PSY 511 2018-08-25 Functional Methods

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Prelude

Today's topics

- Spatial and temporal scales
- A bit more about structural methods
- Functional methods

Your turn

1. Pick two papers you want to read and (better) understand

- Email me APA formatted citation (with DOIs)
- Indicate three concepts/terms you are especially interested in understanding

1. Choose a behavior or mental state you want to (better) understand

- Take an information processing perspective and briefly sketch out (in no more than a short paragraph) the main inputs, outputs, and computations involved.
- When thinking about *outputs* make sure to distinguish between *behaviors* (e.g., movements, facial expressions, vocalizations) and *physiological states* (e.g., changes in heart rate, hormone concentrations in the blood, etc.)

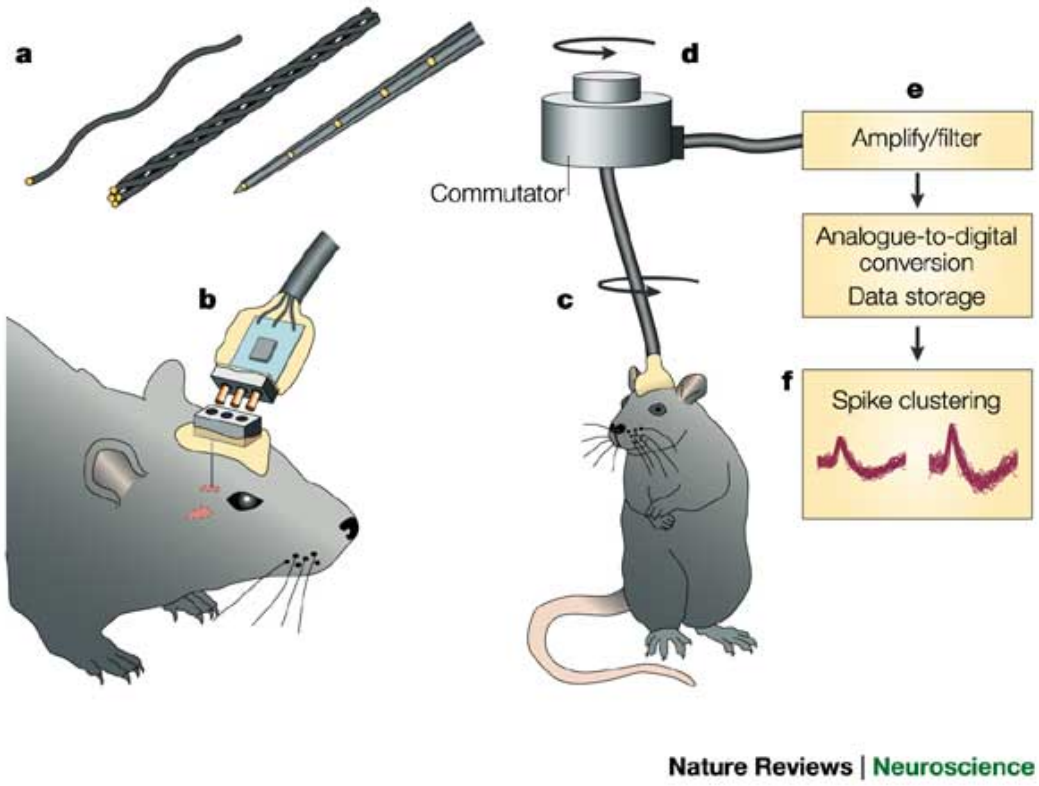
Functional methods

- Recording from the brain
- Interfering with the brain
- Stimulating the brain
- Simulating the brain

Recording from the brain

- **Single/multi unit recording**
- Microelectrodes
- Small numbers of nerve cells

