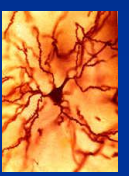
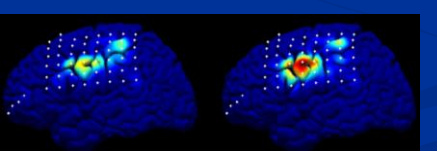
CSE 599E

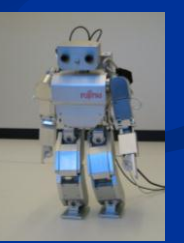
Introduction to Brain-Computer Interfacing



Instructor: Rajesh Rao

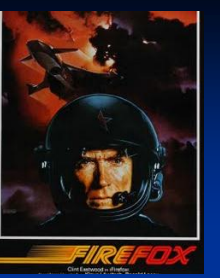
TA: Sam Sudar





The Matrix (1999)

Brainstorm (1983)

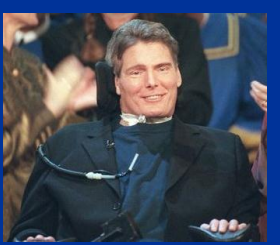


Firefox(1982)

Spiderman 2 (2004)

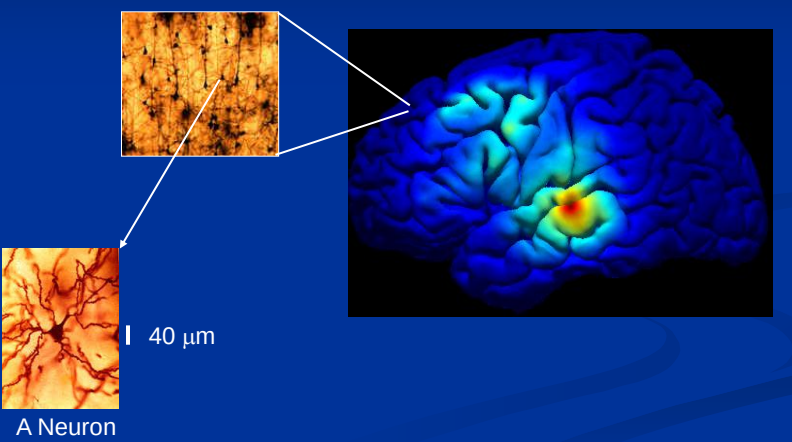
Hollywood fantasy apart, why would we want to engineer such devices?

Treating neurological conditions

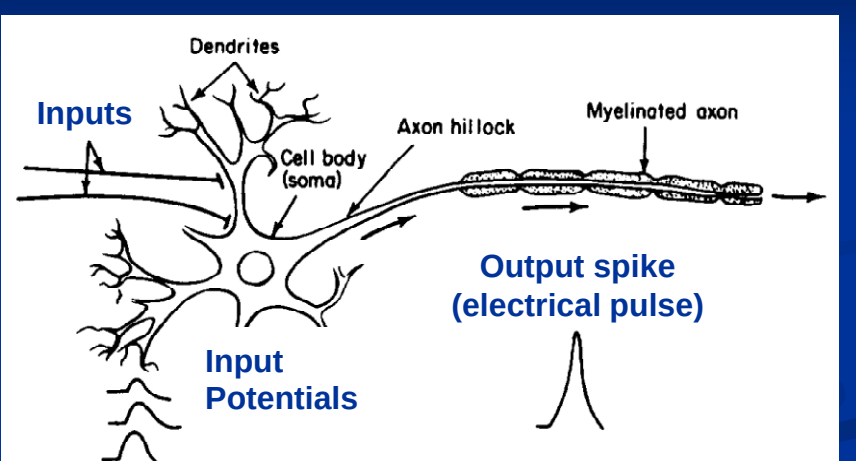


Can we build devices to help people with neurological disabilities?

