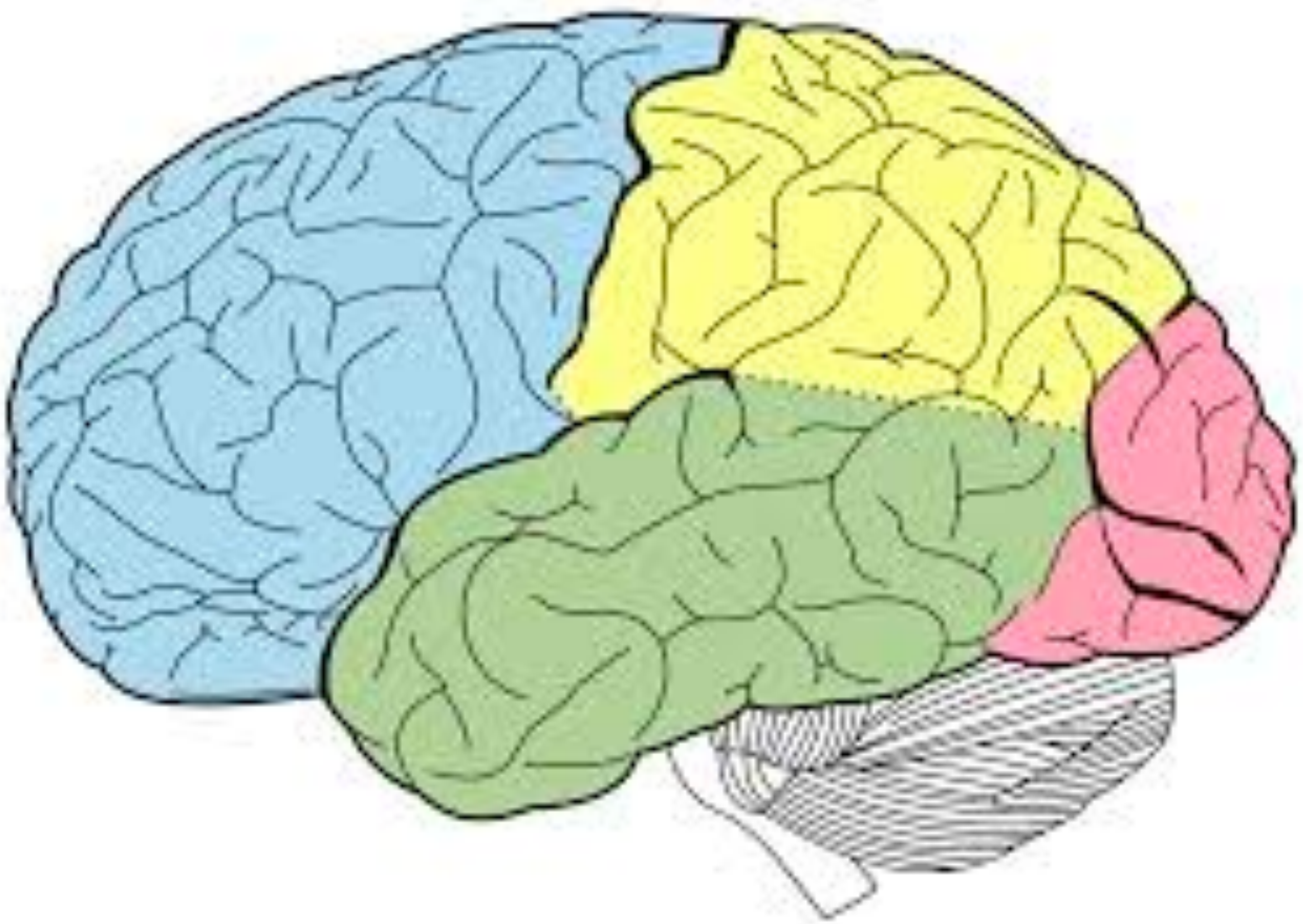
Question of the Day



Which part of the human brain shown here has the highest number of neurons?

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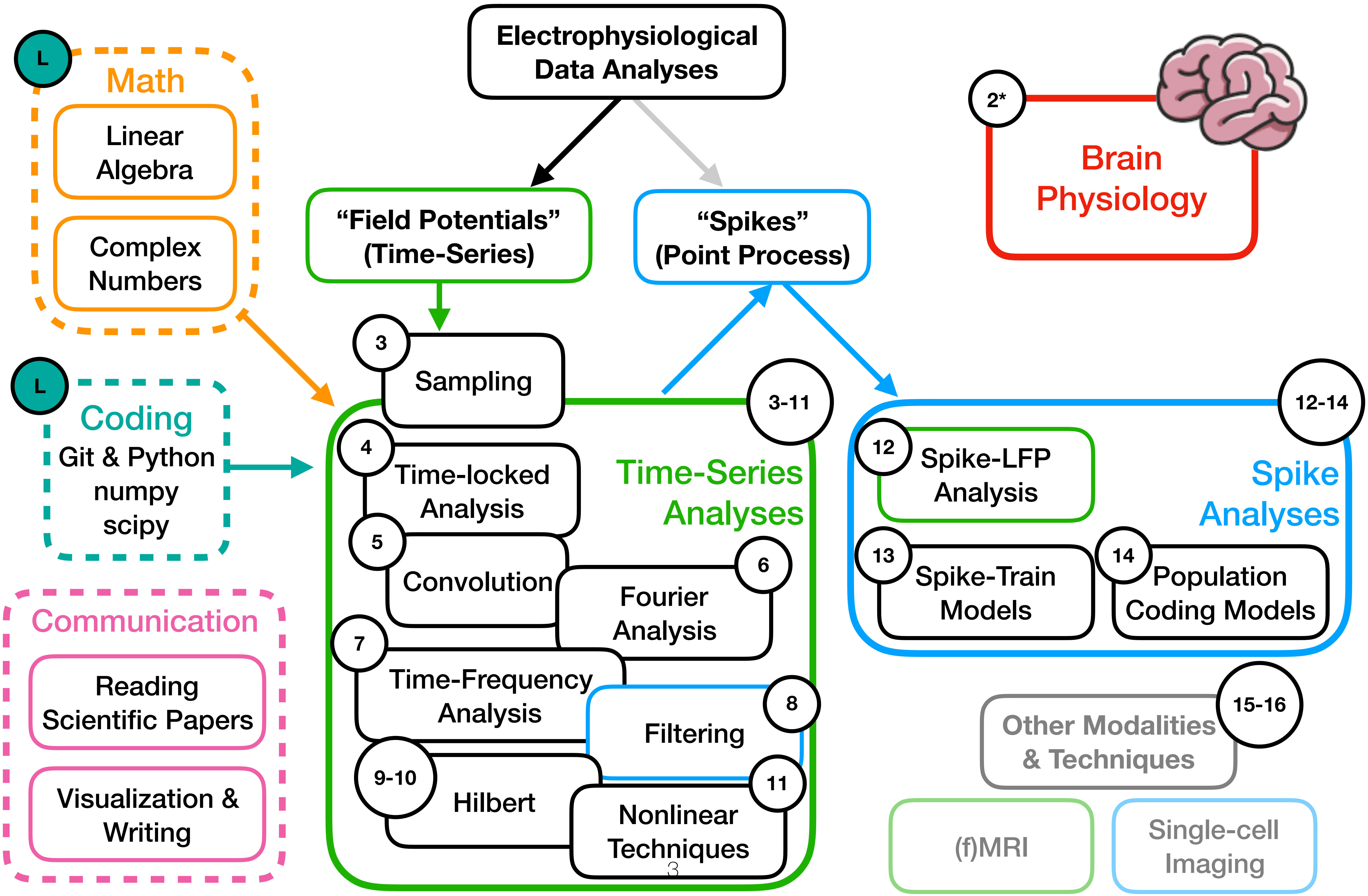
Noise & Event-Related Potentials