Single/multi-unit Recording

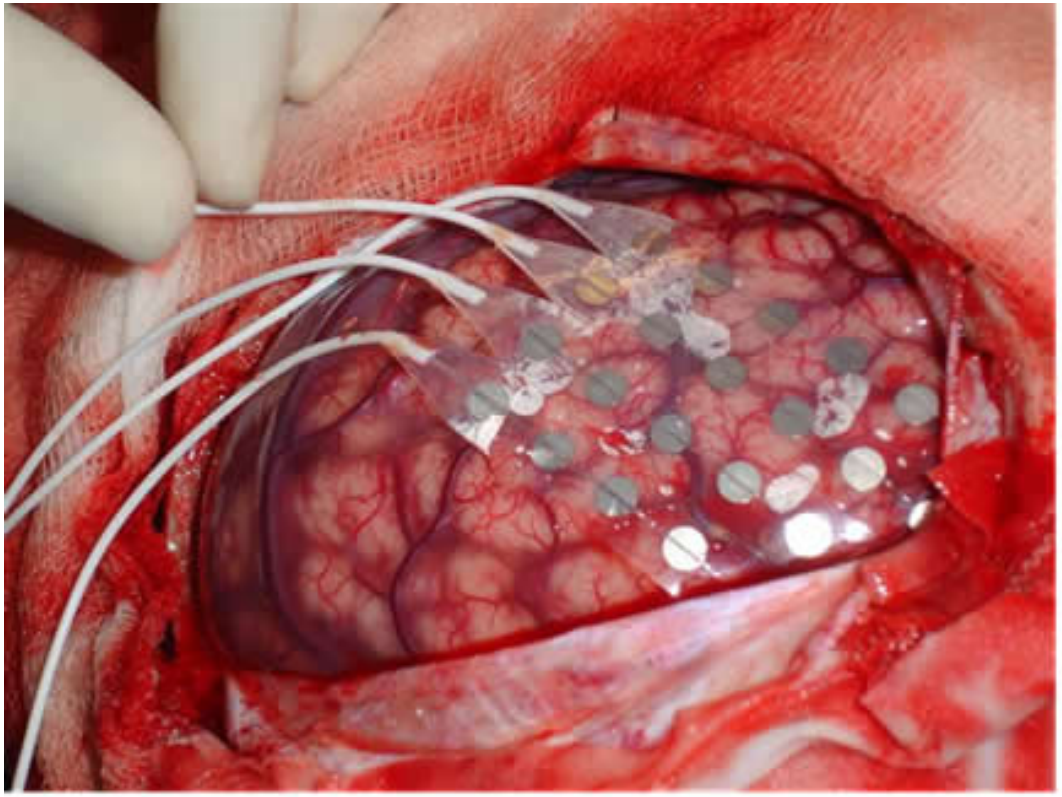


http://www.nature.com/nrn/journal/v5/n11/images/nrn1535-i1.jpg

Single/multi-unit recording

- What does neuron X respond to?
- Great temporal (ms), spatial resolution (um)
- Invasive
- Rarely suitable for humans, but…

Electrocorticography (ECoG)



Story about child who underwent ECoG surgery.

Single-cell studies ask…

- How does firing frequency, timing vary with behavior?

Positron Emission Tomography (PET)

Positron Emission Tomography (PET)

- Radioactive tracers (glucose, oxygen)
- Positron decay activates paired detectors
- Tomographic techniques reconstruct 3D geometry
- Experimental condition - control
- Average across individuals

More on PET

- Temporal (~ s) and spatial (mm-cm) resolution worse than fMRI
- Radioactive exposures + mildly invasive
- Dose < airline crew exposure in 1 yr

Functional Magnetic Resonance Imaging (fMRI)

- Neural activity -> local O_2 consumption increase
- Blood Oxygen Level Dependent (BOLD) response
- Oxygenated vs. deoxygenated hemoglobin ≠ magnetic susceptibility

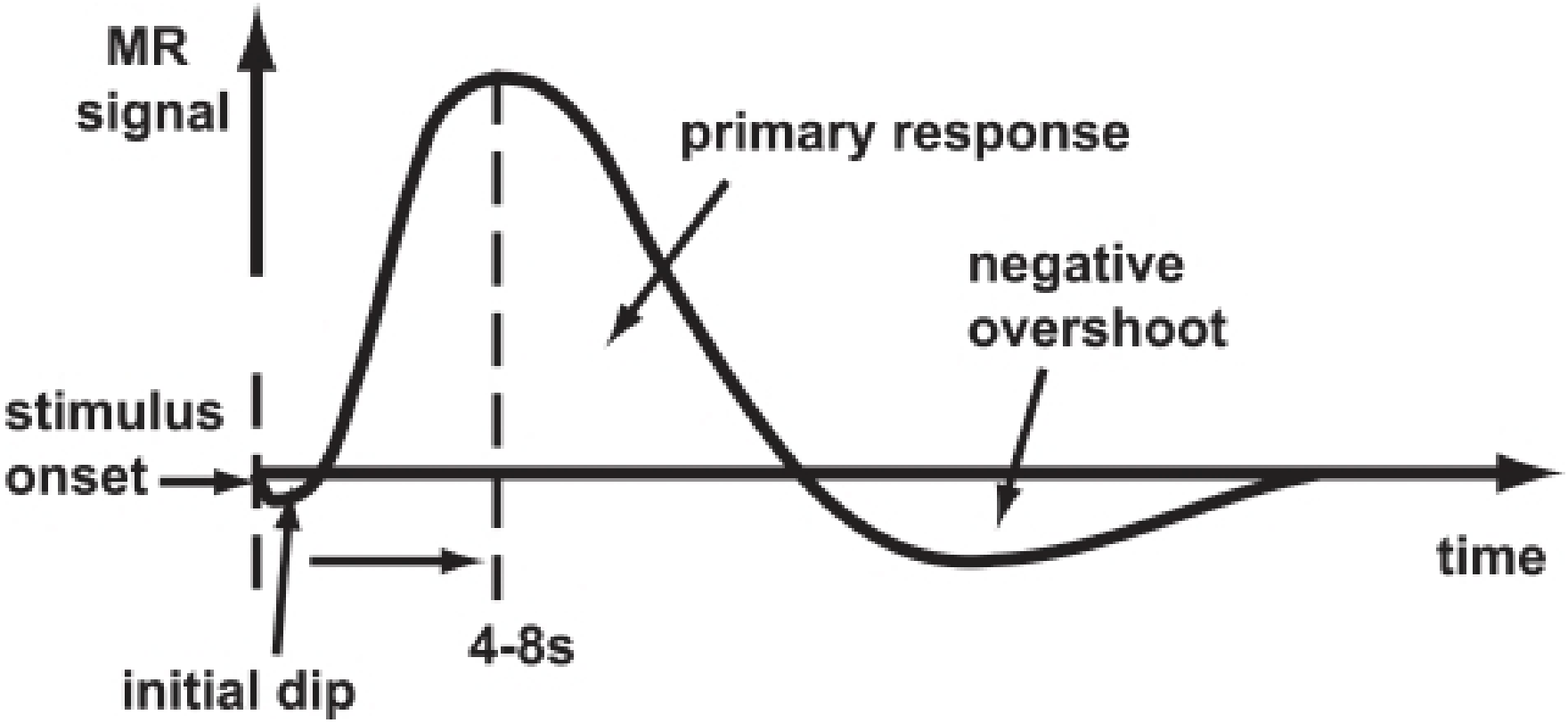
- How do regional blood O_2 levels (& flow & volume) vary with behavior X?
- MRI "signals" relate to the speed (1/T) of "relaxation" of the perturbed nuclei to their state of alignment with the main (B_0) magnetic field.
- Imaging protocols emphasize different time constants of this relaxation ($T1$, $T2$, $T2^*$); T^2* for BOLD imaging

