# Human Neuroscience: Design, Measurement, and Signals

Lecture 1

September 27, 2022

# Sections

# Objectives in Integrating Brain and Behavior Research

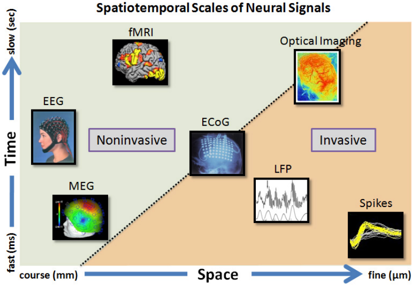
# Research Goals

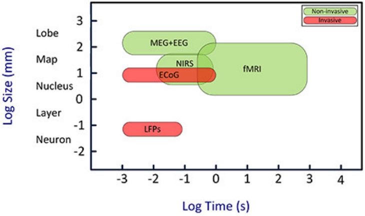
- Understand how the brain works by combining experimental psychology with measurements from the human brain.
- Validate hypothesis about cognitive functions by obtaining brain data.
- Predict behavior from brain data.
- Augment the information available in behavior from brain data.
- Integrate neural signals into cognitive models of behavior
- Decode brain activity to control devices or enable communication.

**Why is this important?**

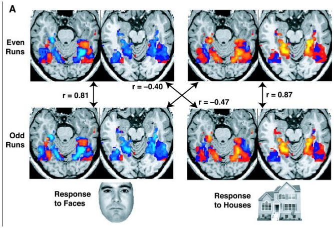
# Approach

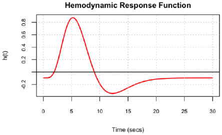
# Overview of Neuroimaging Methods



# What does functional MRI measure?

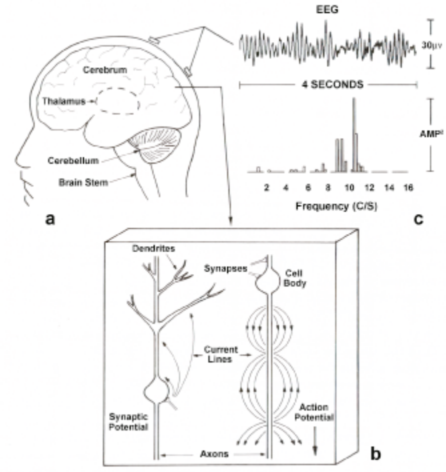



## BOLD Response

- BOLD - Blood Oxygenation Level Dependent signal provides indirect information about electrical brain activity through blood flow.

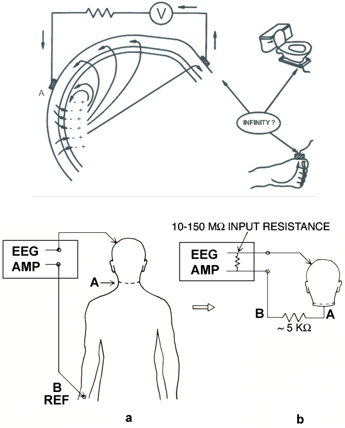
# What does EEG measure?




## Scalp potentials

- Every EEG recording is the difference in potential between two points on the surface of the head. Thus, it is a measure of current in the scalp due to sources in the brain.
- The potential fluctuates on a millisecond time scale, reflecting extracellular currents generated (mainly) around the pyramidal cells in the cortex.
- The dominant characteristic of EEG is oscillations. Properties of these oscillations can be used to characterize healthy and diseased brain state - awake, drowsy, asleep, coma, epilepsy by simple visual examination.

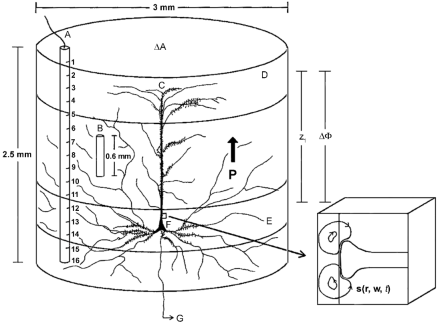
# Recording EEG

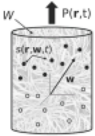



## Choice of Reference Electrode

- The choice of reference electrode location is challenging because the reference electrode must be on the body, and any reference on the body is effectively a reference on the head.
- The recorded EEG depends on both reference and recording electrode position.
- To **estimate** the potential at one location, we subtract the average of all electrodes from each electrode.