Lecture 4
July 8, 2019

Course Outline: Road Map



Goals for Today

1. Understand conceptually signal vs. noise

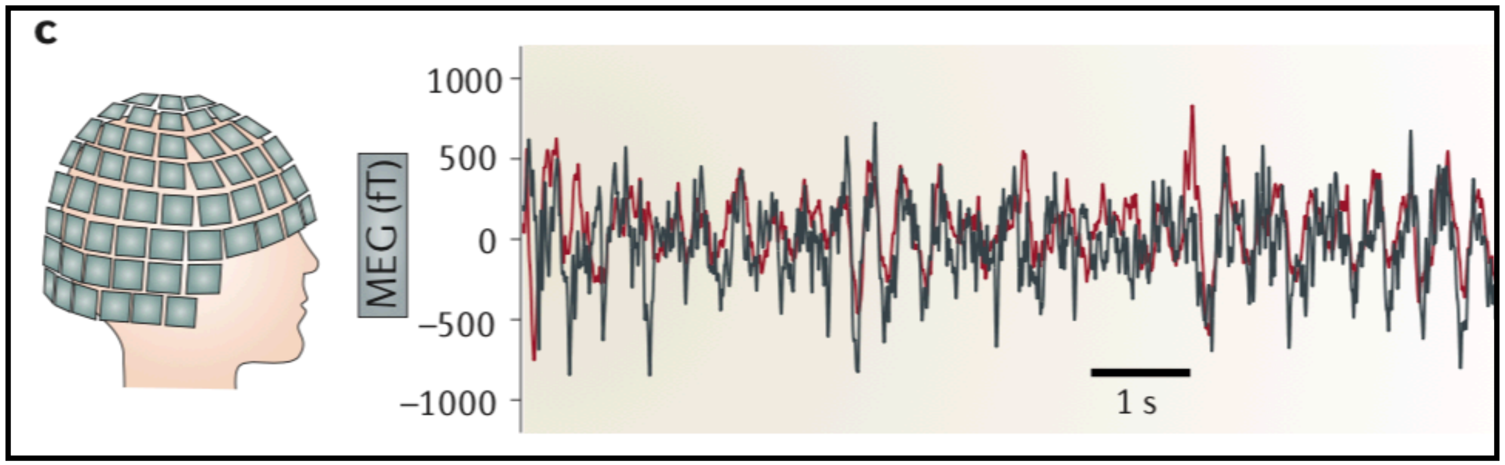
2. List sources of noise in brain recordings

3. Event-related experimental design and analysis

WvD. Chapters 3 & 4

Signal Vs. Noise

Recorded Signal



"True" Neural Signal

+

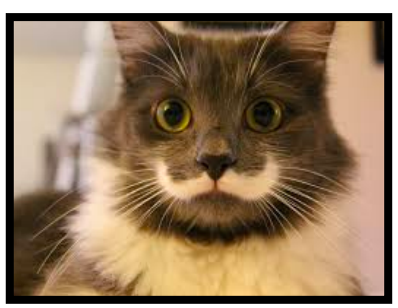
Various Noises

We often make a fundamental assumption about the distinction between signal vs. noise.

"True" signal: the brain's underlying & consistent response to stimulus or action.

Noise: everything else.

Signal Vs. Noise

	Stimulus	Brain Response (Signal)		"Noise"
Trial 1		Response C	+	Noise(1)
Trial 2		Response D	+	Noise(2)
Trial 3		Response D	+	Noise(3)
	...			
Trial N		Response C	+	Noise(N)

Assumptions

Signal and Noise are **Linearly Additive**

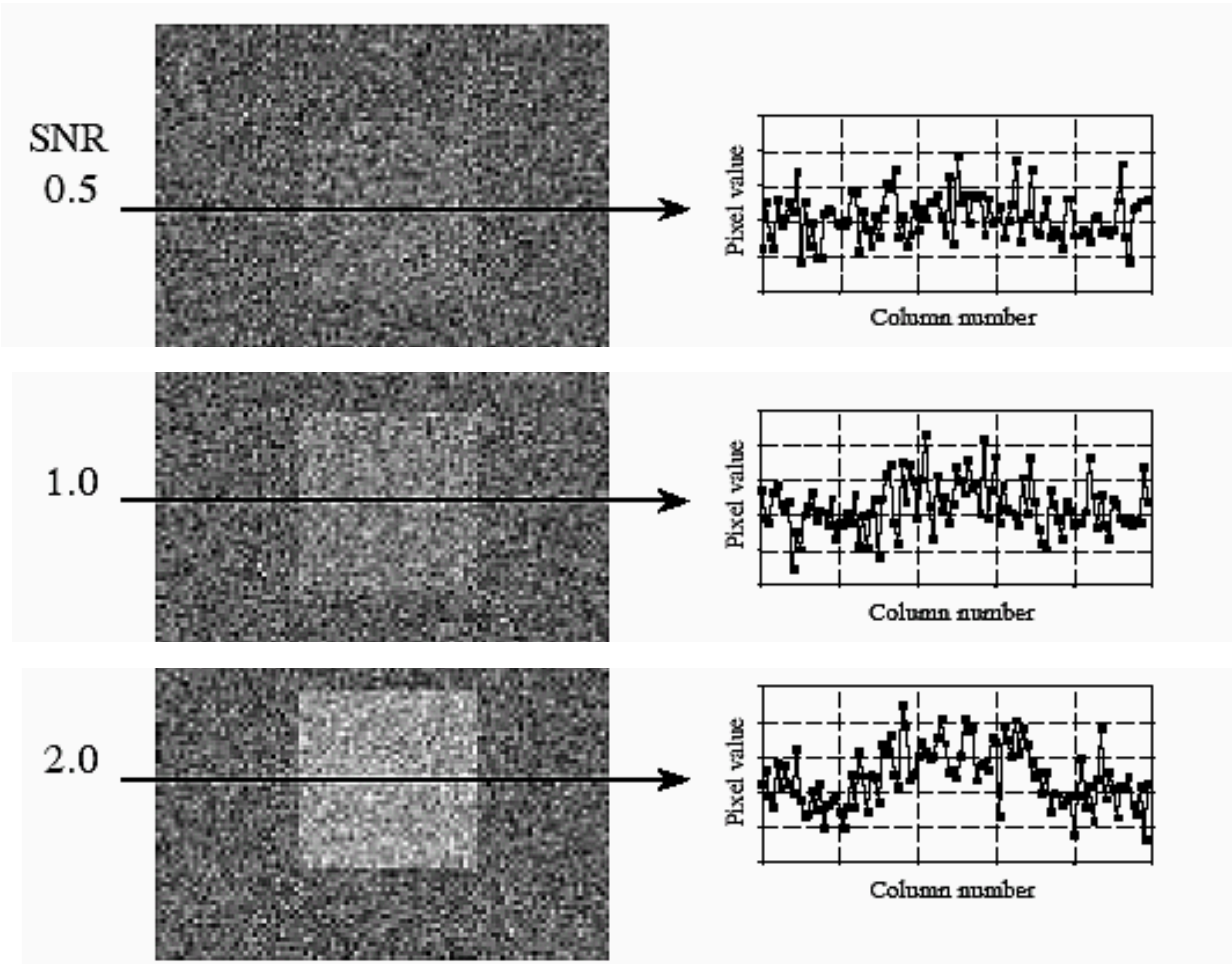
Brain signal is **Time-Invariant**

[Linear Time Invariant (LTI) system]

Noise is **Statistically Independent**

Signal to Noise Ratio (SNR)

Detecting a signal depends on the
signal to noise ratio (SNR)



Noise amplitude is constant here while signal amplitude increases.

How to quantify signal and noise?

Signal to Noise Ratio (SNR)

