Brain-computer interface

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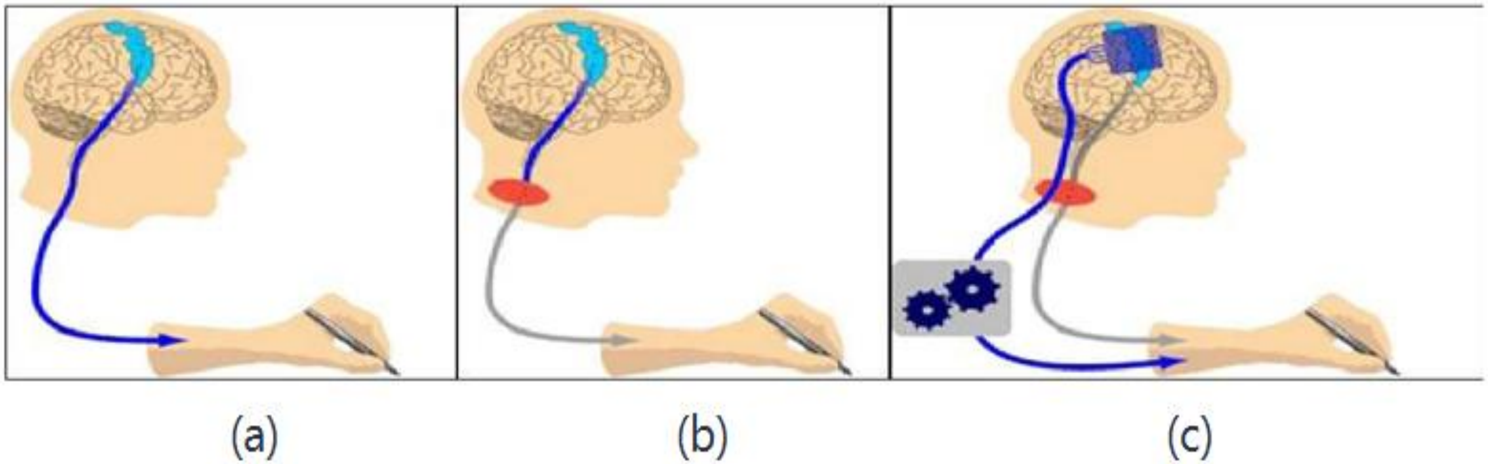
Invasive BCI

Nicoletis lab, Duke, 2006

Invasive BCI

- Can be used to amazing things
  - Blind can see
  - Lame can walk

Invasive BCI



(a) In healthy subjects, primary motor area sends movement commands to muscles via spinal cord.

(b) But in paralyzed subjects this pathway is interrupted.

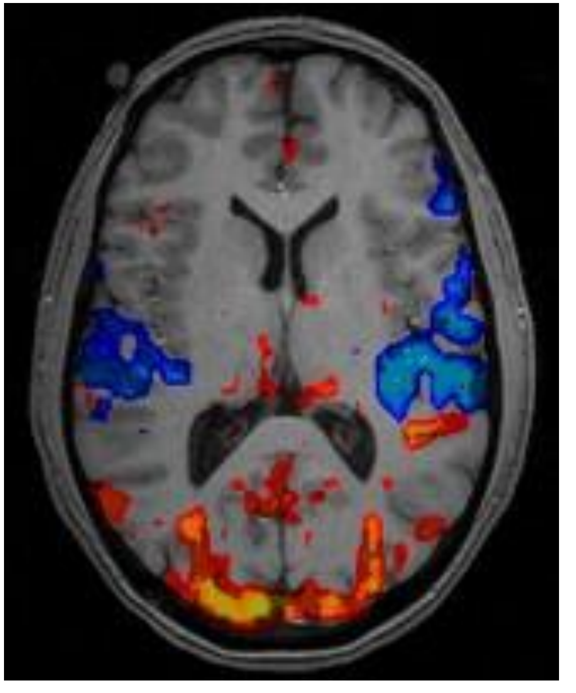
(c) An implant monitors primary motor area neuronal activity

(d) A decoder is used, which translates this activity into commands for muscle control.

