain networks!



Darby et al., PNAS, 2017

Two kinds of mechanistic insight

Mechanistic insight: Insight into brain mechanisms

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Manipulate psychological processes & observe brain				
Manipulate brain and observe psychological effects			Focal lesions	**Lesion network mapping**

Lesion studies: Advantages and limitations

- Advantages
  - Can demonstrate a region is necessary for a particular function (and not for another)

- Limitations
  - Patients in short supply
  - Damage not neatly limited to one region
  - Damage to region itself or connections to other regions responsible to the deficit (region or network?)
    - But see lesion network mapping!

Anything else?

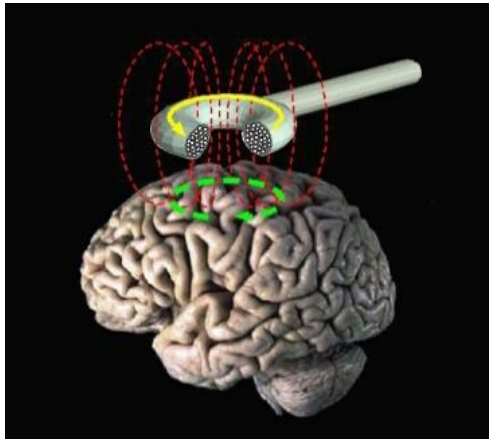
Making lesions

Is there a way to make lesions in humans?

(temporarily)

Neuromodulation: Transcranial Magnetic (TMS) & Electric Brain Stimulation (TES)

- Uses an electromagnetic coil/electrodes to ramp up or damp down neuron activity
- Induces weak electric currents using rapidly changing magnetic field/direct electrical stimulation
- Can activate or inhibit specific regions of cortex
- Test behaviour/cognitive processes
- Spatial resolution not great



Lesions and neuromodulation

- Lesions: Can isolate cognitive processes by testing deficits after injury
  - Messy
  - Is it the region or the network that's disrupted?
- Neuromodulation can create "temporary" lesions
  - Not great spatial resolution
- BOTH Lesions and transcranial stimulation allow us to infer whether a region is necessary for a function

Two kinds of mechanistic insight

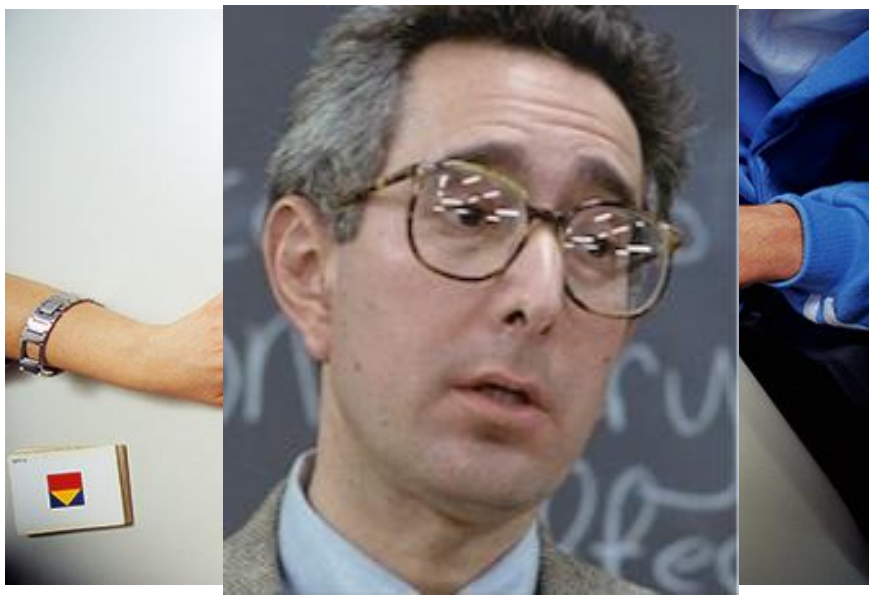
Mechanistic insight: Insight into brain mechanisms

Strength of Causal Evidence	**Level of Mechanism**			
	Molecules	Cells	Populations	Networks
Purely observational (no causality)				
Manipulate psychological processes & observe brain				
Manipulate brain and observe psychological effects			Focal lesions **Neuromodulation (TMS/TES)**	Lesion network mapping

Summary: Lesions Found or Created

- The brain is either damaged or manipulated
- Behaviour is used as the dependent measure
- Allows inference that a brain region is necessary for that function

  … or the network it's part of



QUESTIONS?