Evaluating fMRI

- Non-invasive, but expensive
- Moderate but improving (mm) spatial, temporal (~sec) resolution
- Spatial limits due to
    - field strength (@ 3T ~3mm^3 voxel)
    - Physiology of hemodynamic response

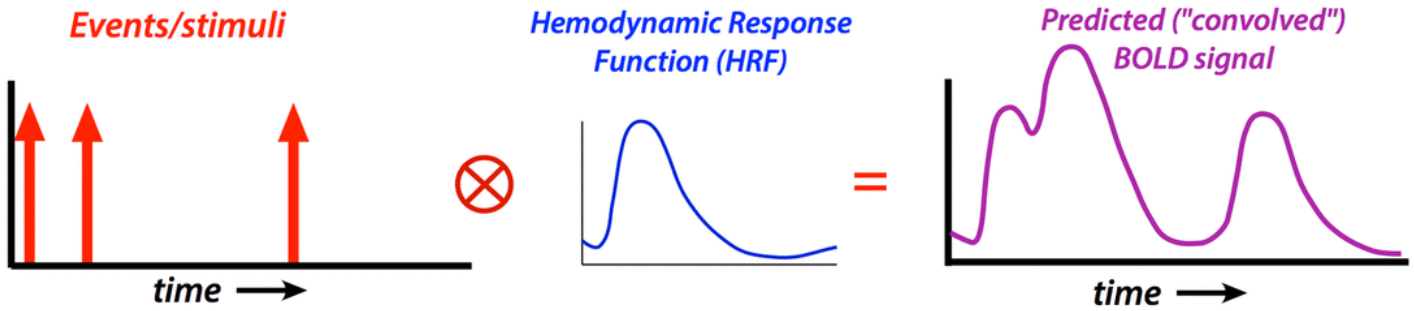
- Temporal limits due to
  - Hemodynamic Response Function (HRF): ~ 1s delay plus 3-6 s ramp-up
  - Speed of image acquisition
- *Indirect* measure of neural activity

Hemodynamic Response Function (HRF)



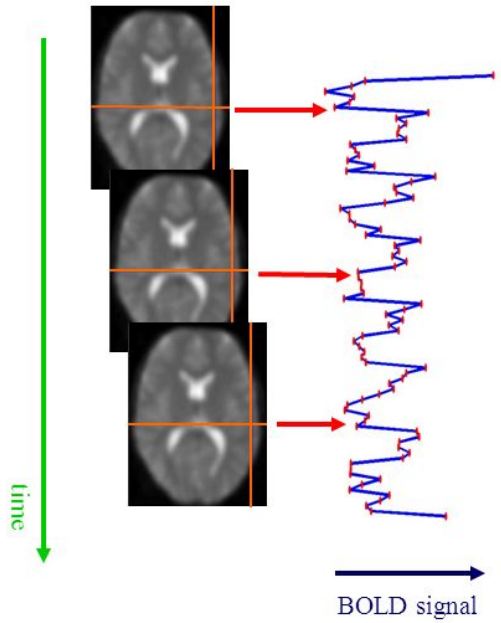
http://openi.nlm.nih.gov/imgs/512/236/3109590/3109590_TONIJ-5-24_F1.png