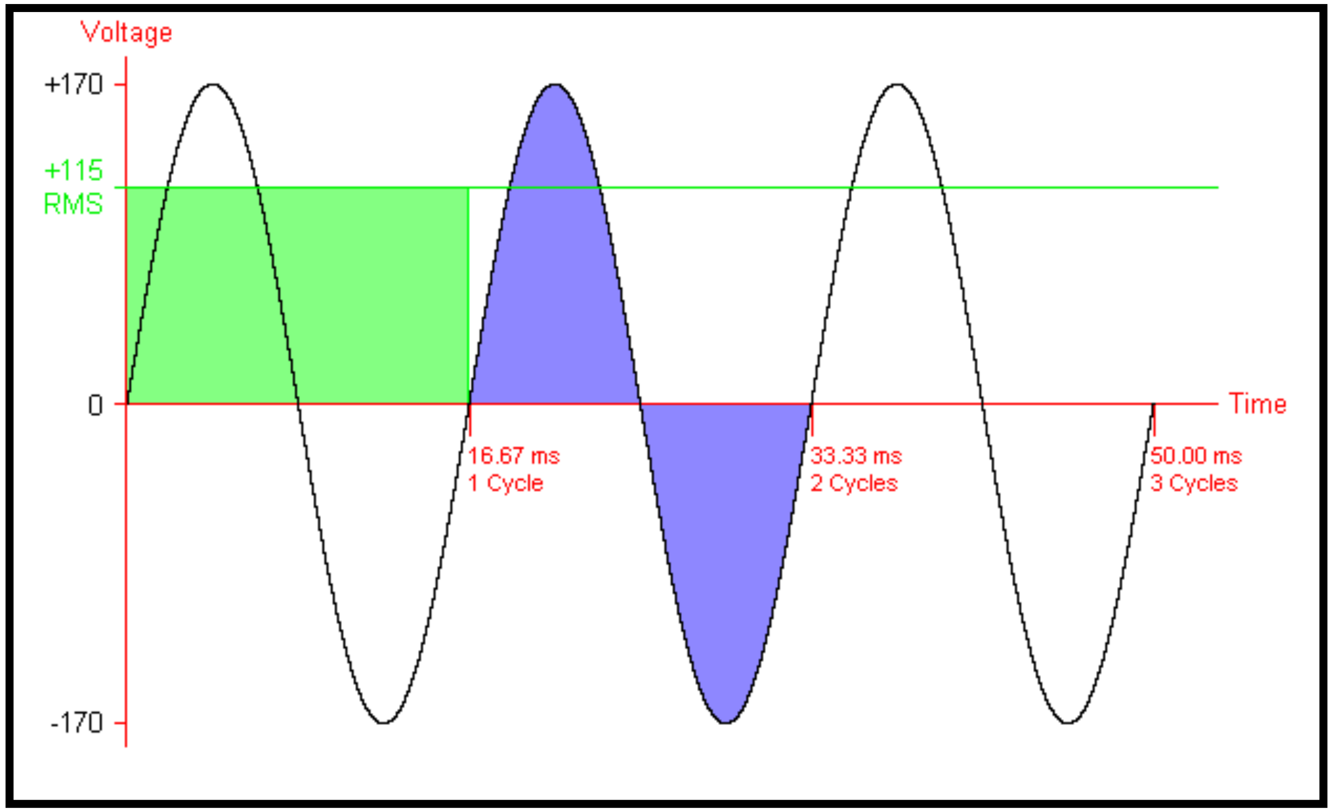
Power is measured by **"mean square" (ms)**:

$$\frac{1}{N}\sum_{i=1}^{n} x_i^2$$

...similar to variance & standard deviation.
Measures average fluctuation.

"root mean square" (rms):

$$rms = \sqrt{\frac{1}{N}\sum_{i=1}^{n} x_i^2}$$



Signal-to-noise ratio (SNR) in decibels (dB):

$$SNR = 20\log_{10}\frac{rms_{signal}}{rms_{noise}}$$

Signal to Noise Ratio (SNR)

or **"root mean square" (rms)**:

$$\sqrt{\frac{1}{N}\sum_{i=1}^{n} x_i^2}$$

Signal-to-noise ratio (SNR) in decibels (dB):

$$SNR = 20\log_{10}\frac{rms_{signal}}{rms_{noise}}$$

signal: [1,2,3,4,-3,-2,-1]

noise: [1,-1,1,-1,1,-1,1]

SNR = ?

What if we amplify signal by 100x?

Signal to Noise Ratio (SNR)

or **"root mean square" (rms)**:

$$\sqrt{\frac{1}{N}\sum_{i=1}^{n} x_i^2}$$

signal: [1,2,3,4,-3,-2,-1] ×100

noise: [1,-1,1,-1,1,-1,1]

SNR = ?

What if we amplify signal by 100x?

Signal-to-noise ratio (SNR) in decibels (dB):

$$SNR = 20\log_{10}\frac{rms_{signal}}{rms_{noise}}$$

×100

$rms_s \times 100$

$$rms_s = \sqrt{\frac{1}{7}(1^2+2^2+3^2+\dots)}$$

$$= 2.507$$

$$rms_n = \sqrt{\frac{1}{7}(7)}$$

$$= 1$$

×100

$$SNR = 20\log\left(\frac{2.507}{1}\right)$$

$$= 7.98$$

1. Understand conceptually signal vs. noise

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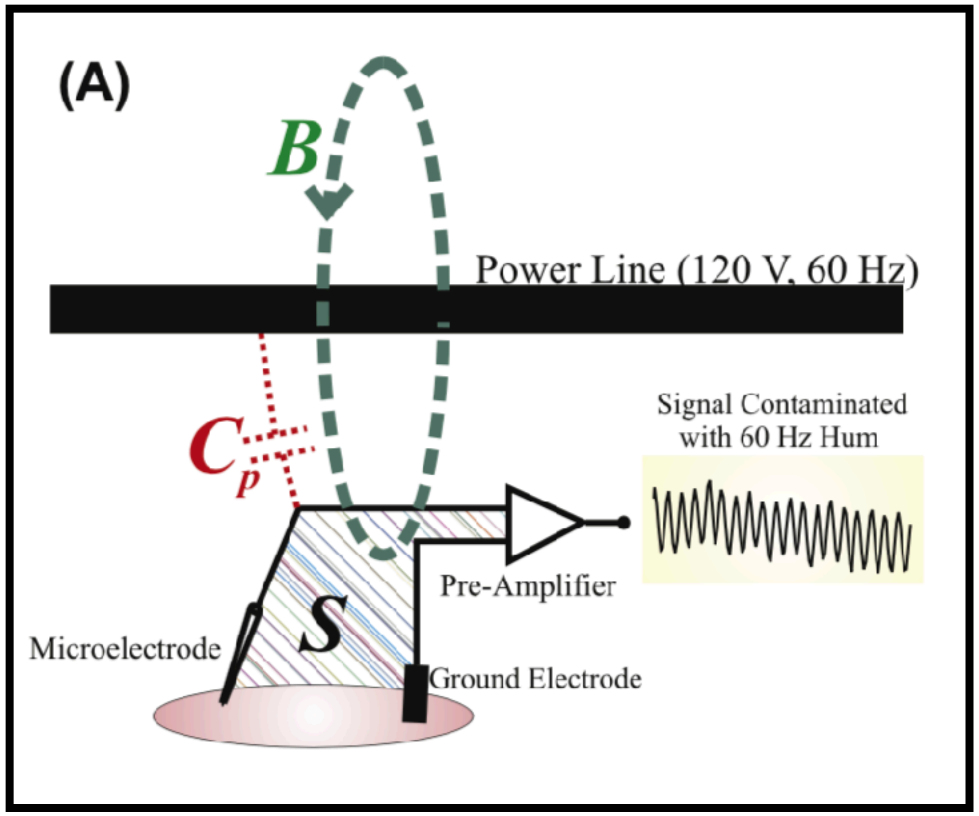
“Noise” in the Brain

3 Main “Types” of Noise in Brain Recordings

1. Sensor & Environmental Noise
2. Non-Neural (Physiological) Noise
3. Neuronal Stochasticity

Sensor & Environmental Noise

60Hz (50Hz) AC Power Line Noise *



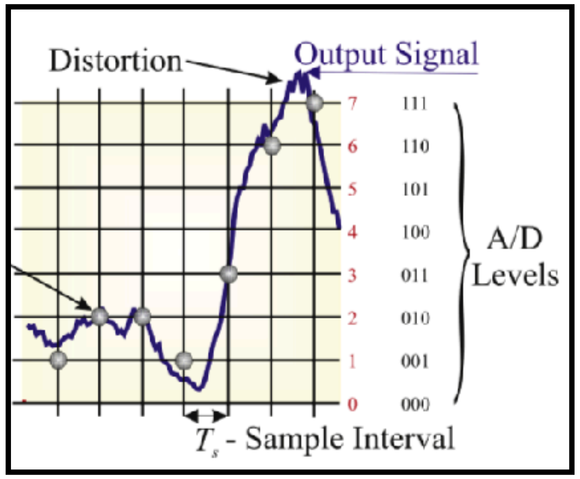
WvD Figure 3.4

Non-Ideal Electronics

- Thermal Noise (random motion of charges)
- Electrode Noise
- "Shot Noise"