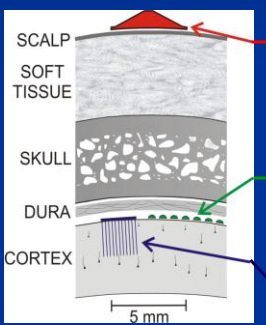
The brain is comprised of networks of neurons (about 10^{11})



Neurons Communicate through Electrical Activity



The Brain's Electrical Activity Can Be Measured



Picture courtesy of Wadsworth Center

EEG (scalp)

ECoG (brain surface)

Electrodes (inside the brain)

Non-invasive

Invasive

Electrical nature of neural information processing allows us to *record* neural activity as well as *stimulate* parts of the brain

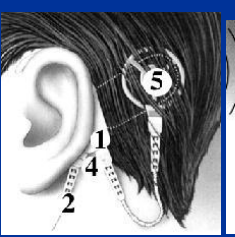
Example: Cochlear Implants for the Deaf

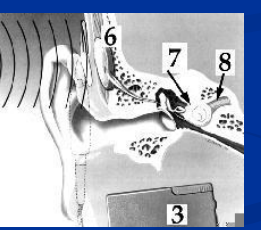
Cochlear implants have improved hearing ability in about 190,000 deaf children and adults

1. Microphone

3. Sound processor

5. FM radio transmitter



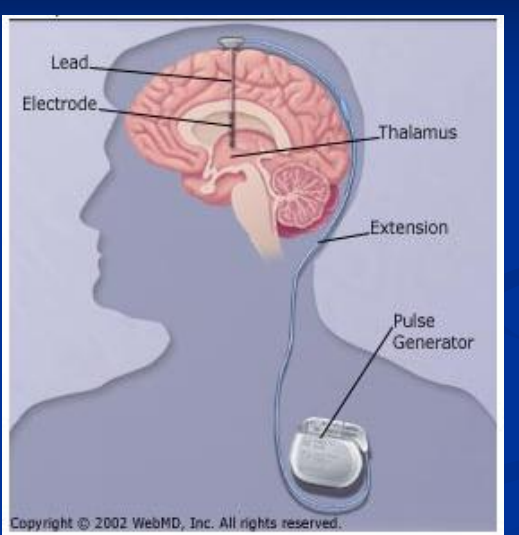


6. Receiver & Stimulator

7. Electrode array

From: http://www.deafblind.com/cochlear.html

Example: Deep Brain Stimulation (DBS) for Parkinson's Disease



Implanted device electrically stimulates parts of the brain to help reduce tremors, rigidity, and other symptoms

Videos:
Before DBS
After DBS

Such devices are examples of "brain-computer interfaces" or BCIs

This Course (CSE 599E)

- Goal: Provide an overview of the field of brain-computer interfacing
- Class web page:
  - http://www.cs.washington.edu/599e
- The course will include:
  - Introductory Lectures
  - Invited Speakers
  - Student-Led Discussion of Research Papers
- Who are we?

Syllabus

- Basic Neuroscience
- Recording/Stimulating the Brain
- Signal Processing
- Machine Learning

Lectures

- Major Types of BCIs
  - Invasive BCIs
  - Semi-Invasive BCIs
  - Non-Invasive BCIs
  - Stimulating/Bidirectional BCIs
- BCI Applications

Papers presented by student teams & discussion

- Ethics of BCI

Lecture

Workload

- No exams or homeworks
- Paper presentation: You and a selected colleague from class will work as a team to present 2-3 selected papers on an assigned day
  - See schedule on website for list of papers
  - Team members/days selected by staff (this week)
  - Presentations should use slides and/or board
- Final project: You will work with 1-2 other colleagues on a “mini-research” project
  - BCI experiment/BCI data analysis/Literature survey
  - Project presentation on May 31
  - Project write-up due on June 3

Grading

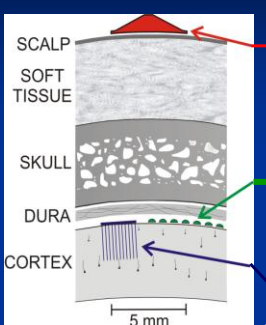
- Credit/No Credit (CR/NC) only
- Grade based on:
  - Student team presentation of assigned papers
  - Final team project completion
  - Participation in on-line/in-class discussions

Enuff logistics, let's get started…

BCI: What is involved?