Question

Which is NOT the view of the brain that Poldrack claims is advanced by contemporary methods of human neuroscience?

a. A modular view of brain function involving localized and separable regions that carry out basic mental operations.

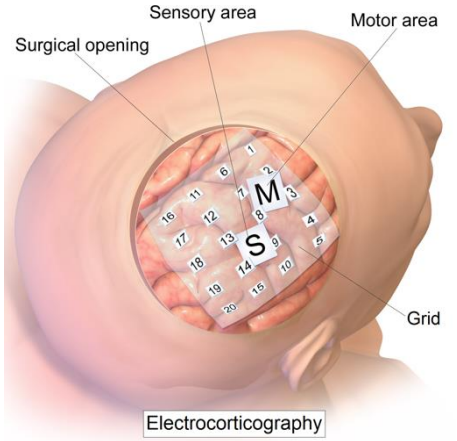
b. A balance of regional specialization and network integration

c. A dynamic network with multiple levels of organization.

Brain reading

Methods looking directly at brain structure or activity

- EEG (scalp)
- MEG
- ECoG
- PET
- MRI/DTI
- fMRI

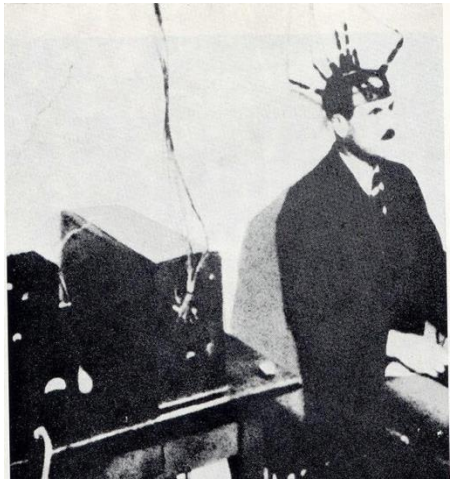


Causality of functional neuroimaging studies

> Although functional neuroimaging (EEG/MEG) and single-cell recordings are sometimes criticized as being purely correlative and therefore uninformative about mechanism, that criticism is only partly accurate.
> -Poldrack & Farah, 2015

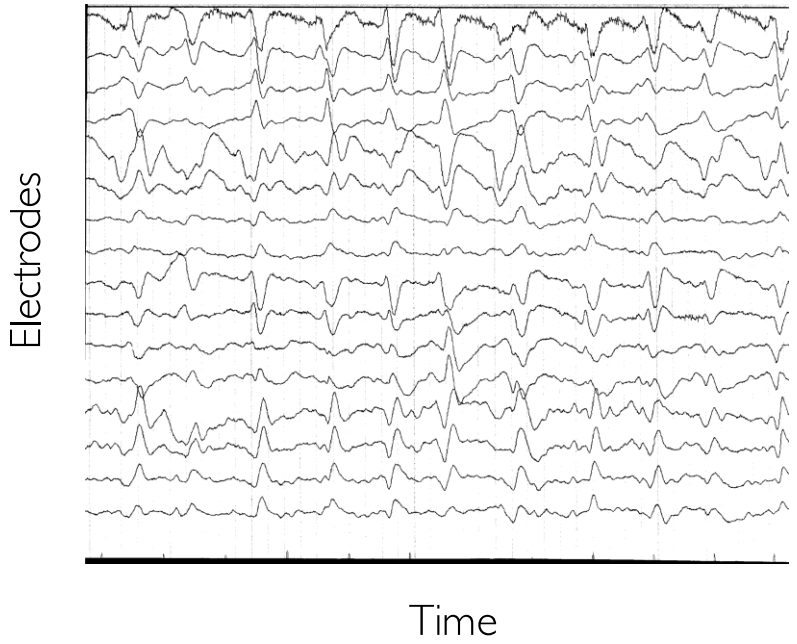
- The demands of the experimental task CAUSE brain activity
- Brain activity does not necessarily CAUSE psychological processes