Signal Acquisition

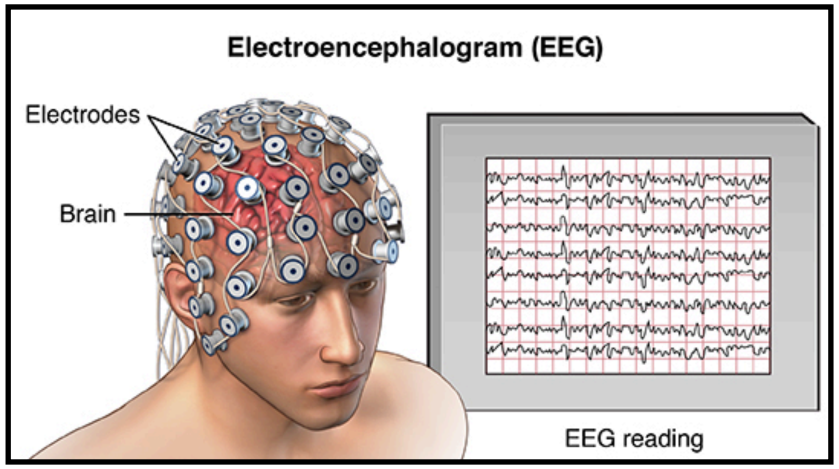
- **Digitization ***
- **Aliasing ***



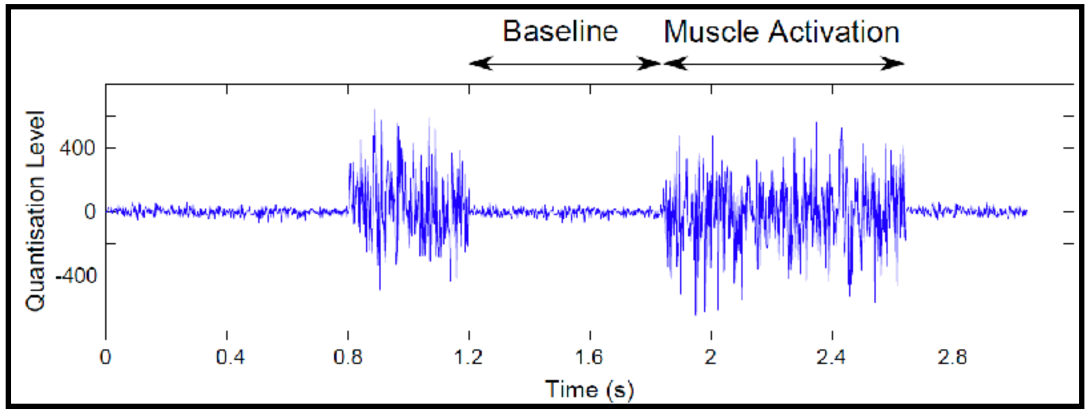
Environmental Noise

- Vibrations
- Electrical Appliances
- Trains
- …

Non-Neural Physiological Noise

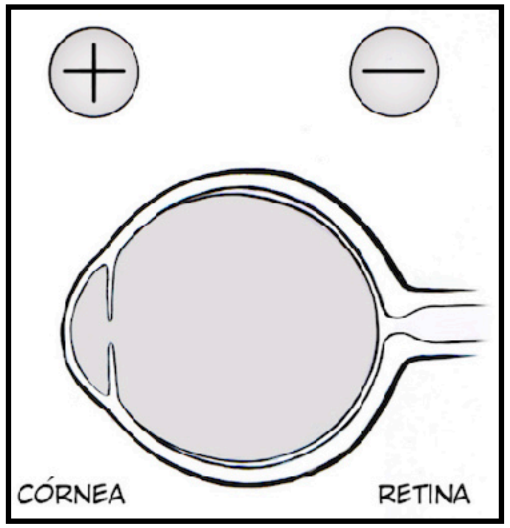


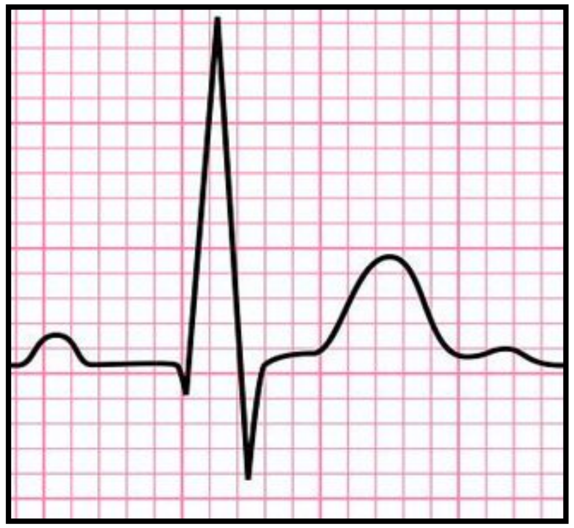
The EEG measures electrical activity across the scalp.



Muscle artifact (EMG - electromyography)

Blinks / Saccades (EOG - electrooculography)

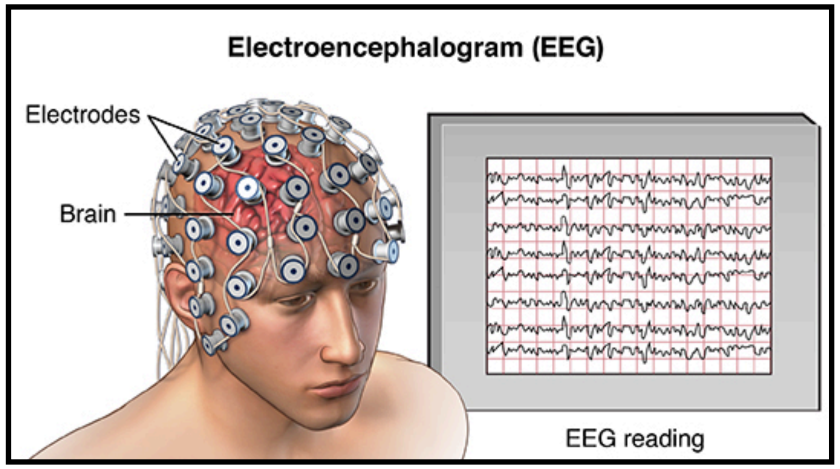


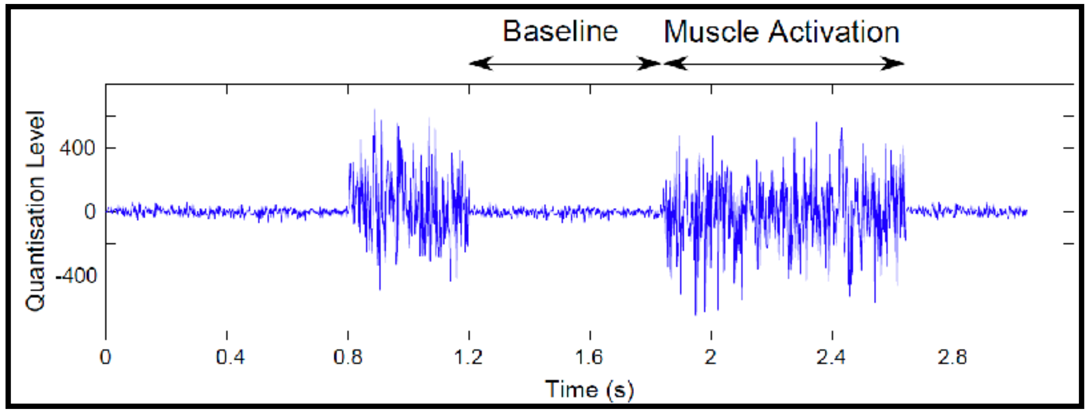


Heartbeat (ECG - electrocardiography)

Movement (accelerometer)

Non-Neural Physiological Noise





A key assumption is that noise is independent (and thus separable) from the brain's response.

Can you think of examples of physiological noise that are not independent?