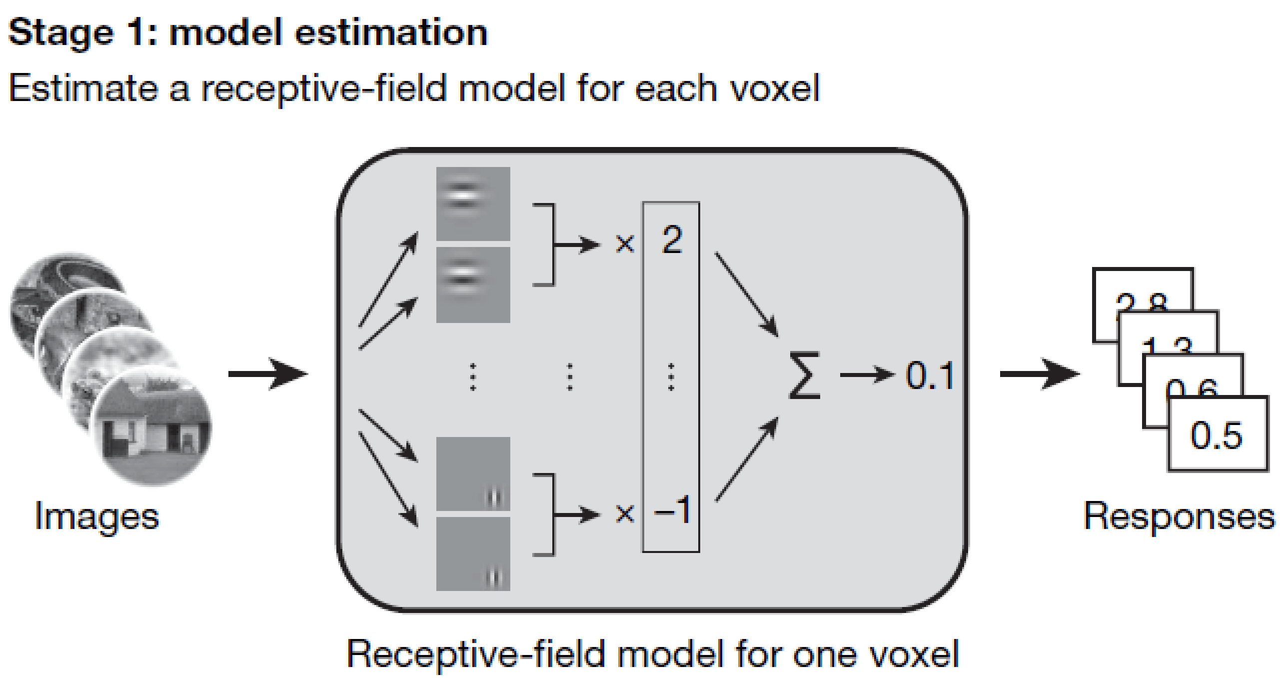
(e) Requires some feedback and training

Expensive BCI

- Use fMRI
  - fMRI measures flow of blood into different brain regions
  - Idea is that brain regions that are activated in response to task demand are delivered oxygen via the bloodstream
  - This is picked up by the BOLD (blood oxygen level-dependent) signal