Generate "predicted" BOLD response to event; compare to actual



y: Activity of a single voxel over time

$$y = X\beta + \varepsilon$$



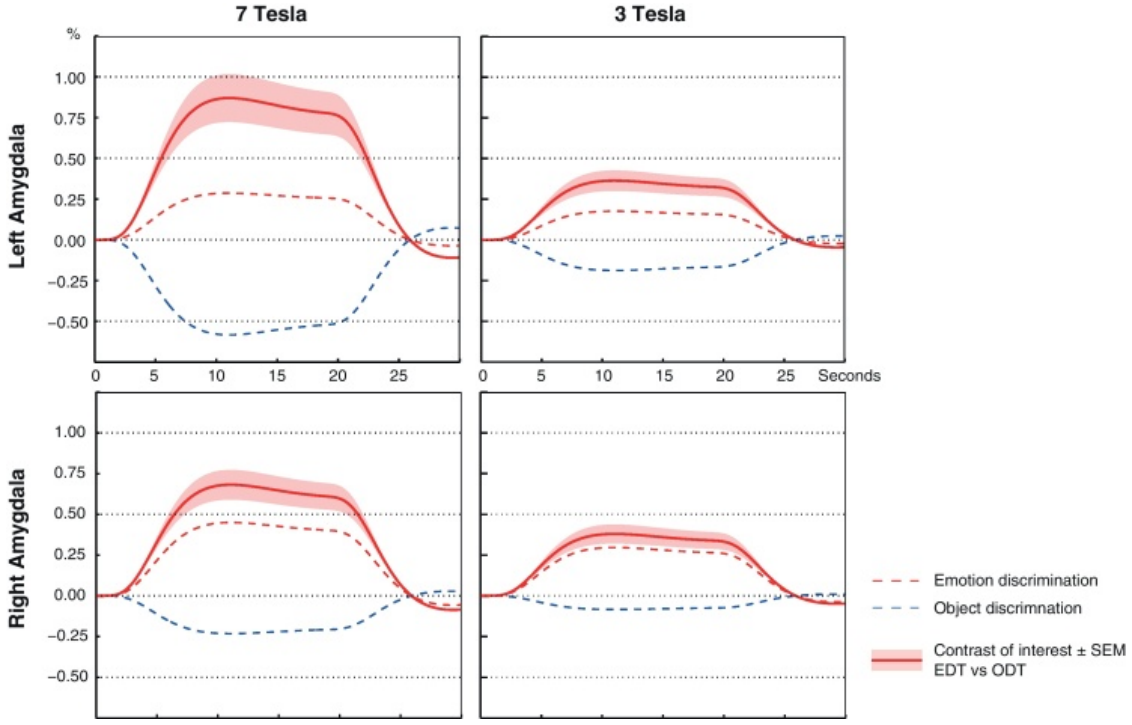
Voxel 1
57.84
57.58
57.14
55.15
55.90
55.67
58.14
55.82
55.10
58.65
56.89
55.69
…

$$\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{pmatrix} = \mathbf{y}$$

One voxel at a time:

Mass Univariate

Higher field strengths (3 Tesla vs. 7 Tesla)



(Sladky et al., 2013)

As Szucs and Ioannides have shown based on an analysis of more than 10,000 papers in the cognitive neuroscience literature, sample sizes are small, and the probability of false negatives is high, especially for small to medium effect sizes.

"*Assuming a realistic range of prior probabilities for null hypotheses, false report probability is likely to exceed 50% for the whole literature.*"

(Szucs & Ioannides, 2017)

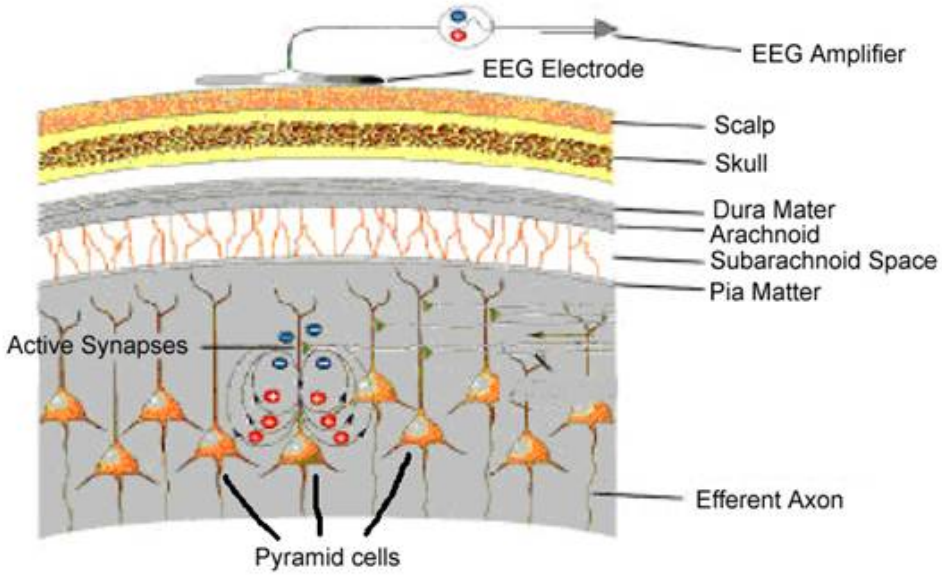
- Solution
  - Make data, materials (analysis code) more widely and openly available
  - OpenNeuro.org, Human Connectome Project, etc.
  - Increases sample size, improves detection of small effects

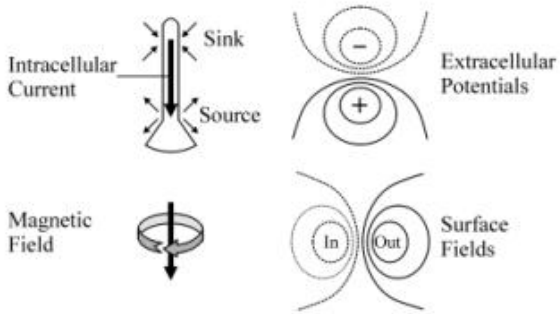
Electroencephalography (EEG)

- How does it work?
- Electrodes on scalp or brain surface
- What do we measure?
  - Voltage *differences* between source and reference electrode
- Combined activity of huge # of neurons

How does EEG arise?