# Current Sources in the Brain

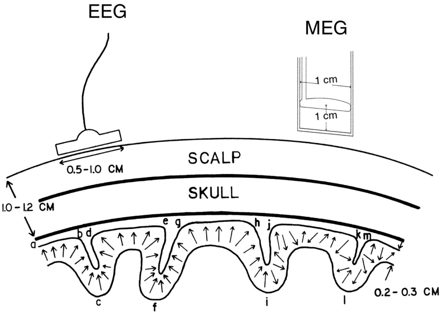


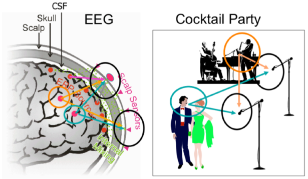




## Dipole Sources

- Within this cylinder there are perhaps $10^5 - 10^6$ neurons and $10^8 - 10^{10}$ synapses
- The far-field approximation allows us to approximate the complex source sink configuration of the cylinder by a dipole moment per unit volume, P.
- The strength of the dipole depends on the excitatory and inhibitory synaptic currents, the spatial distribution of active synapses, and synchrony of the synaptic currents

# EEG, MEG, and the Cocktail Party

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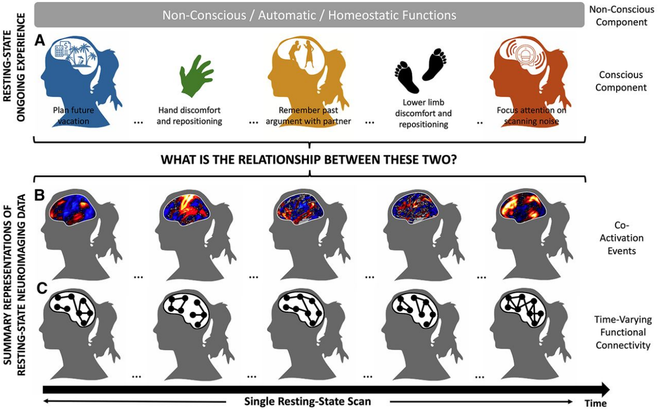
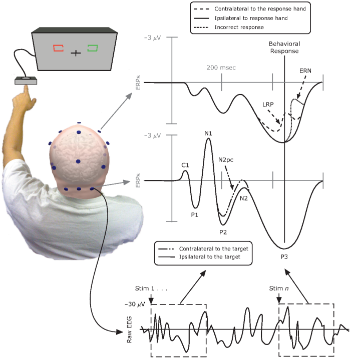
# Experimental Designs

# Spontaneous Activity or Resting State



# Stimulus



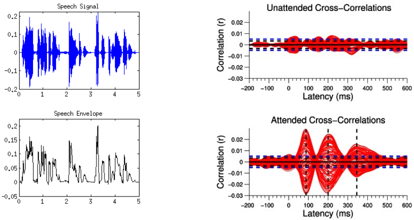

## Event Related Potential

- A single discrete stimulus presentation of finite duration.
- Repeated trials of a stimulus, or stimulus category are usually averaged to estimate brain responses.
- Evoked potentials (EPs) or Event-Related Potentials (ERPs) are computed by aligning the trials on the stimulus onset and averaging at each point in time following the stimulus.
- Fourier analysis is used to identify evoked and induced oscillations.
- The main *advantage* of this design is to identify the timing of neural events in relation to stimulus (or response).
- The main *disadvantage* of this design is that responses can be obtained only from the onset of singular stimulus presentations.

# Stimulus

## Response to Natural Stimuli

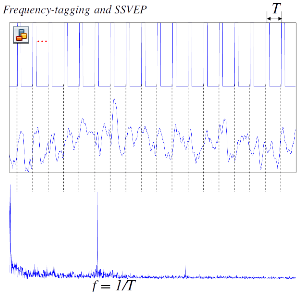
- Naturalistic visual or auditory stimulus sequences are presented, e.g. natural speech or a movie
- The time course of stimulus energy in specific channels are cross-correlated with the EEG time series to estimate stimulus response.
- The main *advantage* of this design is the ability to work with natural stimuli.
- The main *disadvantage* of this design is low signal-to-noise ratio.



# Stimulus

## Steady-state Response

- Visual stimuli are flickered at a fixed frequency. This induces a brain response at the flicker frequency and harmonics (multiples of the flicker frequency).
- Auditory stimuli are amplitude modulated at a fixed frequency, inducing a response at the modulation frequency.
- The brain's response to two or more stimuli can be simultaneously measured by flickering each stimulus at a different frequency, known as *frequency tagging*.
- The main *advantages* of this design are very high signal-to-noise ratio, and the use of frequency tagging to monitor responses to distinct stimuli.
- The main *disadvantages* of this design are unnatural stimulus presentation and somewhat reduced temporal resolution.