Possible application - see



Kay et al, 2008, *Nature*

Expensive BCI demo

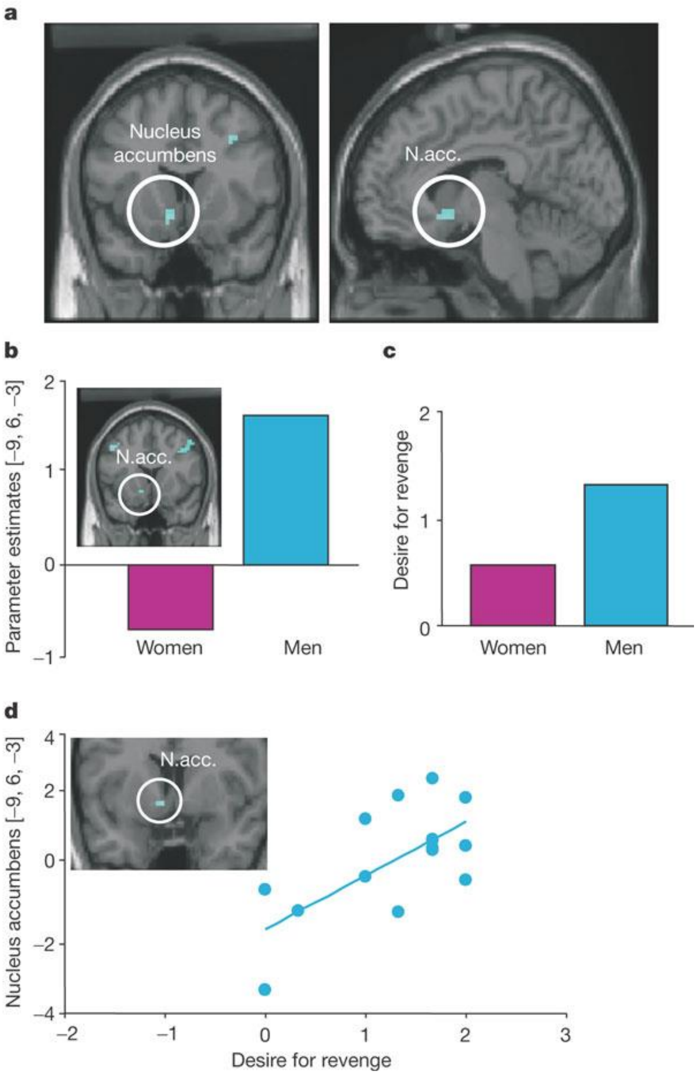
Jack Gallant's lab at UC Berkeley, 2011

Problem - selective attention

Selective attention

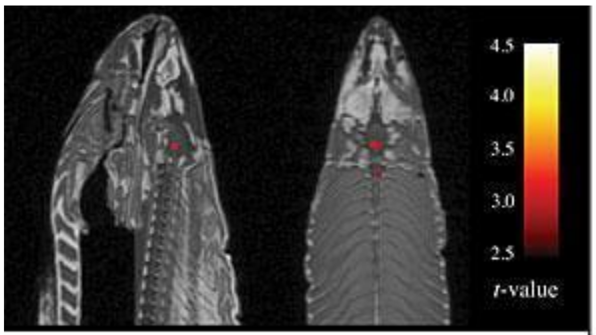
Other problem – often wrong

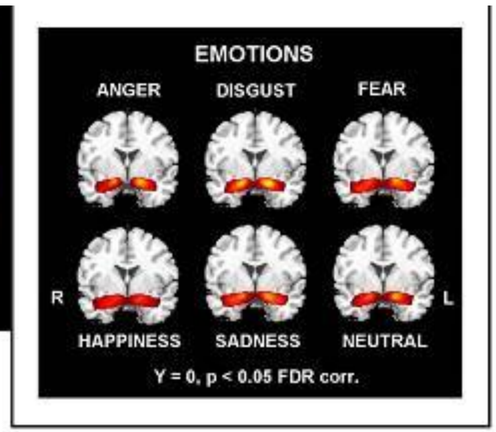
- Lots of bad statistical practices in fMRI research
- Tons of parameters
- Few subjects
- Almost certain to overfit
- Certain to over-interpret



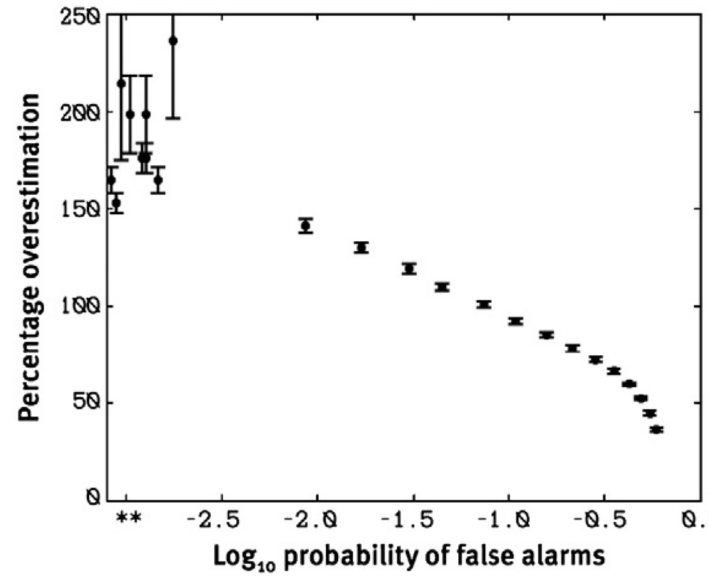
(Singer et al, 2006)