Record

Stimulate

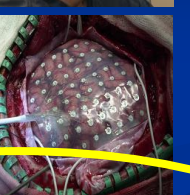


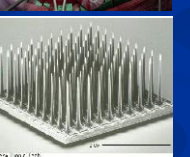
(Picture credit: Wadsworth Cente

EEG (scalp)

ECoG (brain surface)

Electrodes (inside the brain)



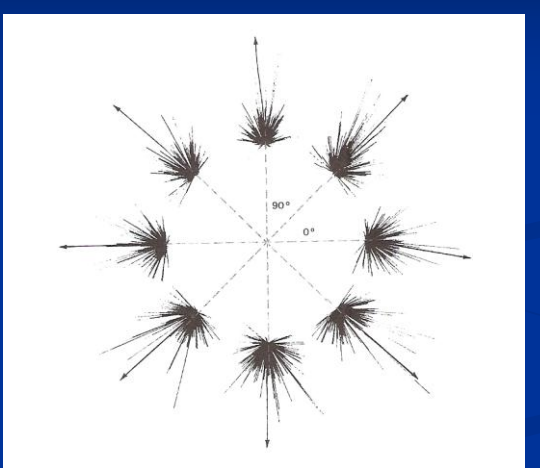


Non-invasive

Invasive

INVASIVE BCI IN ANIMALS

Movement direction can be predicted from motor cortex activity

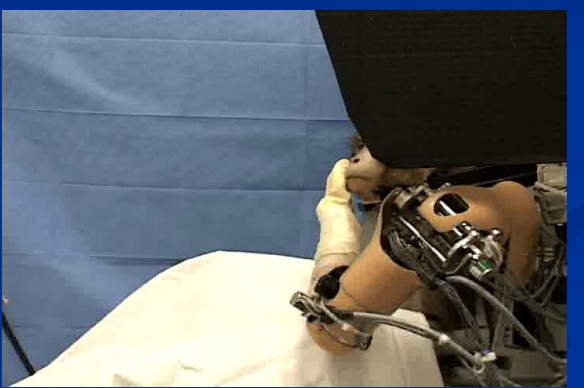


$$\hat{\mathbf{d}} = \sum_i \mathbf{p}_i \left(\frac{r - r_0}{r_{\max}} \right)_i$$

(Georgopoulos et al., 1988)

Monkey BCI

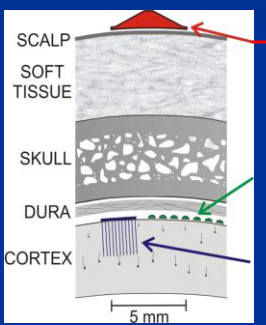
Robot arm-hand control using motor cortical activity



(Video from Schwartz lab, Pittsburgh)

NON-INVASIVE BCI IN HUMANS

Non-Invasive BCIs: Electroenchephalography (EEG)



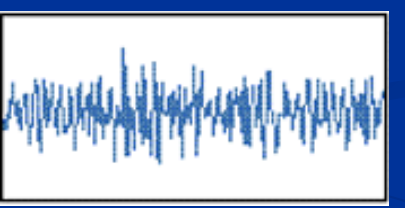
Picture courtesy of Wadsworth Center

EEG (recording from scalp)

Rick Owens 2012 Collection

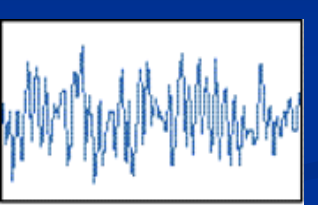
EEG is noisy but correlates with brain activity

Beta waves (14-18 Hz): Associated with *alertness* and heightened mental activity



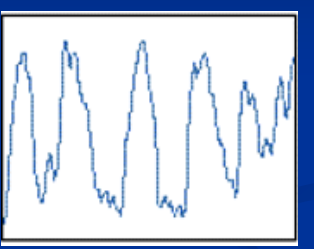
(From Scientific American, 1996)

Alpha waves (8-12 Hz): Associated with unfocusing attention (*relaxation*)