- Current/voltage gradients between *apical* (near surface) dendrites and *basal* (deeper) dendrites and cell body/soma





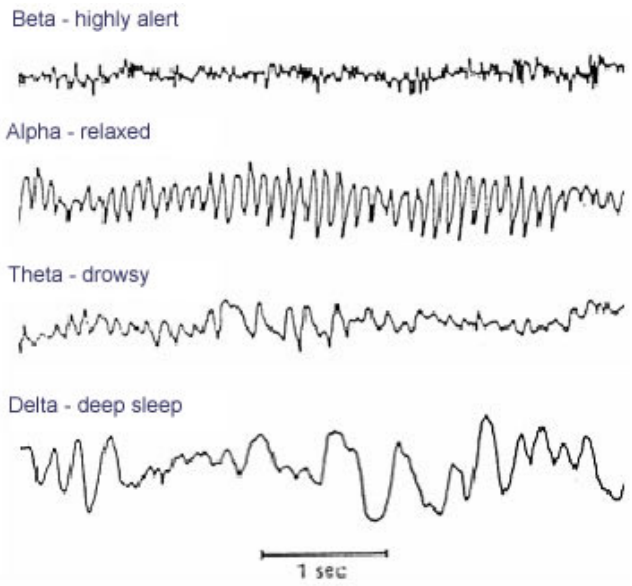
Collecting EEG

http://sfari.org/images/images-2013-folder/images-sfn-2013/20131110sfneeg

EEG

- High temporal, poor spatial resolution
- Analyze activity in different 'bands' of frequencies
  - LOW: deep sleep (δ band)
  - MIDDLE: Quiet, alert state (α band)
  - HIGHER: Sensorimotor activity reflecting observed actions? (μ band), (Hobson & Bishop, 2017)
  - HIGHER STILL: “Binding” information across senses or plasticity? (γ band), (Amo et al., 2017)