Example



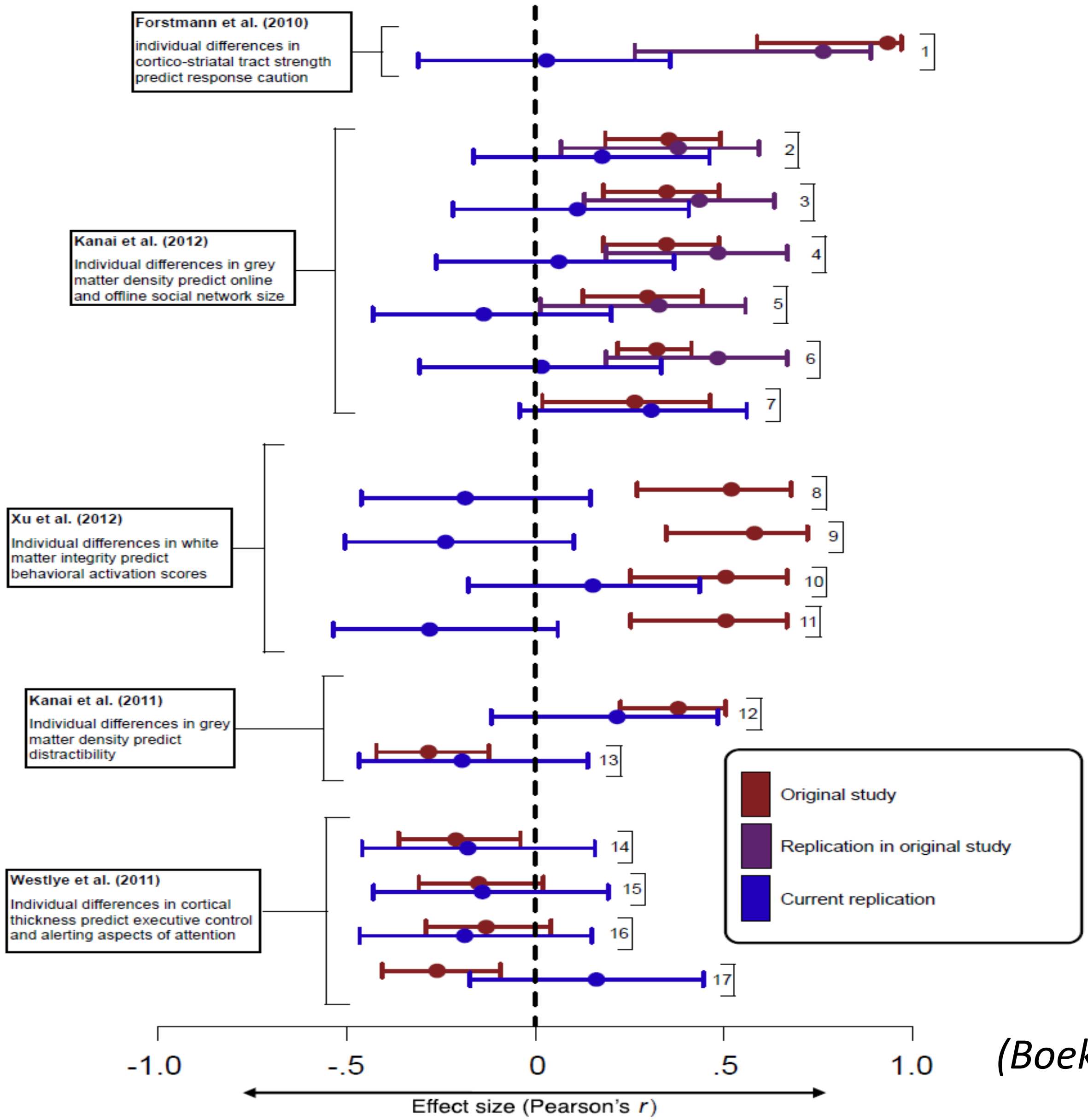


Failing to correct for multiple comparisons infers social cognition in a dead salmon (Bennett et al, 2010)



Correcting for multiple comparisons using FWER etc. overestimates effect sizes, creating *voodoo* correlations (Vul & Pashler, 2012)

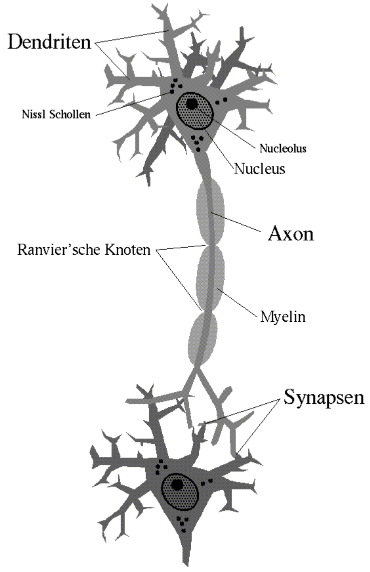
Crisis of confidence in fMRI results



(Boekel et al, 2015)

Cheap non-invasive BCI - EEG

- An *electroencephalogram* is a measure of the brain's voltage fluctuations as detected from scalp electrodes.
- It is an approximation of the cumulative electrical activity of neurons.



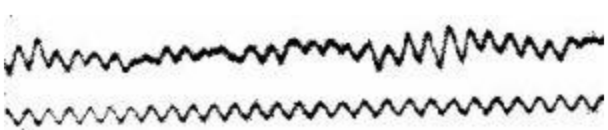
What is it good for?

- Neurofeedback
  - treating ADHD
  - guiding meditation
- Brain Computer Interfaces
  - People with little muscle control (i.e. not enough control for EMG or gaze tracking)
  - People with ALS, spinal injuries
  - High Precision
  - Low bandwidth (bit rate)

Fancier still?

EEG Background

- 1875 - Richard Caton discovered electrical properties of exposed cerebral hemispheres of rabbits and monkeys.
- 1924 - German Psychiatrist Hans Berger discovered alpha waves in humans and invented the term "electroencephalogram"
- 1950s - Walter Grey Walter developed "EEG topography" - mapping electrical activity of the brain.