EEG: Brain electrical activity



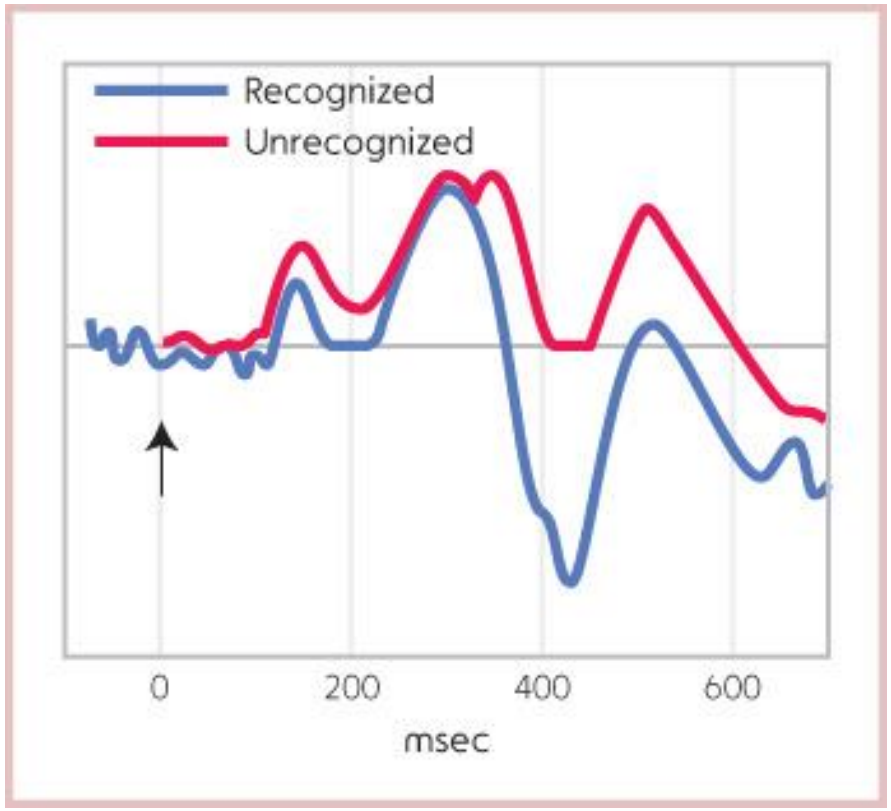
Scalp EEG, 1929

Scalp EEG, today



- Electrodes on the scalp record the electrical activity of the brain
- EEG waves (brain waves) reflect the electrical output of columns of cortical neurons

Event-**R**elated **P**otential**s** (ERPs)



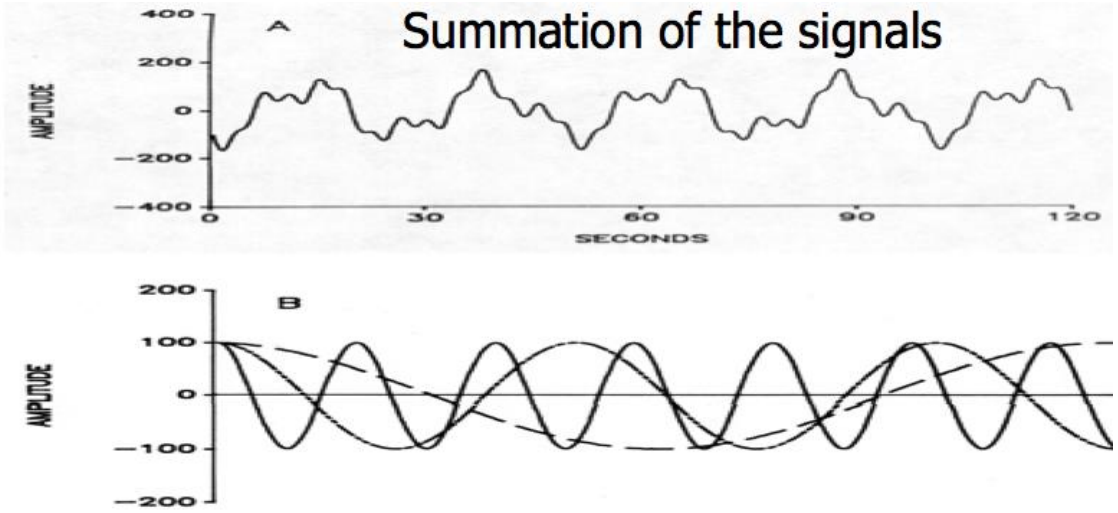
- Averaged EEG signal following a stimulus or response
- Compared between groups and conditions
- ERP components: Linked to specific cognitive processes
- Can tell you when but not where!