EEG Frequency

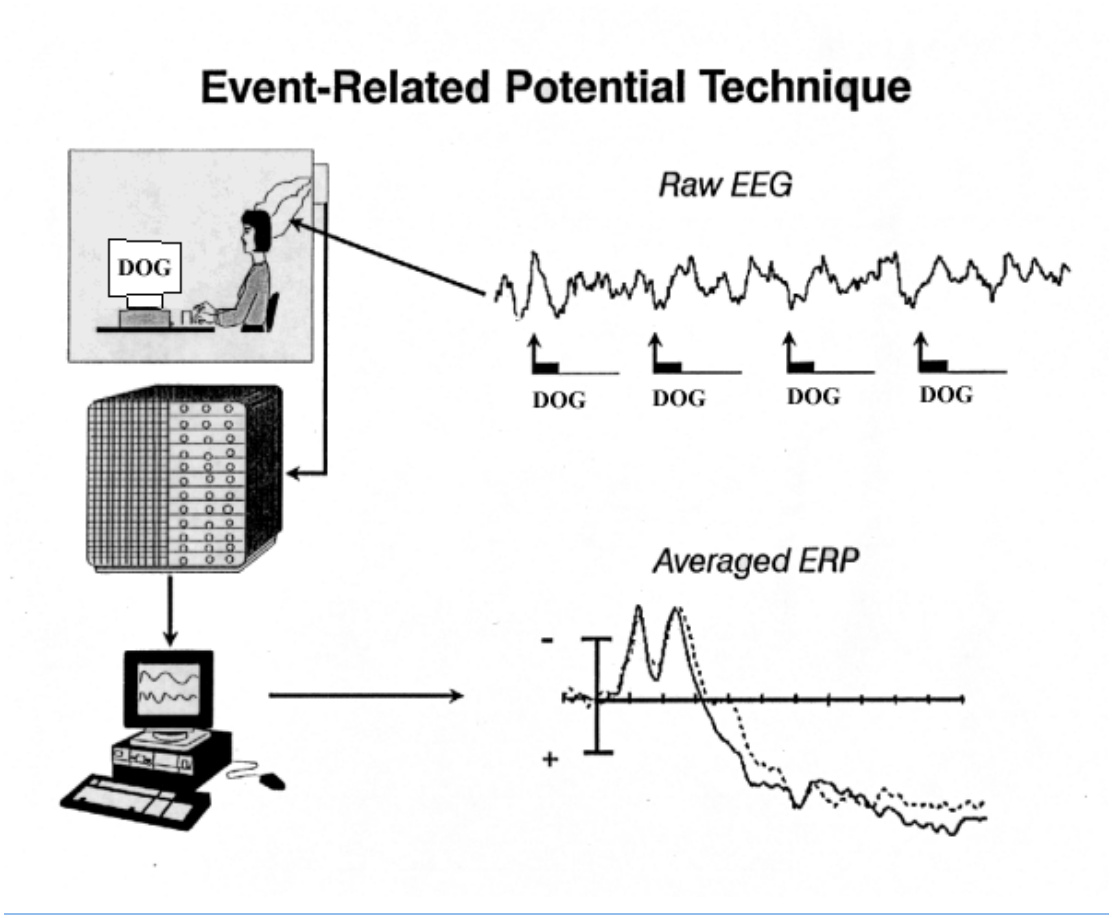


http://www.peakmind.co.uk/images/frequency.jpg

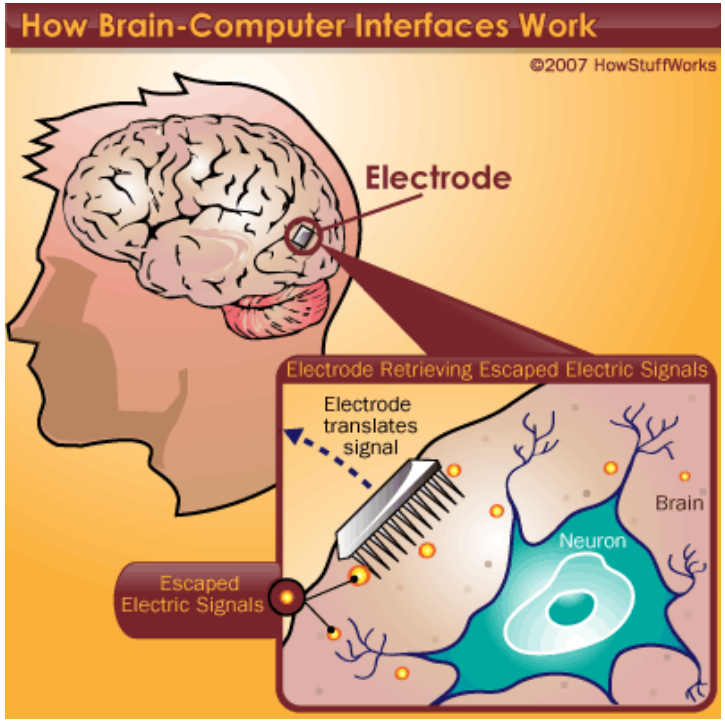
Event-related potentials (ERPs)

- EEGs time-locked to some event - Averaged over many trials

ERPs


Event-Related Potential Technique
DOG
Raw EEG
DOG
DOG
DOG
DOG
Averaged ERP
-
+

Brain Computer Interface (BCI)



http://s.hswstatic.com/gif/brain-computer-interface-3.gif

Magneto-encephalography (MEG)

- Like EEG, but measuring magnetic fields
- High temporal resolution
- Magnetic field propagates w/o distortion
    - But are orthogonal to electric field
- Requires shielded chamber (to keep out strong magnetic fields)
- ++ cost vs. EEG

MEG

How do EEG/MEG and fMRI relate?

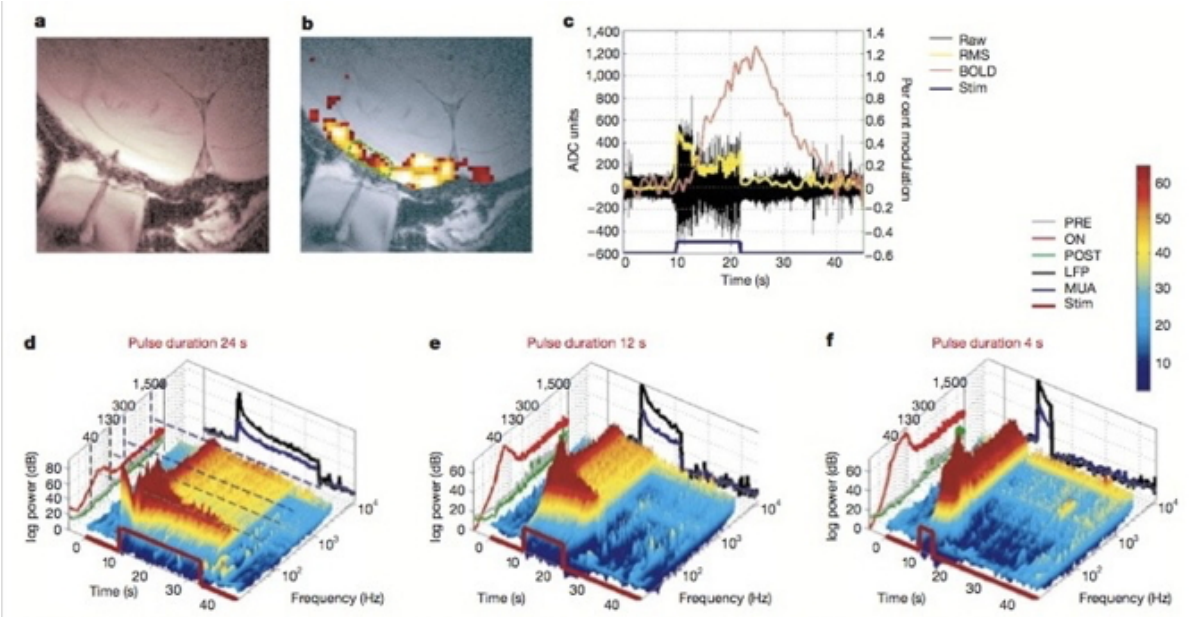


Figure 1 Neural and BOLD responses to pulse stimuli. **a**, FLASH scan (see Methods) showing the location of the electrode tip in primary visual cortex. **b**, BOLD response to rotating chequerboard patterns in striate cortex. Activation can be measured around the electrode tip. **c**, Haemodynamic response (red) superimposed on the de-noised raw neural signal (black). The term 'de-noised raw' denotes that no other signal processing beyond the removal of gradient interference (see Methods) was done. The r.m.s. of the signal is indicated by a thick yellow line. **d**–**f**, Spectrograms for data collected over 24, 12 and 4 s. In each three-dimensional plot, the vertical panel along the time axis shows the average LFP and MUA responses, namely the mean vector of the time series between black and blue dashed lines, respectively. The vertical panel along the frequency axis shows the average spectra for the pre-stimulus, stimulation, and post-stimulus periods. Colour bar shows the logarithm of power. ADC, Analogue to digital converter; STIM, time course of the visual stimulus; PRE, pre-stimulus period; ON, stimulus presentation period; POST, post-stimulus period.