(From Scientific American, 1996)

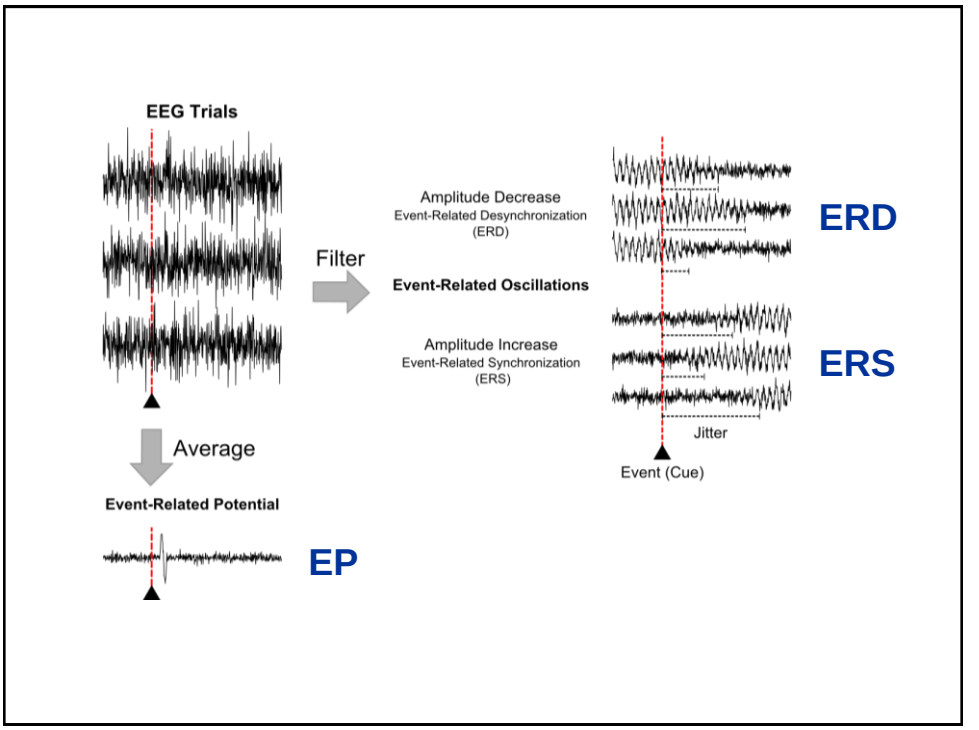
Delta waves (0.5-3 Hz): Associated with *deep sleep*



(From Scientific American, 1996)

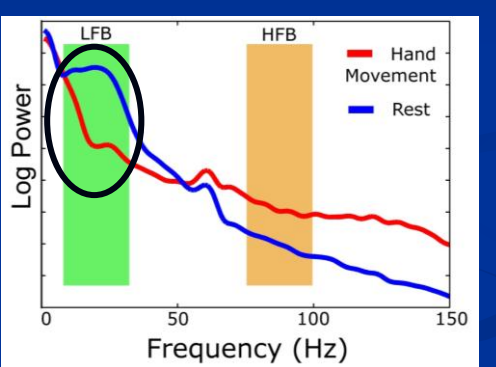
Using EEG for BCI: Two Types of Responses

- Event Related Desynchronization or Synchronization (ERD/ERS):
  - Change in power in specific frequency-bands
- Evoked Potentials (EPs)
  - Stereotypical response caused by a stimulus (e.g., P300)



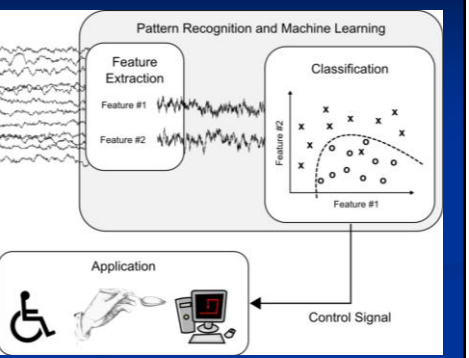
Event-Related Desynchronization (ERD)