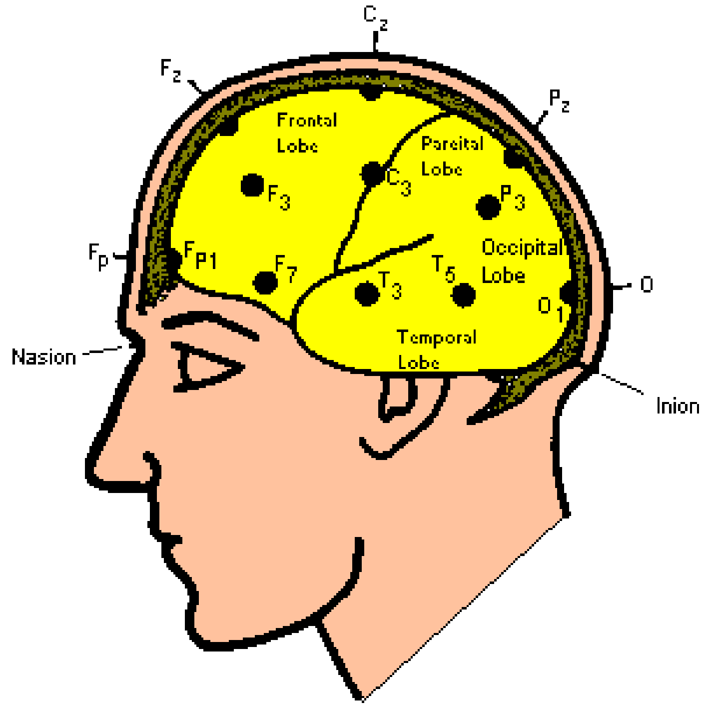
Physical Mechanisms

- EEGs require electrodes attached to the scalp with sticky gel

- Require physical connection to the machine

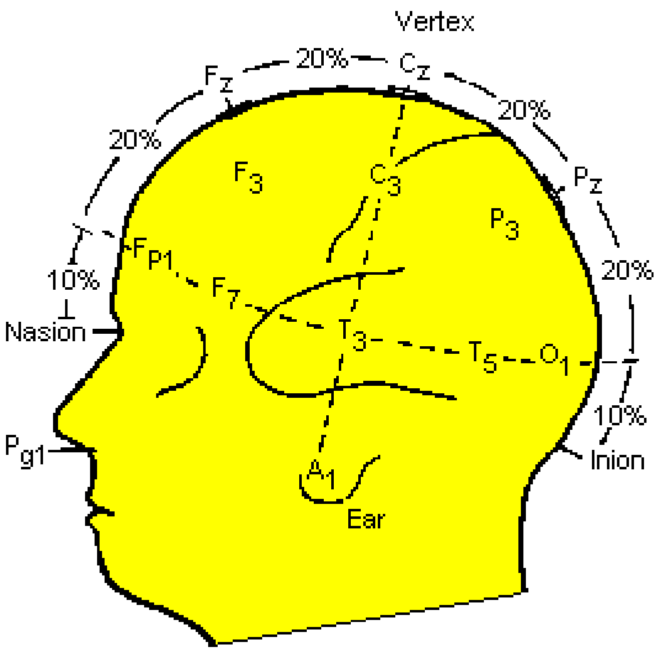
Electrode Placement

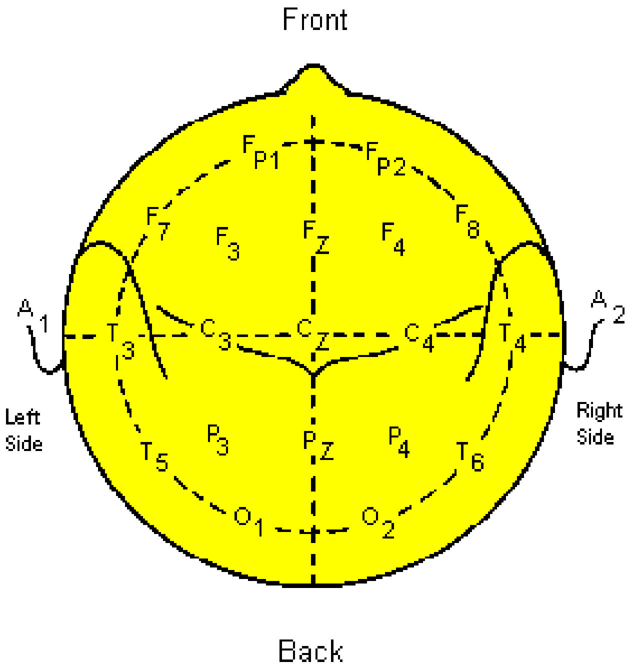
- Standard “10-20 System”
- Spaced apart 10-20%
- Letter for region
  - F - Frontal Lobe
  - T - Temporal Lobe
  - C - Center
  - O - Occipital Lobe
- Number for exact position
  - Odd numbers - left
  - Even numbers - right



Electrode Placement

- A more detailed view:





Brain “Features”

- User must be able to control the output:
  - use a feature of the continuous EEG output that the user can reliably modify (waves), or
  - evoke an EEG response with an external stimulus (evoked potential)

Continuous Brain Waves

- Generally grouped by frequency: (amplitudes are about 100µV max)

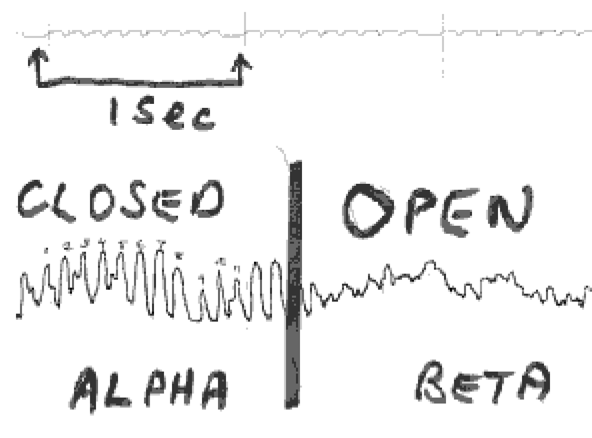
Type	Frequency	Location	Use
Delta	<4 Hz	everywhere	occur during sleep, coma
Theta	4-7 Hz	temporal and parietal	correlated with emotional stress (frustration & disappointment)
Alpha	8-12 Hz	occipital and parietal	reduce amplitude with sensory stimulation or **mental imagery**
Beta	12-36 Hz	parietal and frontal	can increase amplitude during intense **mental activity**
Mu	9-11 Hz	frontal (motor cortex)	diminishes with movement or **intention of movement**
Lambda	sharp, jagged	occipital	correlated with visual attention
Vertex			higher incidence in patients with epilepsy or encephalopathy

Brain Waves Transformations

- wave-form averaging over several trials
- auto-adjustment with a known signal
- Fourier transforms to detect relative amplitude at different frequencies