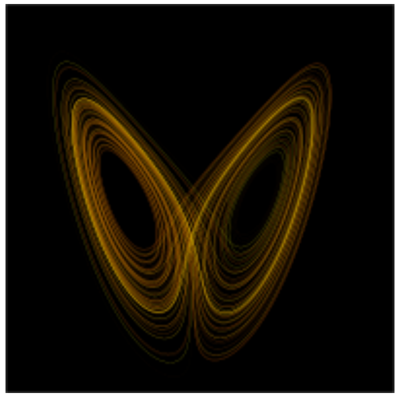
Neuronal Stochasticity & Variability

Inherent Stochasticity (Randomness) or Chaos of Neuronal Firing

Trial to trial variability

Same input produces different spike timing

Chaos



Strong dependence on initial conditions

Neuronal Stochasticity & Variability

Noise in the nervous system

A. Aldo Faisal, Luc P. J. Selen and Daniel M. Wolpert

REVIEWS

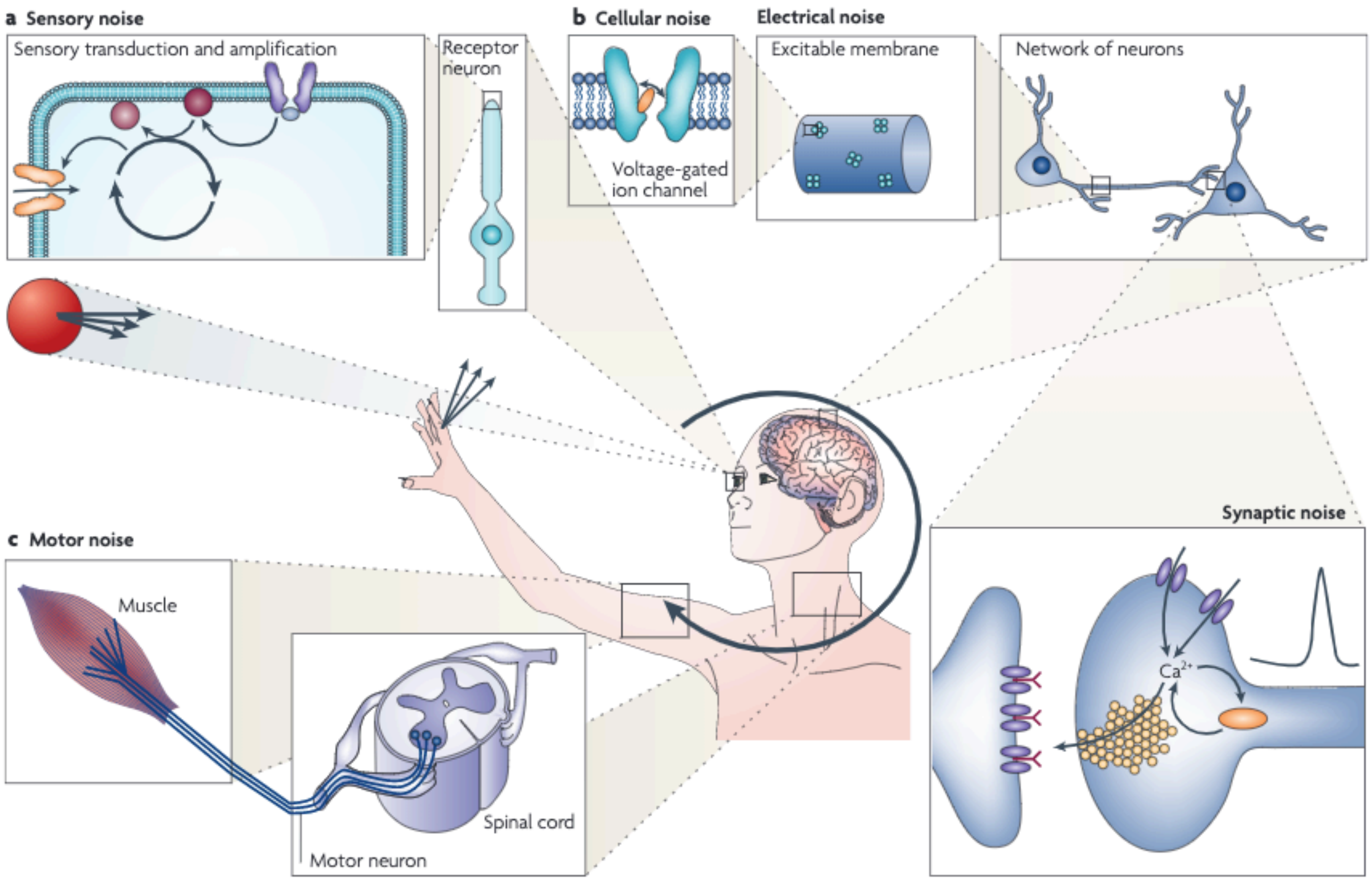


Figure 1 | **Overview of the behavioural loop and the stages at which noise is present in the nervous system.** **a** | Sources of sensory noise include the transduction of signals. This is exemplified here by a photoreceptor and its signal-amplification cascade. **b** | Sources of cellular noise include the ion channels of excitable membranes, synaptic transmission and network interactions (see BOX 2). **c** | Sources of motor noise include motor neurons and muscle. In the behavioural task shown (catching a ball), the nervous system has to act in the presence of noise in sensing, information processing and movement.

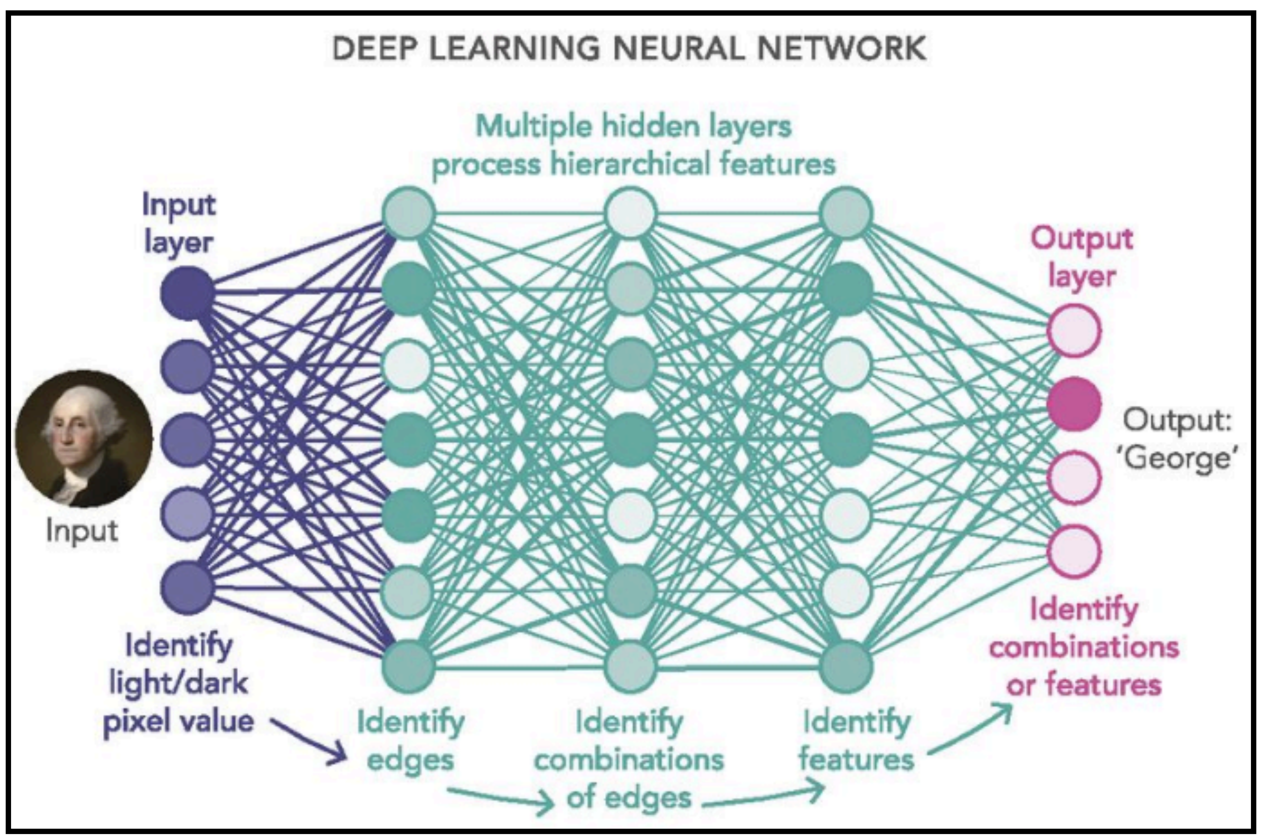
Variability vs. Noise

Are all sources of variability noise?

What does this assume about the brain as a system?