- Suppression of oscillatory activity due to voluntary movement or imagery

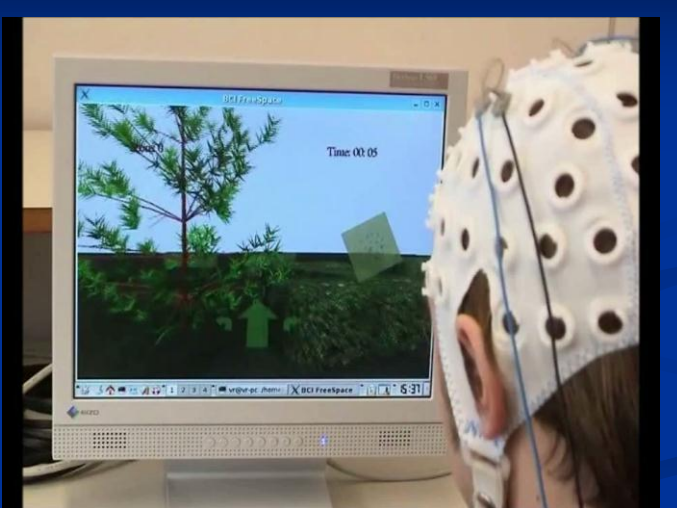


Using ERD for BCI

- Extract band power features (8-12Hz)
- Train a classifier to classify ERD for different imagined movements (e.g., left hand vs. foot movement)
- Use trained classifier to classify new data for moving a cursor or robot



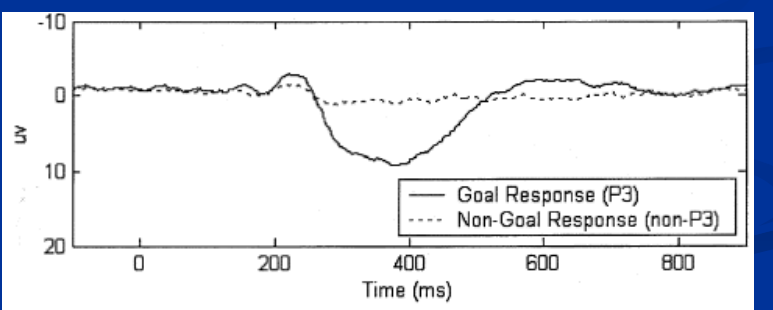
Navigating a Virtual World using Imagined Movements



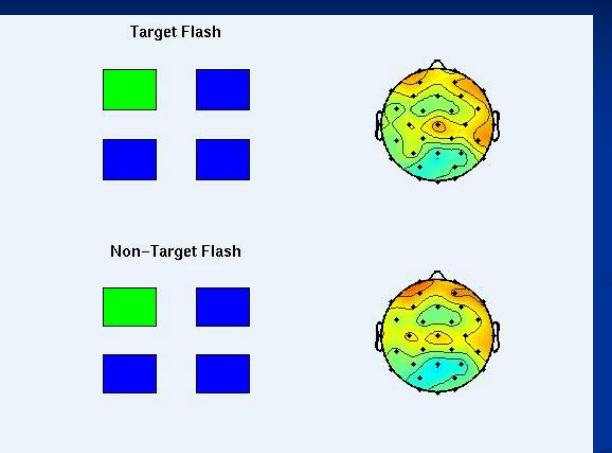
(Scherer et al., 2008; Rao & Scherer, 2010)

BCI based on Evoked Potentials

- Example:
  - P300: Characteristic “mental aha” signal caused by a discrete event