Two kinds of mechanistic insight

Mechanistic insight: Insight into brain mechanisms

Strength of Causal Evidence	**Level of Mechanism**			
	Molecules	Cells	Populations	Networks
Purely observational (no causality)				
Manipulate psychological processes & observe brain			**Task activation studies (EEG)**	
Manipulate brain and observe psychological effects			Focal lesions Neuromodulation (TMS/TES)	Lesion network mapping

EEG frequency analysis

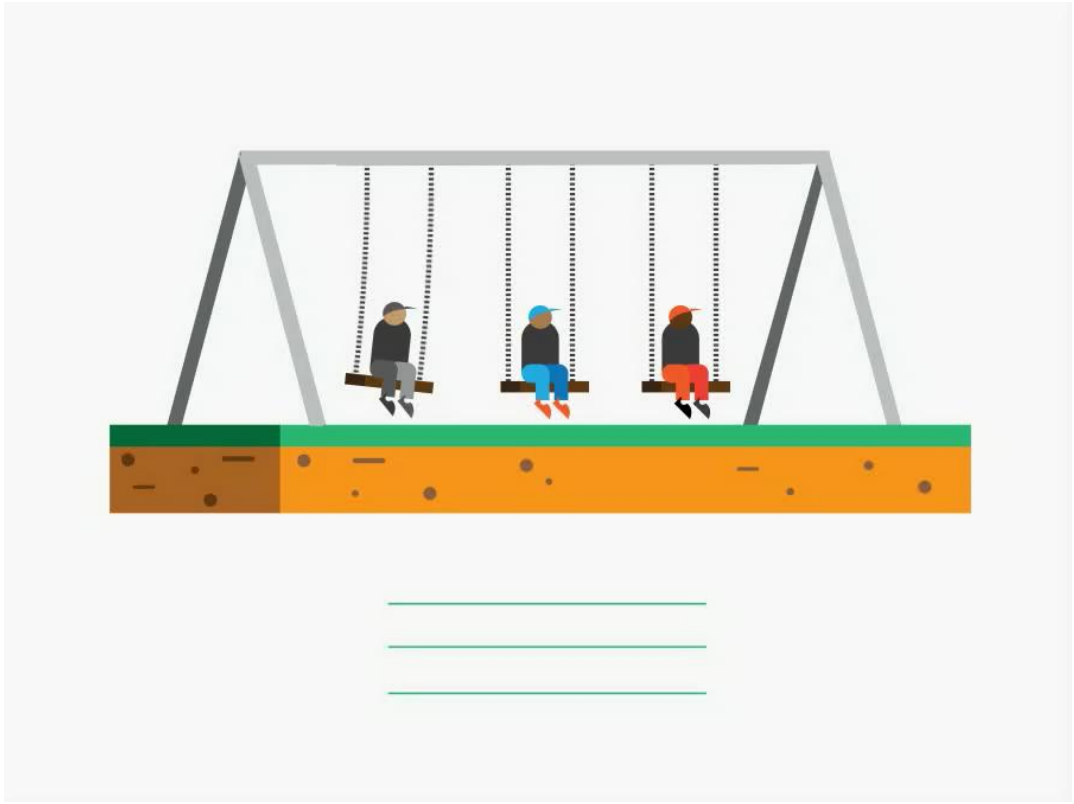


- Fourier transform: Any complex timeseries can be broken down into a series of superimposed sinusoid functions with differing frequencies
- **Frequency Domain Analysis** decomposes EEG signal into signals of different frequencies