Alpha and Beta Waves

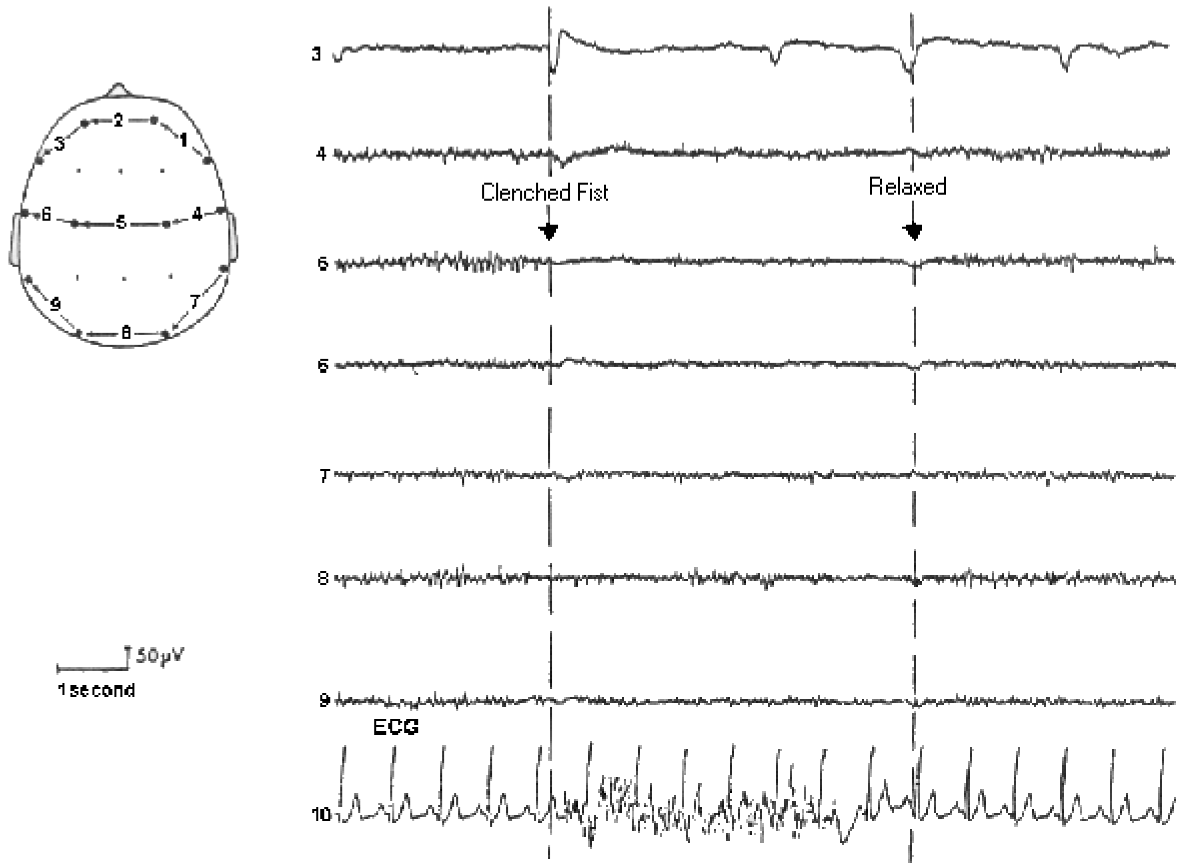
- Studied since 1920s
- Found in Parietal and Frontal Cortex
- Relaxed - Alpha has high amplitude
- Excited - Beta has high amplitude
- So, Relaxed -> Excited
  means Alpha -> Beta



Mu Waves

- Studied since 1930s
- Found in Motor Cortex
- Amplitude suppressed by Physical Movements, or *intent to* move physically
- (Wolpaw, et al 1991) trained subjects to control the mu rhythm by visualizing motor tasks to move a cursor up and down (1D)