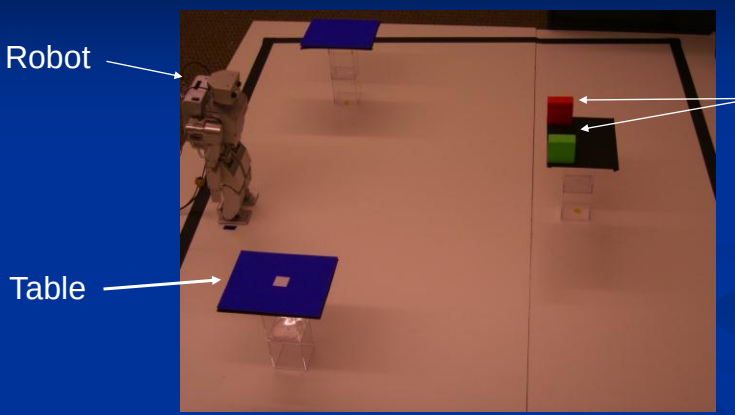


Example P300 Response

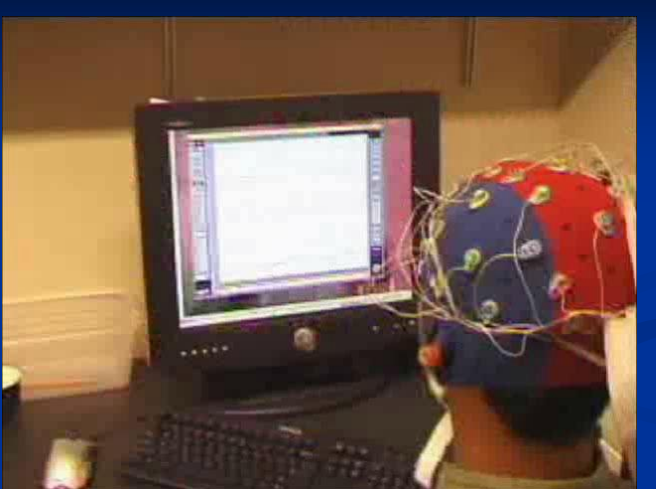


Classifier can be used to classify EEG as containing P300 or not

Robotic “Avatar” based on P300 BCI



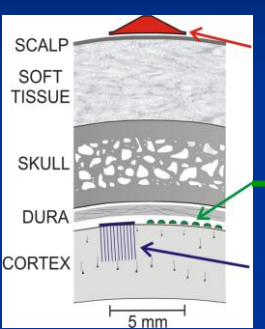
Robotic “Avatar” based on P300 BCI



(J. Neural Engineering, 2008)

INVASIVE BCI IN HUMANS

Invasive BCIs: Electrocorticography (ECoG)



(Picture credit: Wadsworth Center)

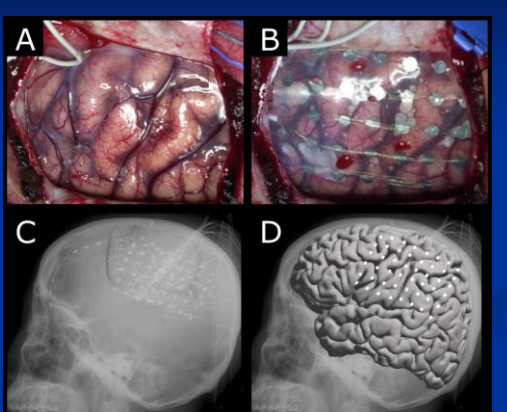
ECoG (brain surface)

Patient Population and Setup

(photo courtesy Seattle Times)

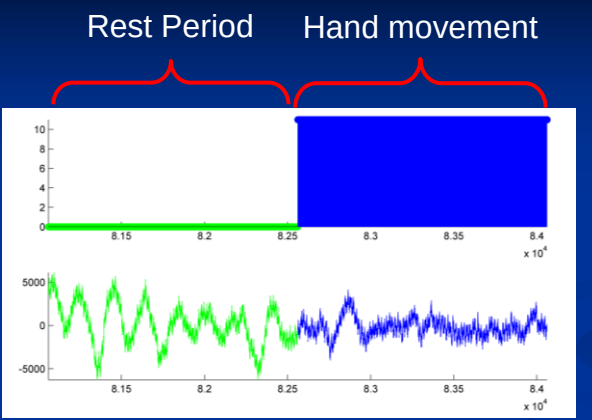
- Patients implanted for localization of seizure
- Experiments at bedside in 7-10 days between surgeries