# Event-related Potentials

# Time course of auditory brain activity

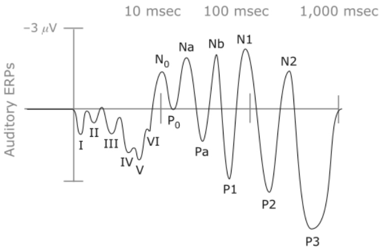
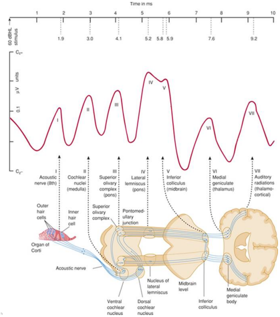
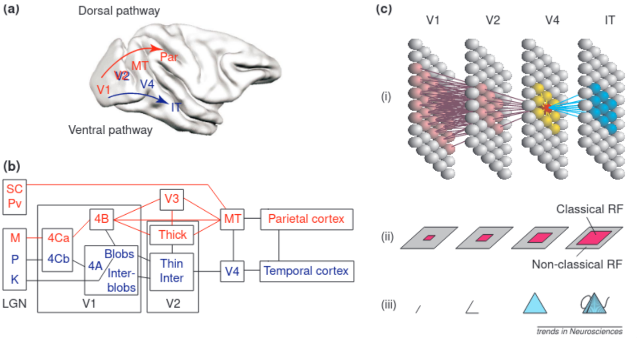
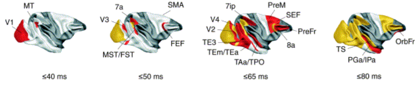



**Figure 2. Idealized event-related potential (ERP) waveform evoked by a brief auditory stimulus. Waveforms shown would be expected from a central electrode site (i.e., Cz). Note that the waveforms are plotted as a function of log time.**

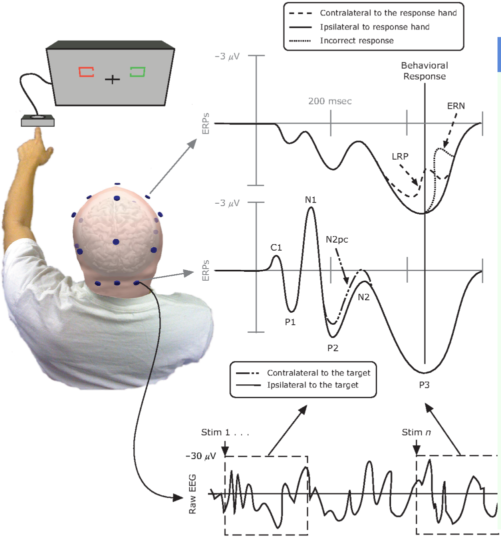


# Time course of visual information processing



# Stimulus-locked and Response-locked event-related potentials




## Event-related potentials

- In Behavioral experiments, we present a stimulus and collect a response.
- These events organize our analysis of the EEG data.
- The data can be analyzed in relation to the stimulus onset as shown in the lower trace.
- The stimulus can be analyzed in relation to the response as shown in the upper trace.

# Naming Conventions for Event-Related Potentials

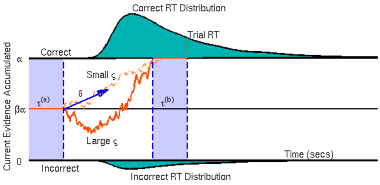
**Table 1**
**Summary of Event-Related Potential Components Using a Variety of Nomenclatures During a Simple Visual–Manual Task Similar to That of Figure 1**

| Nomenclature | Ordinal | Latency (Peak) | Scalp Distribution | Task/Stimulus Specificity | Hypothesized Process(es) Indexed | Useful Reference |
|---|---|---|---|---|---|---|
| Components preceding a stimulus | | | | CNV (O- & E-waves) | anticipation, cognitive & motor preparation | Brunia, van Boxtel, & Böcker (in press) |
| Components following a stimulus | C1 | P/N50–70 | | | sensory processing | Pratt (in press) |
| | P1 | P90–100 | | | sensory/perceptual processing | Pratt (in press) |
| | N1 | N170–200 | posterior versus anterior N1 | N170 for faces | perceptual processing, expert recognition, visual discrimination | Hillyard, Vogel, & Luck (1998); Rossion & Jacques (in press); Vogel & Luck (2000) |
| | P2 | | | | not well understood | Crowley & Colrain (2004) |
| | N2 | N225–250 | | | object recognition, categorization | Folstein & Van Petten (2008); Pritchard et al. (1991) |
| | N2pc | | PCN | | deployment of covert attention | Luck (in press) |
| | P3 | P300 | P3a/P3b | P3a/P3b | stimulus evaluation time, categorization, context (working memory) updating, cognitive load | Polich (in press) |
| | | | SPCN | CDA | maintenance in visual working memory | Perez & Vogel (in press) |
| | | | | LRP | response preparation | Smulders & Miller (in press) |
| Components following a response | | | medial frontal negativity | ERN/Ne & FBN | error processing, reinforcement learning or response conflict signal | Gehring, Liu, Orr, & Carp (in press) |
| | | | | Pe | affective or conscious assessment of task performance | Falkenstein et al. (2000) |