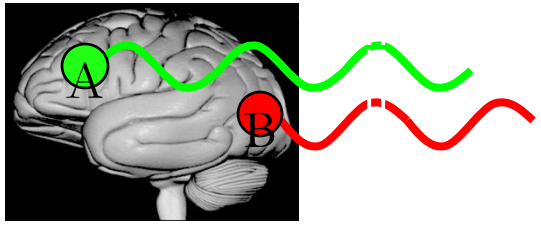
Slide courtesy of Bob Knight

Synchrony as a connectivity mechanism

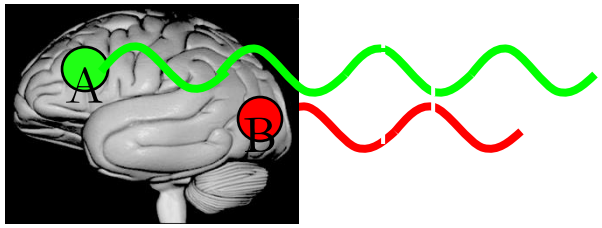
Are distant regions dancing in step?



Increased communication



Decreased communication



Slide courtesy of Bob Knight

Magneto**e**ncephalo**g**raphy (MEG)

- Uses magnetic detectors surrounding the head
- Detects very small magnetic fluctuations in brain activity
- Signal not distorted by the skull, so better for localizing sources of signal than EEG
- Now portable as well! (like EEG)

New: Portable MEG

Two kinds of mechanistic insight

Mechanistic insight: Insight into brain mechanisms

Strength of Causal Evidence	**Level of Mechanism**			
	Molecules	Cells	Populations	Networks
Purely observational (no causality)				
Manipulate psychological processes & observe brain			Task activation studies (EEG/**MEG)**	**Task-based functional connectivity (EEG/MEG)**
Manipulate brain and observe psychological effects			Focal lesions Neuromodulation (TMS/TES)	Lesion network mapping

Strengths & weaknesses of EEG & MEG

Strengths

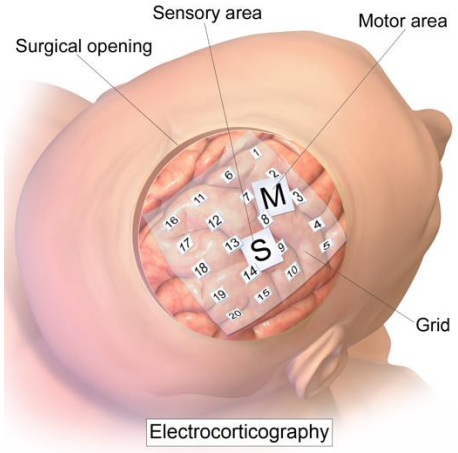
- Good temporal resolution
- Inexpensive (EEG)
- Non-invasive
- Direct measure of brain activity
- Increasingly portable!

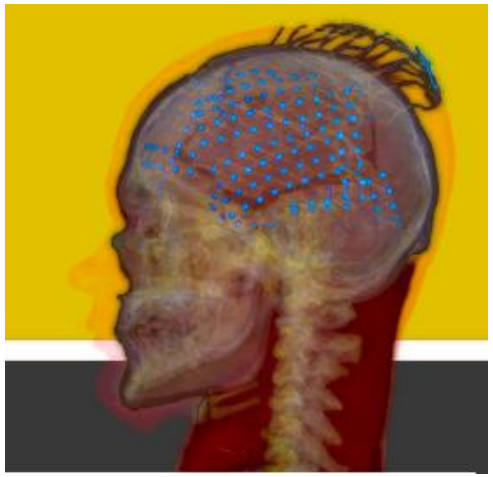
Weaknesses

- Poor spatial resolution (estimation ok for MEG)
- Correlational
  - Can't infer that activity in a region is necessary for a behaviour