Mu Waves

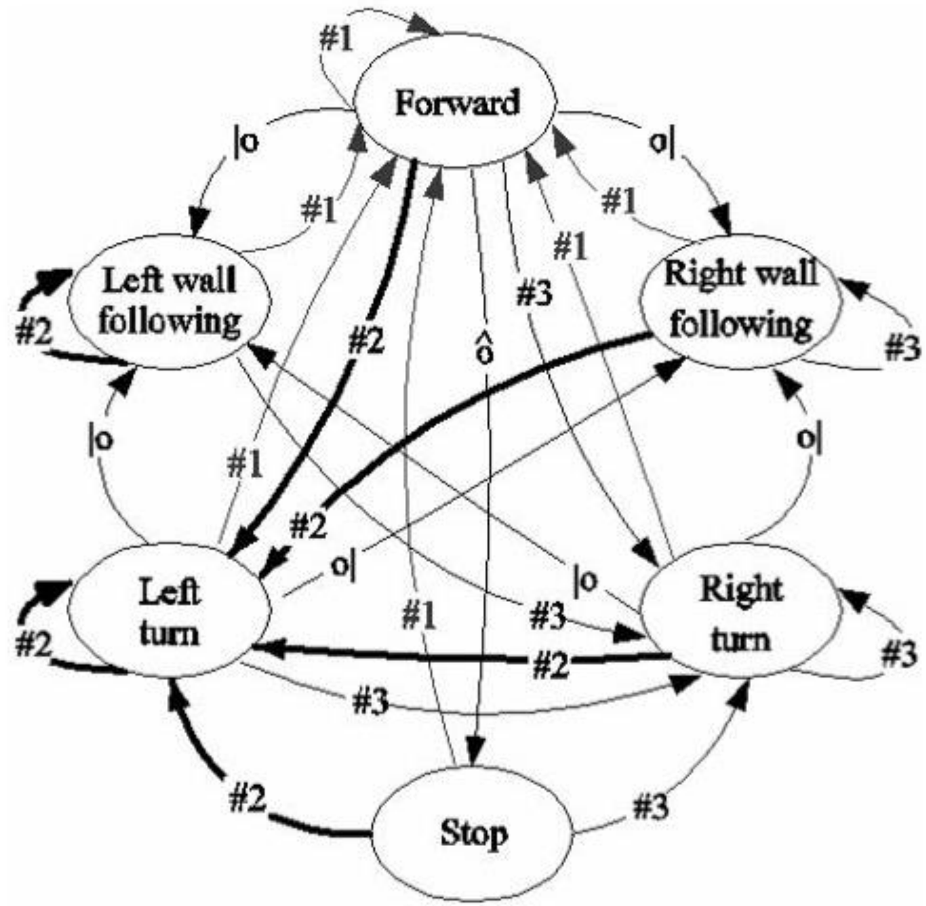


Mu and Beta Waves

- (Wolpaw and McFarland 2004) used a linear combination of Mu and Beta waves to control a 2D cursor.
- Weights were learned from the users in real time.
- Cursor moved every 50ms (20 Hz)
- 92% “hit rate” in average 1.9 sec

Mu and Beta Waves

- How do you handle more complex tasks?
- Finite Automata, such as this from (Millán et al, 2004)



P300 (Evoked Potentials)

- occurs in response to a significant but low-probability event
- 300 milliseconds after the onset of the target stimulus
- found in 1965 by (Sutton et al., 1965; Walter, 1965)
- focus specific

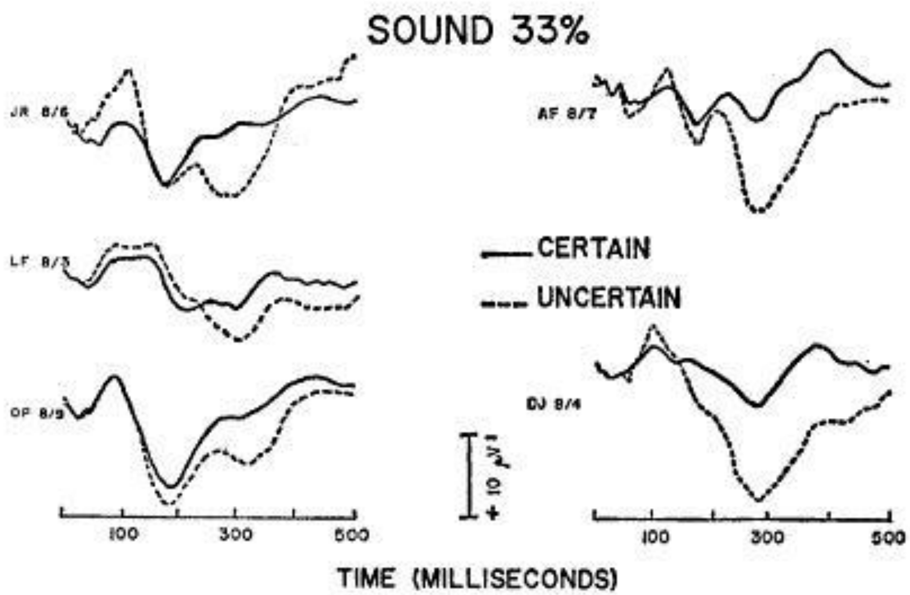
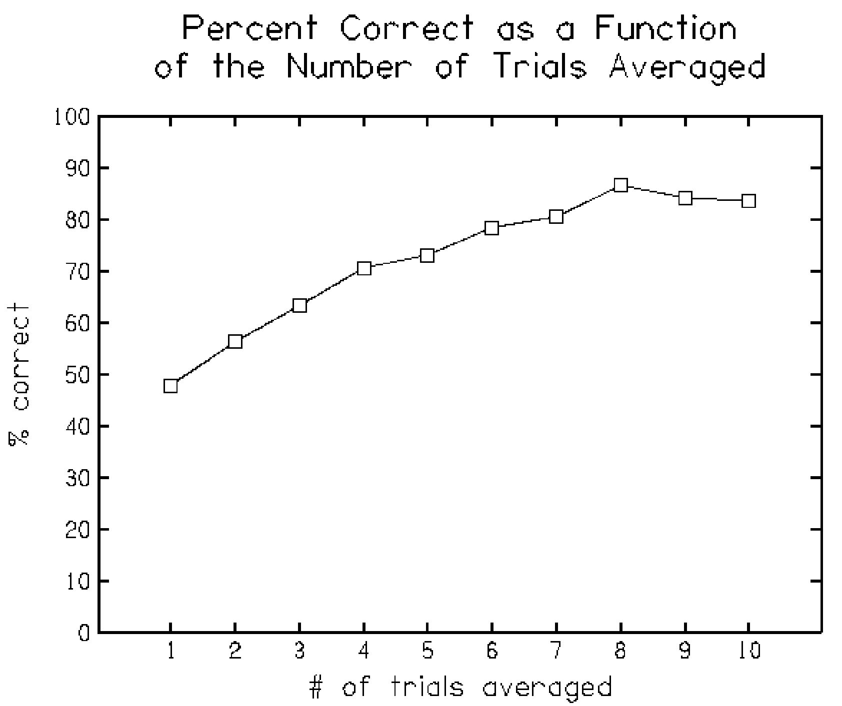


Fig. 1. Average waveforms for certain and uncertain ($P = .33$) sounds for five subjects.