Input →  → **Output**

Consistent inputs will produce consistent outputs



Goals for Today

1. Understand conceptually signal vs. noise

2. List sources of noise in brain recordings

3. Event-related experimental design and analysis

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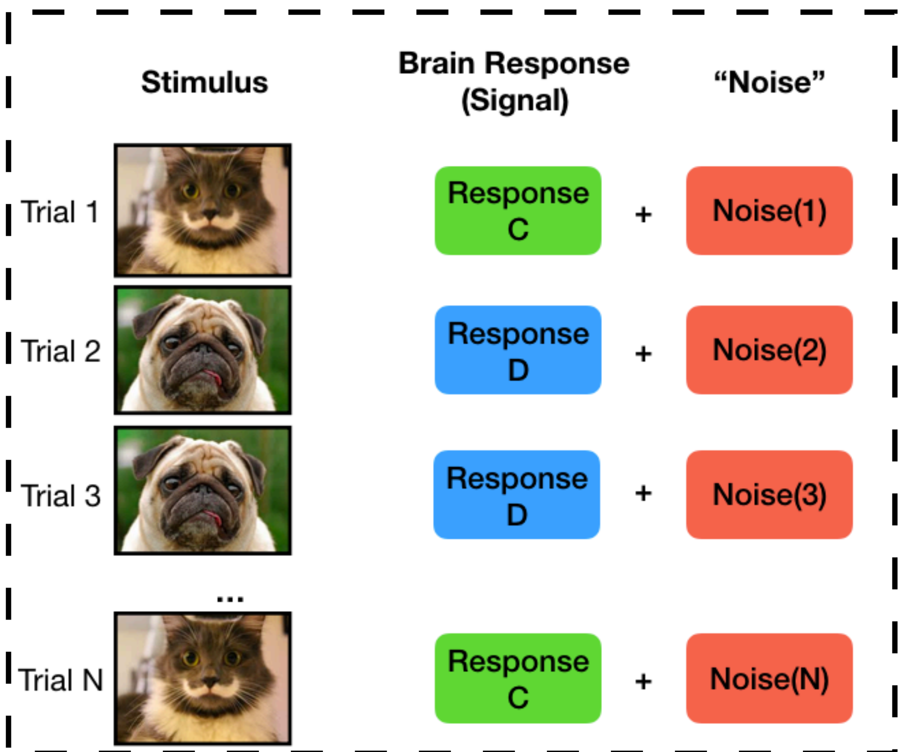
How to Overcome Noise?

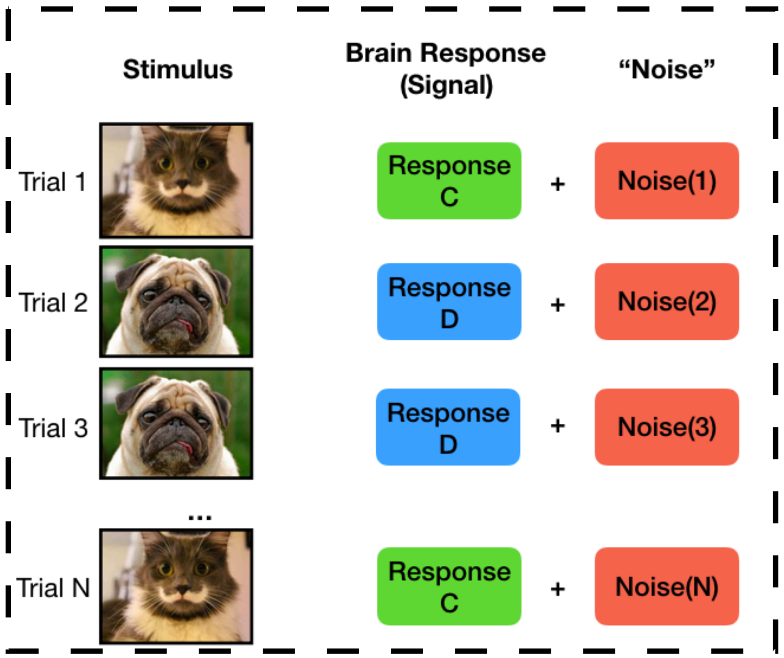


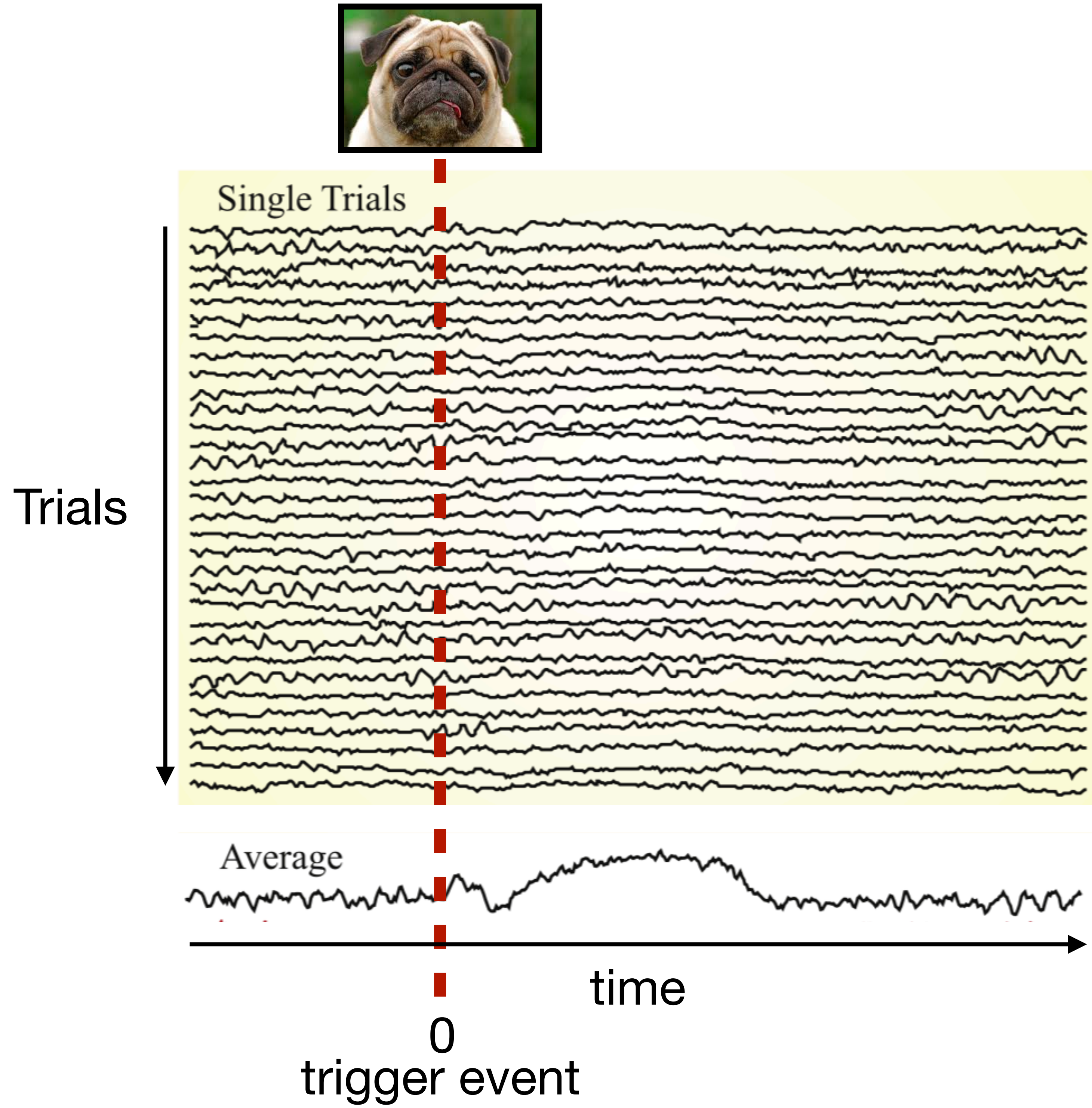
Make the Following Assumptions:

- Same (type of) stimulus generates the same "true" response
- Noise is statistically independent from one trial to another
  > **"ergodic" & "stationary"**

Answer: average to remove (minimize) the effect of noise.