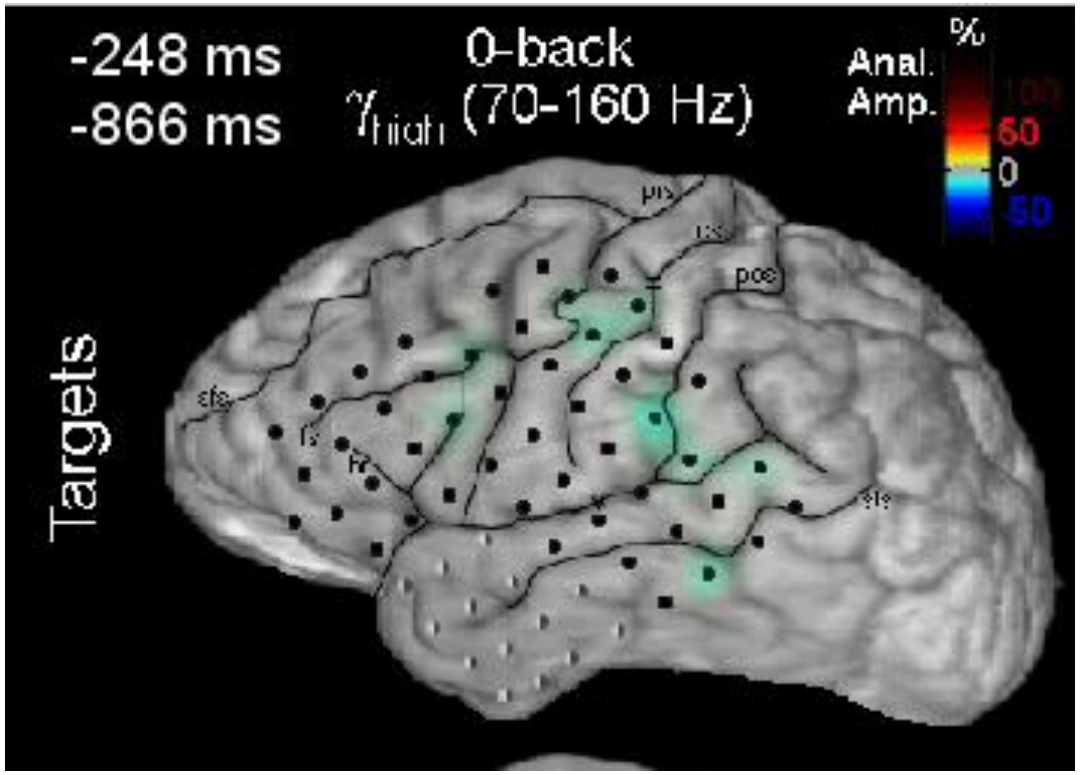
Intracranial EEG

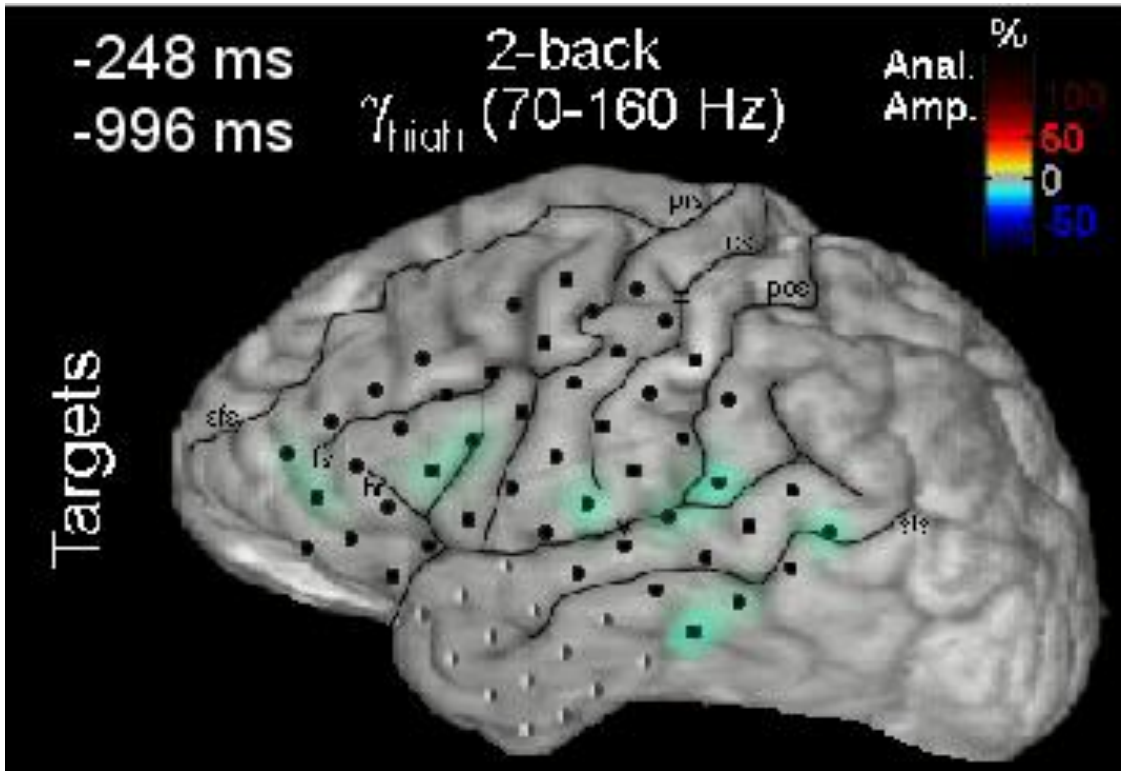
- **ECoG** (electrocorticography): A form of *intracranial* EEG that records activity from grids of electrodes
  - Typically on cortical surface
  - Can be implanted deeper
- **Stereo EEG**: Insert single depth electrodes





Intracranial EEG





Intracranial EEG: Pros and Cons

Strengths

- Great temporal accuracy
- Great spatial accuracy
- Very useful for synchrony measures
- Good for looking at high frequencies

Weaknesses

- Very invasive and data is rare
- No control over where electrodes are placed
- Correlational
- Epileptic brains are different

Two kinds of mechanistic insight

Mechanistic insight: Insight into brain mechanisms

Strength of Causal Evidence	**Level of Mechanism**			
	Molecules	Cells	Populations	Networks
Purely observational (no causality)				
Manipulate psychological processes & observe brain		**Intracerebral recording in surgical patients**	Task activation studies (EEG/MEG)	Task-based functional connectivity (EEG/MEG)
Manipulate brain and observe psychological effects		**Direct brain stimulation in surgical patients**	Focal lesions Neuromodulation (TMS/TES)	Lesion network mapping

PET (**P**ositron **E**mission **T**omography)

- Early PET measured glucose metabolism
- Now radioactive tracers mostly tag neurotransmitters
- Increasingly used in clinical studies