P300 (Evoked Potentials)

- (Polikoff, et al 1995) allowed users to control a cursor by flashing control points in 4 different directions
- Each sample took 4 seconds
- Threw out samples masked by muscle movements (such as blinks)

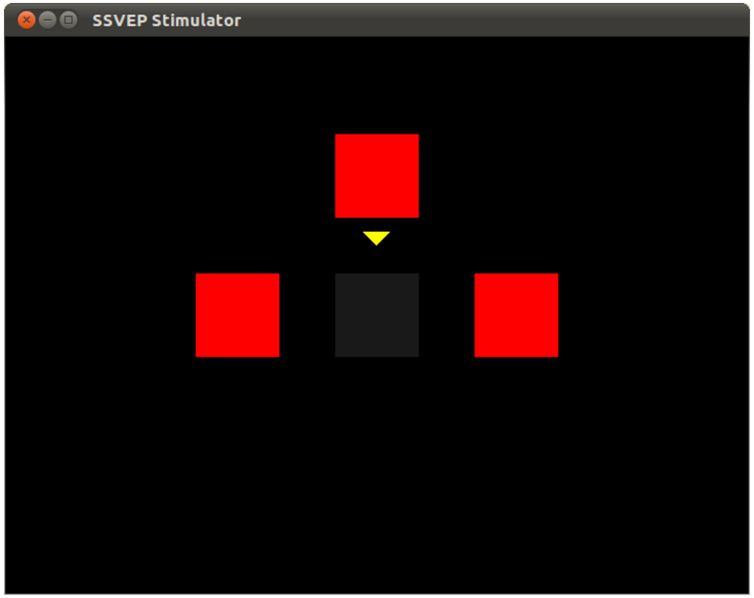
(Polikoff, et al 1995) Results

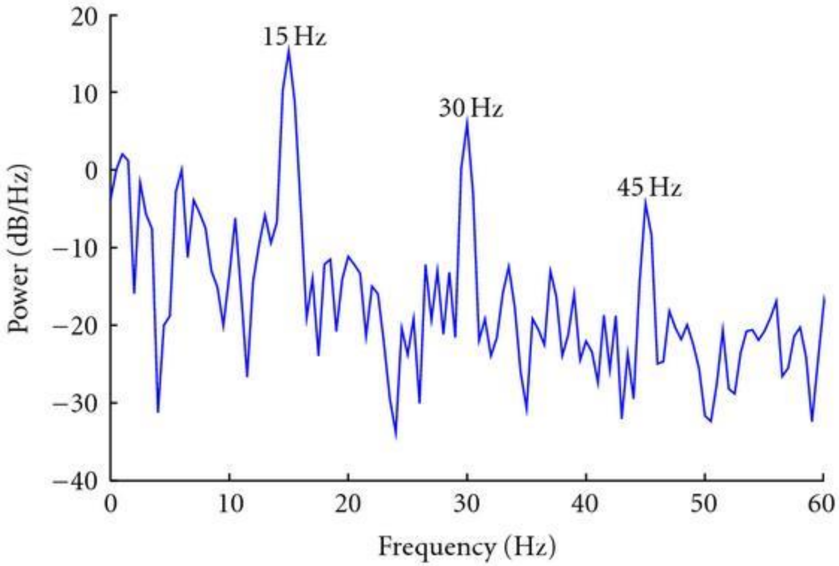


- 50% accuracy at ~1/4 Hz
- 80% accuracy at ~1/30 Hz

VEP - Visual Evoked Potential

- Detects changes in the visual cortex
- Similar in use to P300
- Close to the scalp





Model Generalization (time)

- EEG models so far haven't adjusted to fit the changing nature of the user

- Can use adaptive Filtering algorithms to deal with this
  - Lots of machine learning research in this space

Model Generalization (users)

- Many manual adjustments still must be made for each person (such as EEG placement)

- Currently, users have to adapt to the system rather than the system adapting to the users.

- Current techniques learn a separate model for each user.

Model Generalization (users)

- Can use typical machine learning techniques to reduce the need for training data.
- Support Vector Machines (SVM) and Regularized Linear Discriminant Analysis (RLDA)
- Lots of possible research projects

Summary: EEG

- EEG
  - Allow those with poor muscle control to communicate and control physical devices
  - High Precision (can be used reliably)
  - Also applicable in some gaming environments and quantified self applications

  - Requires extensive training (poor generalization)
  - Low bandwidth (today 24 bits/minute, or at most 5 characters/minute)

Future Work

- Improving physical methods for gathering EEGs
- Improving generalization
- Improving knowledge of how to interpret waves (not just the “new phrenology”)

And marketing