(Logothetis, Pauls, Augath, Trinath, & Oeltermann, 2001)

How do EEG/MEG and fMRI relate?

- BOLD fMRI likely reflects **presynaptic** *input* to area
- EEG/MEG likely reflects **postsynaptic** *response* to those inputs
- (Logothetis et al., 2001) and (Logothetis & Wandell, 2004)

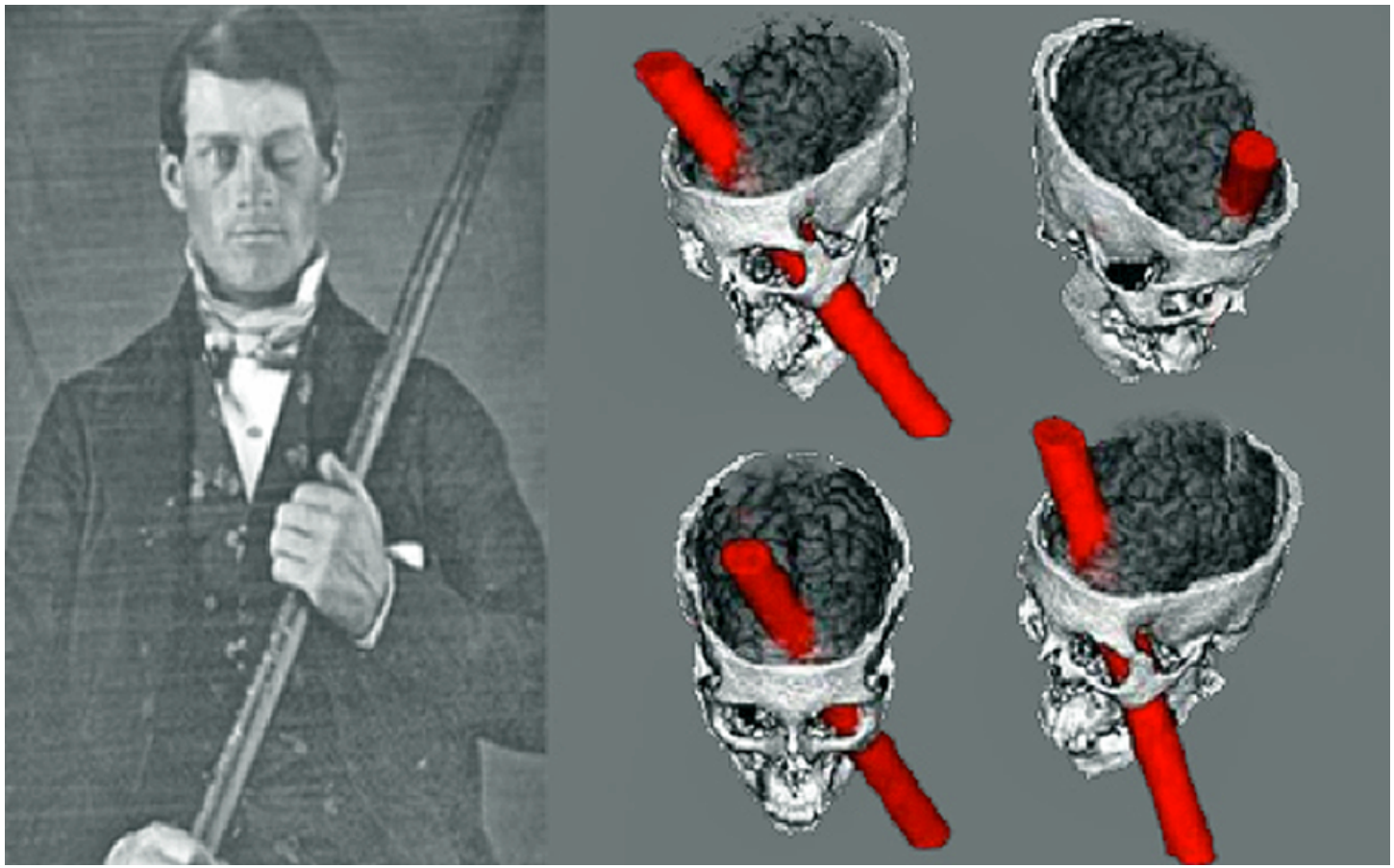
Manipulating the brain

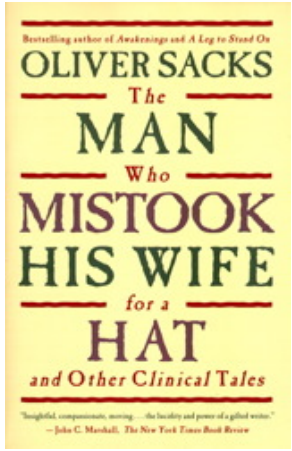
- Interfering with it
- Stimulating it

Interfering with the brain

- Nature’s“experiments”
- Stroke, head injury, tumor
- Neuropsychology

Phineas Gage




Bestselling author of Awakenings and A Leg to Stand On
OLIVER SACKS
The
MAN
Who
MISTOOK
HIS WIFE
for a
HAT
and Other Clinical Tales
"Insightful, compassionate, moving. . . the lucidity and power of a gifted writer."
—John C. Marshall, The New York Times Book Review