- Cool but expensive and invasive and very slow
- Low spatial resolution (1 cm) but can measure molecular processes!

The tracers used are literally under your feet!

https://www.youtube.com/watch?v=eMTZvA8iFgI

Two kinds of mechanistic insight

Mechanistic insight: Insight into brain mechanisms

Strength of Causal Evidence	**Level of Mechanism**			
	Molecules	Cells	Populations	Networks
Purely observational (no causality)	**Correlations of PET imaging with psychological traits**			
Manipulate psychological processes & observe brain	**Task modulation studies using PET w/ neurotransmitter ligands**	Intracerebral recording in surgical patients	Task activation studies (EEG/MEG)	Task-based functional connectivity (EEG/MEG)
Manipulate brain and observe psychological effects		Direct brain stimulation in surgical patients	Focal lesions Neuromodulation (TMS/TES)	Lesion network mapping

Summary

- Change the brain, measure behaviour
  - Lesion studies
  - Neuromodulation (Transcranial stimulation)
  - Can infer **causality**!
- Change behaviour, measure the brain
  - EEG/MEG: Electrical activity at the scalp tells you when but not where
  - ECoG/s-EEG: Tells you when and where but invasive!
  - ALL: Allow measurement of oscillations as *mechanistic* signals of communication
  - Pet allows you to measure neurochemical activity
- **We can use multiple methods to triangulate on a process of interest!**

Questions?

See you next class!

- MRI/fMRI