Electrocorticographic (ECoG) Recording



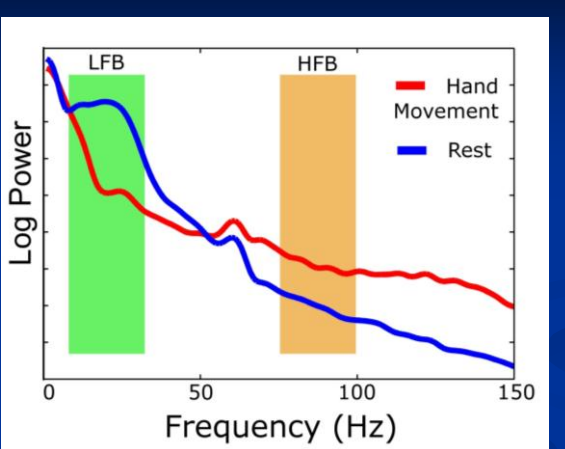
- 8x8 array or strip of platinum electrodes
  - 1.2 to 2.3mm diameter
  - Separated by 3mm to 1cm
- Several hundred thousand neurons beneath each electrode

Modulation of ECoG Activity during Movement



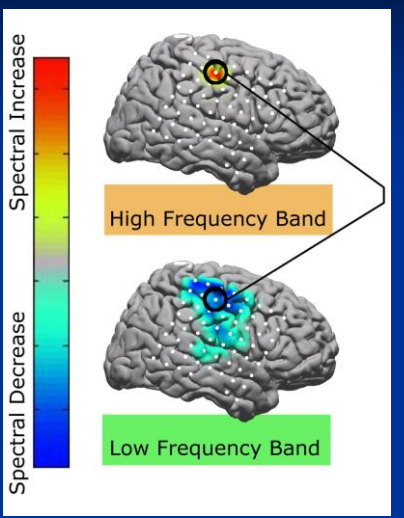
- Decrease in power in low frequency component
- Increase in power in high frequency component

Power Spectral Changes in ECoG



(Miller *et al*., *J Neurosci*, 2007)
(Crone et al., *Brain*, 1998)

Basic ECoG Phenomena

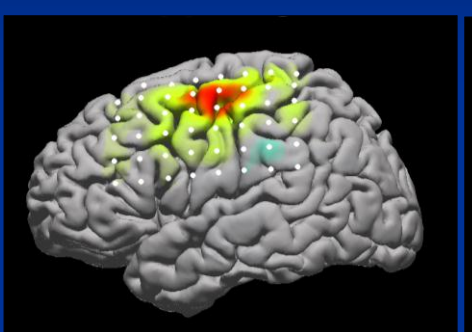


HFB changes are *more functionally localized* than LFB changes

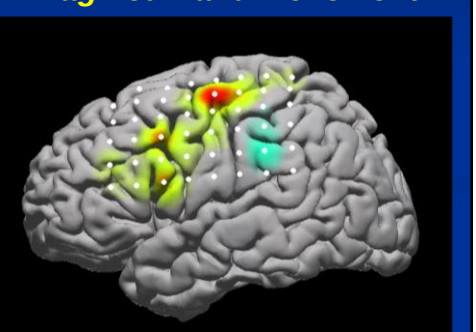
(Miller *et al*., *J Neurosci*, 2007)