Evaluating neuropsychological methods

- Logic: damage impairs performance = region critical for behavior
- Weaker spatial/temporal resolution

Stimulating the brain

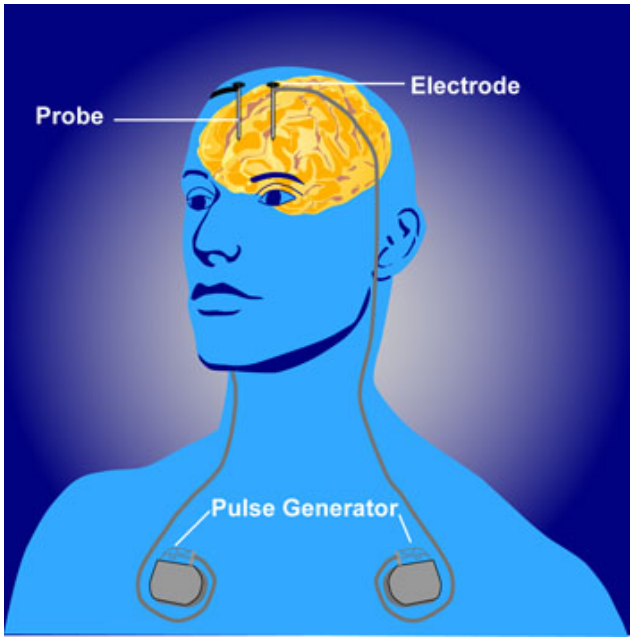
- Electrical (**Direct Current Stimulation - DCS**)
- Pharmacological
- Magnetic (**Transcranial magnetic stimulation - TMS**)

Stimulating the brain

- Spatial/temporal resolution?
- Assume stimulation mimics natural activity?

Deep brain stimulation as therapy

- Parkinson’s Disease
- Depression
- Epilepsy



http://www.nimh.nih.gov/images/health-and-outreach/mental-health-topic-brain-stimulation-therapies/dbs_60715_3.jpg

Optogenetics more closely mimics brain activity

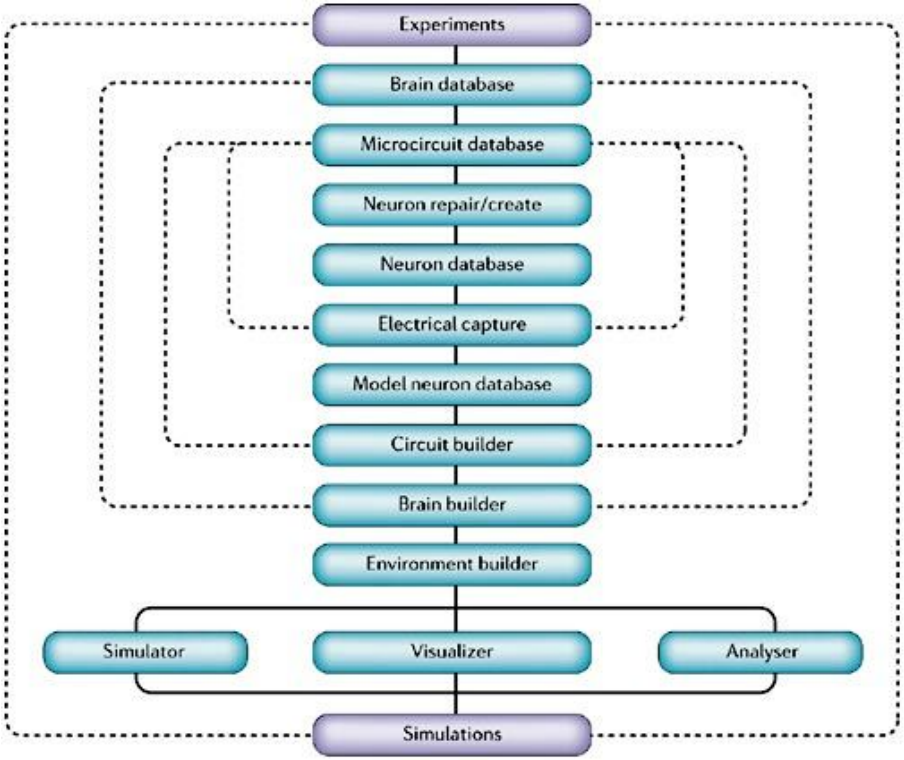
Optogenetics

- Gene splicing techniques insert light-sensitive molecules into neuronal membranes
- Application of light at specific wavelengths alters neuronal function
- Cell-type specific and temporally precise control

Simulating the brain

- Computer/mathematical models of brain function
- Example: neural networks
- Cheap, noninvasive, can be stimulated or “lesioned”

Blue Brain project



Markram, 2006

Main points

- Multiple structural, functional methods
- Different levels of spatial & temporal analysis
- Functional tools have different strengths & weaknesses

References

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