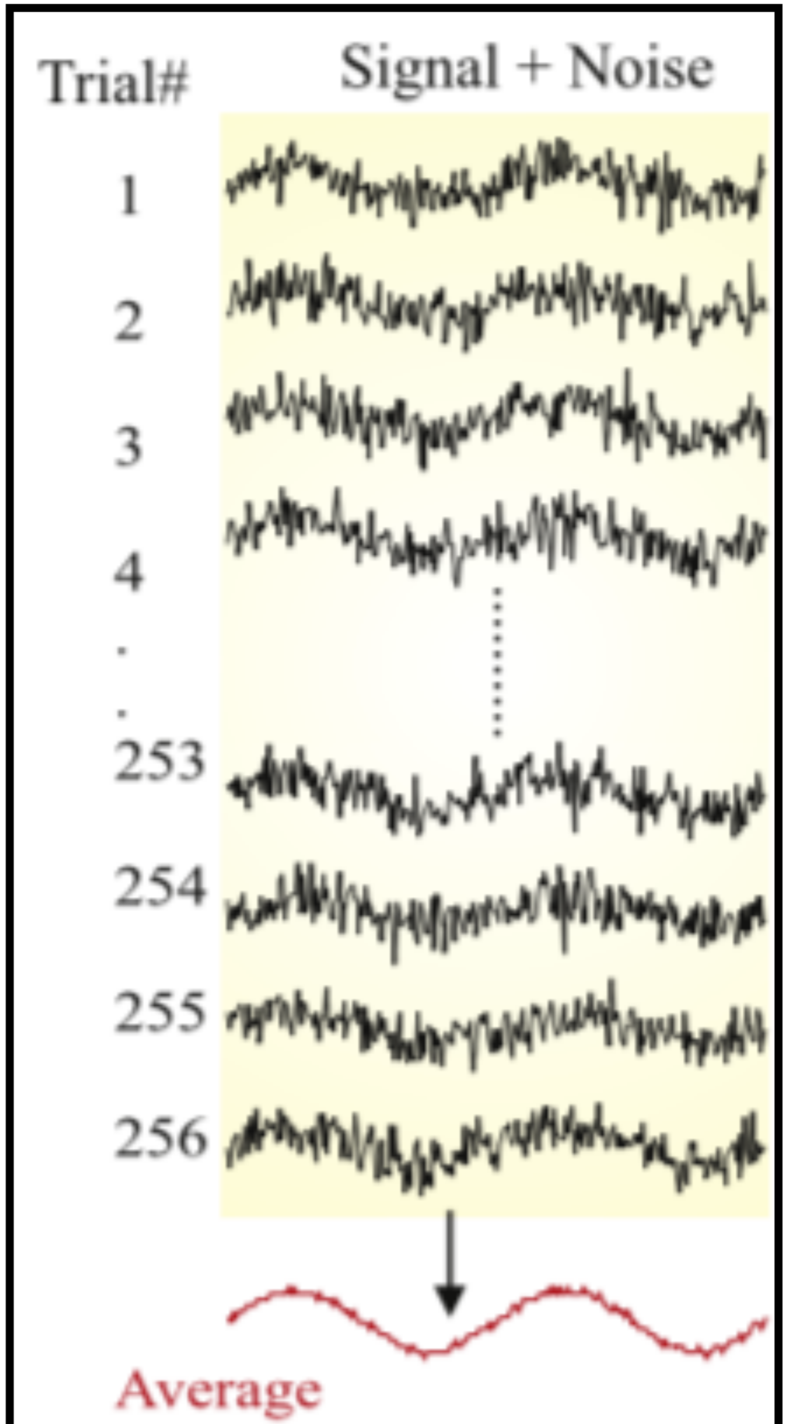
How to Overcome Noise?





Event-Related Potential (ERP) or Evoked Potential

Stationarity & Ergodicity



For the noise to be "averaged away", it has to satisfy certain statistical properties:

Independent of any experimental variable (e.g., trial time, trial type, etc)

Stationary: statistical measures (mean, standard deviation, etc.) do not change over time

Ergodic: averaging over "ensembles" (trials) is equivalent to averaging over time

Event-Related Potentials

Procedure for Event-Related Analysis:

Record raw data (EEG, MEG, etc.)

Preprocess data

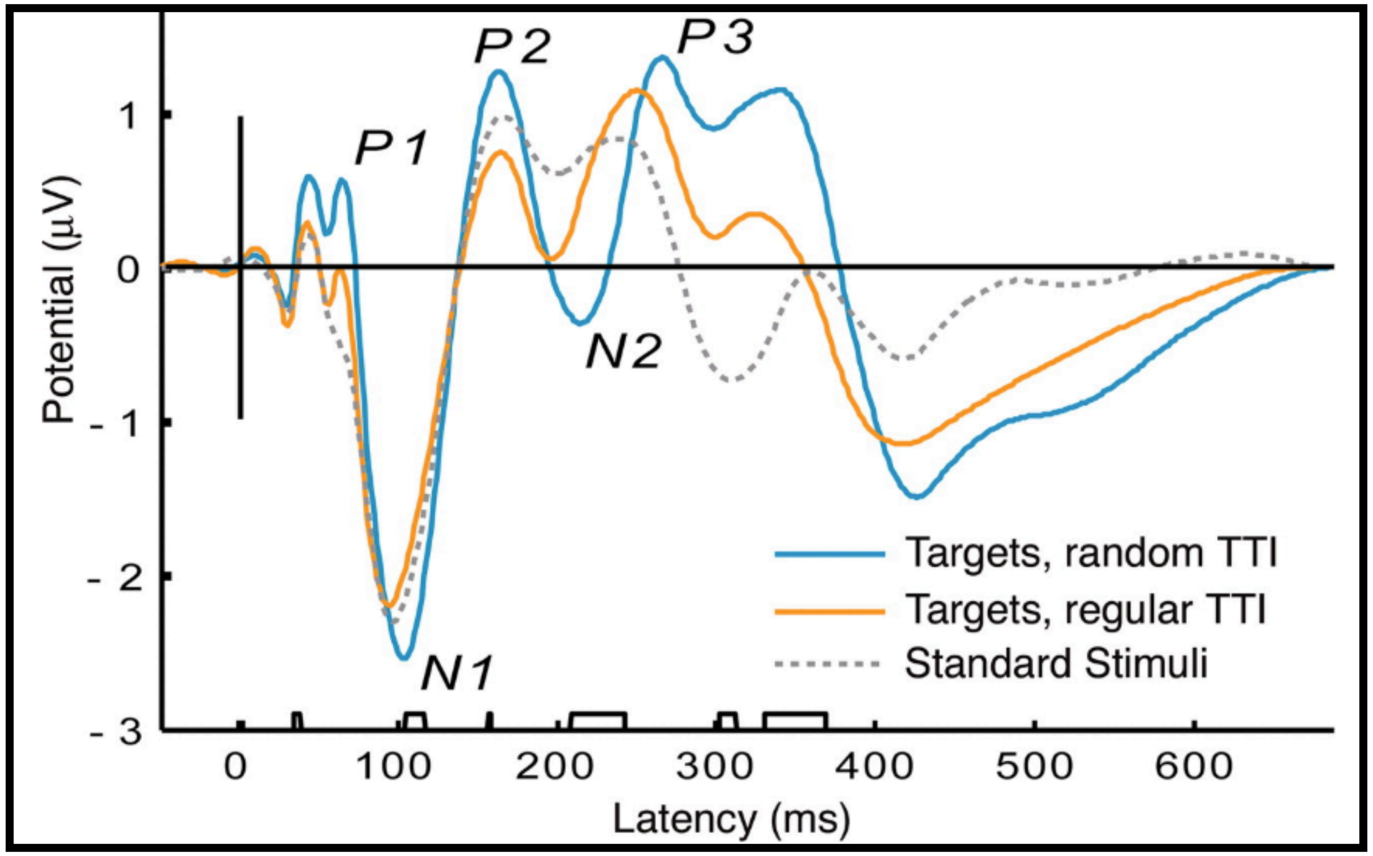
Find event triggers corresponding to stimulus presentation

For each trigger, cut a window of data around it (**epoching**)

Subtract (pre-stimulus) baseline to remove slow drifts

Average over groups/conditions

...



Effect of Averaging

"root mean square" (rms):

$$rms = \sqrt{\frac{1}{N}\sum_{i=1}^{n} x_i^2}$$

Signal-to-noise ratio (SNR) in decibels (dB):

$$SNR = 20\log_{10}\frac{rms_{signal}}{rms_{noise}}$$

Because noise is independent:

Averaging over N trials **maintains signal rms** while **decreasing noise rms**.

$$rms_{trial-averaged\ signal} \approx rms_{single-trial\ signal}$$

$$rms_{trial-averaged\ noise} \approx \frac{rms_{single-trial\ noise}}{\sqrt{N}}$$

How much does your SNR improve by going from 25 to 100 trials?

Effect of Averaging

"root mean square" (rms):

$$rms = \sqrt{\frac{1}{N}\sum_{i=1}^{n} x_i^2}$$

Signal-to-noise ratio (SNR) in decibels (dB):

$$SNR = 20\log_{10}\frac{rms_{signal}}{rms_{noise}}$$

Because noise is independent:

Averaging over N trials **maintains signal rms** while **decreasing noise rms.**

$$rms_{trial-averaged\ signal} \approx rms_{single-trial\ signal} = 20$$

$$rms_{trial-averaged\ noise} \approx \frac{rms_{single-trial\ noise}}{\sqrt{N}} = 10$$

How much does your SNR improve by going from 25 to 100 trials?