Note—This list is focused on visual components and neglects components from the auditory, language, and memory literatures. CNV, contingent negative variation; O- & E-waves, orienting & expectancy waves; C1, Component 1; N, negative; P, positive; N2pc, N2 posterior contralateral; PCN, posterior contralateral negativity; CDA, contralateral-delay activity; SPCN, sustained posterior contralateral negativity; LRP, lateralized readiness potential; ERN/Ne, error-related negativity/error negativity; FBN, feedback negativity; Pe, error positivity.

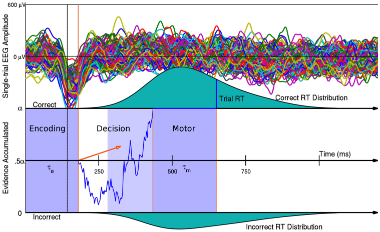
# Neurocognitive Modeling

# Models of Perceptual Decision Making



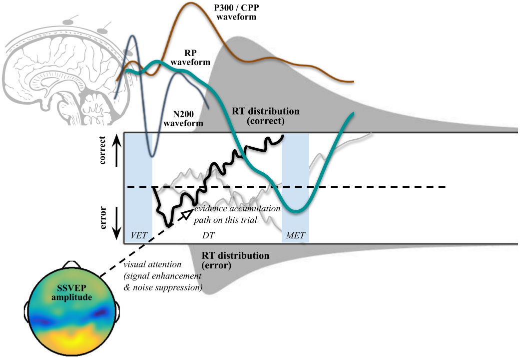

- Speed and accuracy is perceptual decision making can be modeled by a drift-diffusion model. This model hypothesize specific information processing steps in reaching a decison in decision making tasks.
- The model divides the time to respond into three intervals – perceptual encoding, decision making, and motor preparation and execution. The perceptual and motor components are lumped together as the non-decision time parameter ($\tau$)
- The decision-process is evidence accumulation to a boundary which triggers the motor response. This process is parameterized as an evidence accumulation or drift rate ($\delta$), the variability in evidence accumulation ($\zeta$) and the boundary separation ($\alpha$). These three parameters are not fully identifiable with behavioral data alone.

# Visual Encoding Time




Nunez, **Gosai**, Vandekerckhove, Srinivasan (2019) The latency of a visual evoked potential tracks the onset of decision making.Neuroimage.

# Neurocognitive Models




- We have extended the model to incorporate Event Related Potentials, and Induced Oscillations as markers of timing of neural events, in order to improve the identification of model parameters and to enable prediction of behavior from EEG data alone.
- We use single-trial estimates of ERPs to improve our model of the distribution of response times.

**Lui**, Nunez, Cassidy, Cramer, Vandekerckhove, Srinivasan (2020) Timing of the readiness potential reflects a decision process in the human brain, Computational Brain and Behavior.

# Data Analysis Challenge

## Data Structure

All Neuroscience research in humans involves the analysis of data in space and time. Consider an experiment (either fMRI or EEG) in which there are K trials (observations). On each trial k, a data matrix of the form below is collected.

$$Data_k = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1M} \\ \vdots & \ddots & & \\ a_{N1} & \dots & & a_{NM} \end{bmatrix}$$

- In this data matrix there are M columns corresponding to the M different variables being measured.
  1. For EEG studies these might M electrodes on the scalp, M typically ranging from 20-256. For fMRI studies there are M voxels (volume elements) in the brain, M typically on the order 1000-4000.
  2. By design, many fMRI studies choose not to use all the voxels in the brain but a hypothesis driven subset)
- In this data matrix there are N rows corresponding to N time points *within a single trial*
  1. For EEG studies, there are typically 1000 time points every second. If the trial is 2 secs, N = 2000
  2. For fMRI studies there are typically 1 time point every 2 seconds. A trial might be 20 secs consisting of 10 time points

## Data Analysis Goal

$$Data_k = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1M} \\ \vdots & \ddots & & \\ a_{N1} & \dots & & a_{NM} \end{bmatrix}$$

In any experiment, there are K such matrices.In cognitive research, the goal is to take the data in this matrix and relate it to behavior. For example, behavior might be the speed and accuracy of decisions. Or it maybe whether an item is remembered.In clinical research, the goal is often to take these data and isolate a biomarker which can be used to objectively assess disease state.