Imagined movements activate similar areas as actual movements

Actual Hand Movement



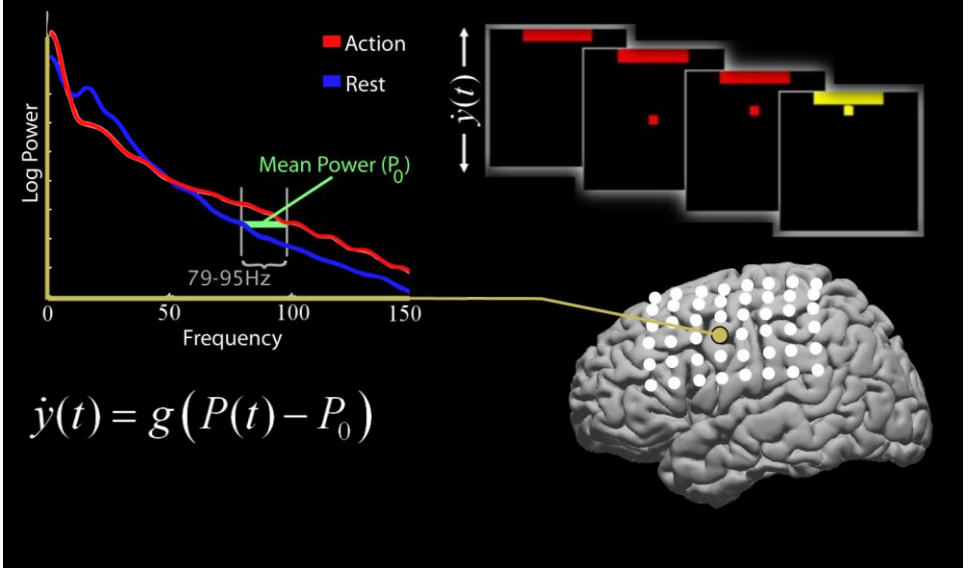
Imagined Hand Movement



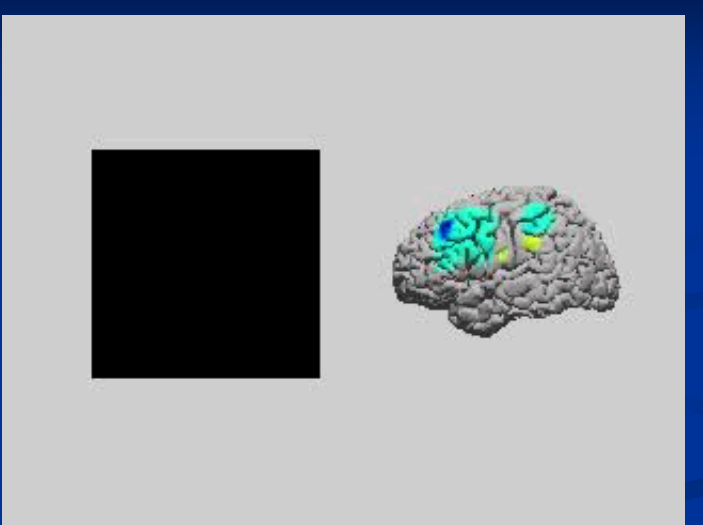
(Miller et al., *PNAS*, 2010)

Activation for imagery is weaker than activation for actual movements. However…

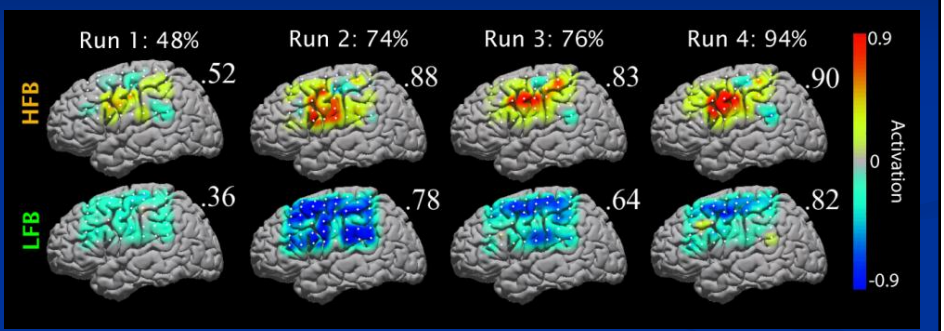
Using imagery to control a cursor



Cursor Control using Imagined Speech



Brain learns to augment imagery-related activity in cursor control task



(Miller et al., *PNAS*, 2010)

What we will learn the rest of the quarter

- What brain responses and algorithms are used in:
  - Invasive BCIs in animals and humans
  - Semi-Invasive BCIs in humans
  - Non-Invasive BCIs in humans
  - Stimulating/Bidirectional BCIs in humans and animals
- What are some of the major BCI applications?
- What are the ethics of brain-computer interfacing?

Next Class:
Primer on Neuroscience and Brain Recording/Stimulation

- To do:
  - Browse class website
- Links to papers and notes for next class will be added on Schedule webpage