25:

$$SNR: 20\log_{10}\frac{20}{10/\sqrt{25}} = 20\log\frac{20}{2} = 20\log 10 = 20$$

100:

$$20\log_{10}\frac{20}{10/\sqrt{100}} = 20\log\frac{20}{1} = 20\log 20 = \_\_\_$$

$$* \ 20\log_{10} 2$$

Effect of Averaging

"root mean square" (rms):

$$rms = \sqrt{\frac{1}{N}\sum_{i=1}^{n} x_i^2}$$

Signal-to-noise ratio (SNR) in decibels (dB):

$$SNR = 20\log_{10}\frac{rms_{signal}}{rms_{noise}}$$

100T:

$$20\log_{10}20$$

$$= 20\left(\log_{10}(2\times 10)\right)$$

$$= 20\left(\log_{10}2 + \log 10\right)$$

$$= 20\log_{10}2 + 20\log_{10}10$$

25T:

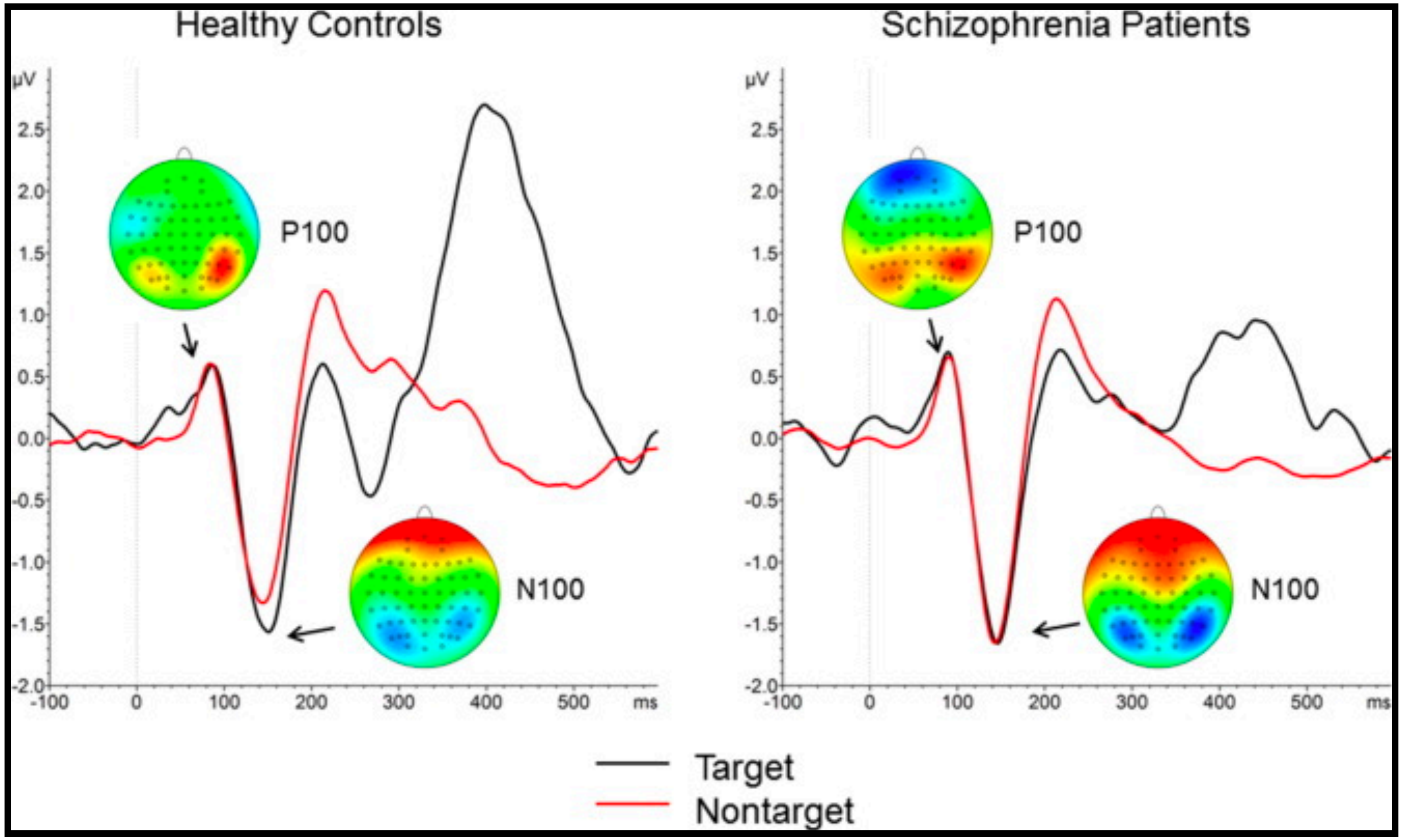
$$20\log_{10}10$$

$$20\log_{10}10$$

$$SNR_{100T} - SNR_{25T}$$

$$= 20\log_{10}2$$

Event-Related Potentials



Schizophrenia patients have a smaller event-related response at 400ms for target stimuli, compared to healthy controls.

Scalp (spatial) topography

Have various different components (N1, P1, N400, etc)

In general, reflects synchronous neuronal population activity

ERP Speller

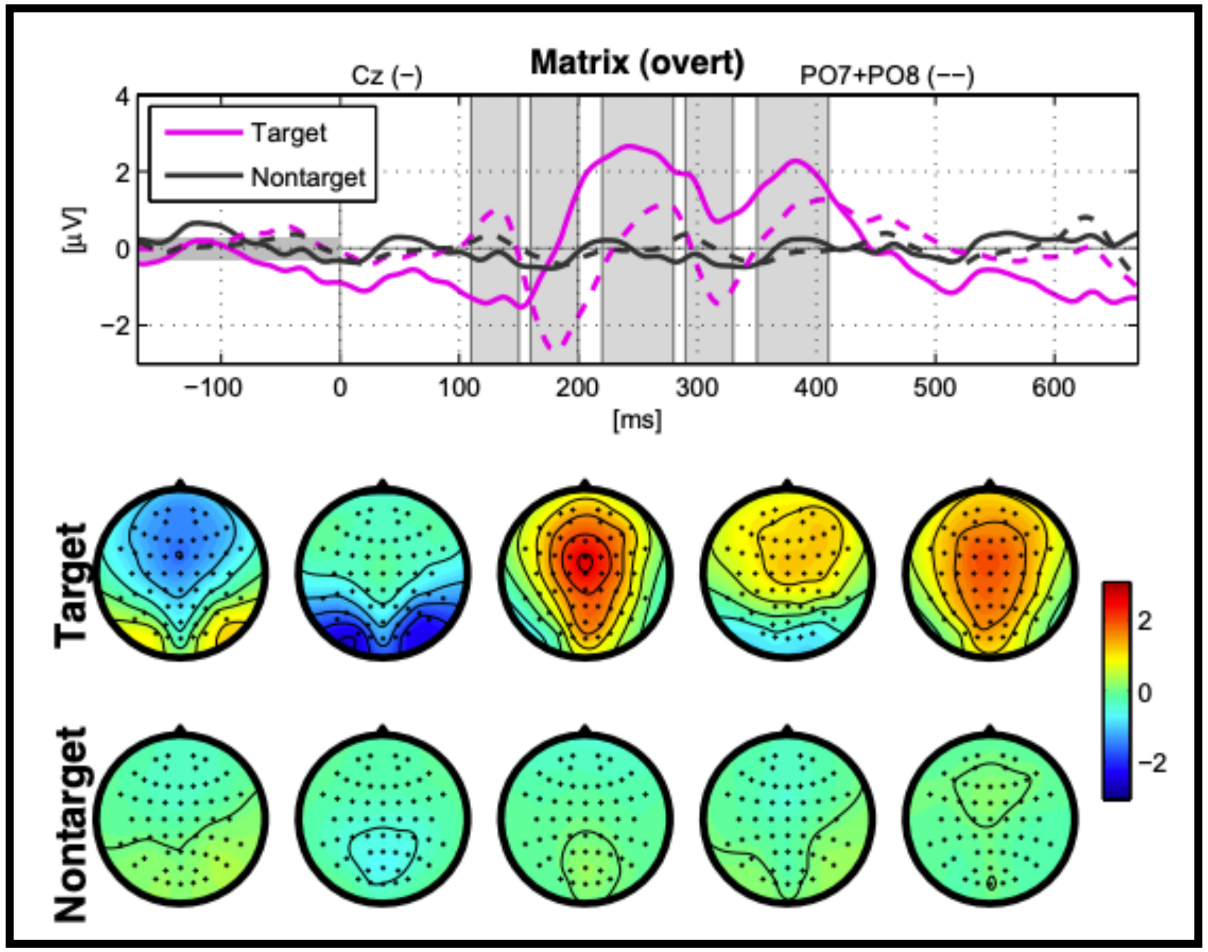
Treder and Blankertz *Behavioral and Brain Functions* 2010, **6**:28
http://www.behavioralandbrainfunctions.com/content/6/1/28

BBF BEHAVIORAL AND BRAIN FUNCTIONS

RESEARCH **Open Access**

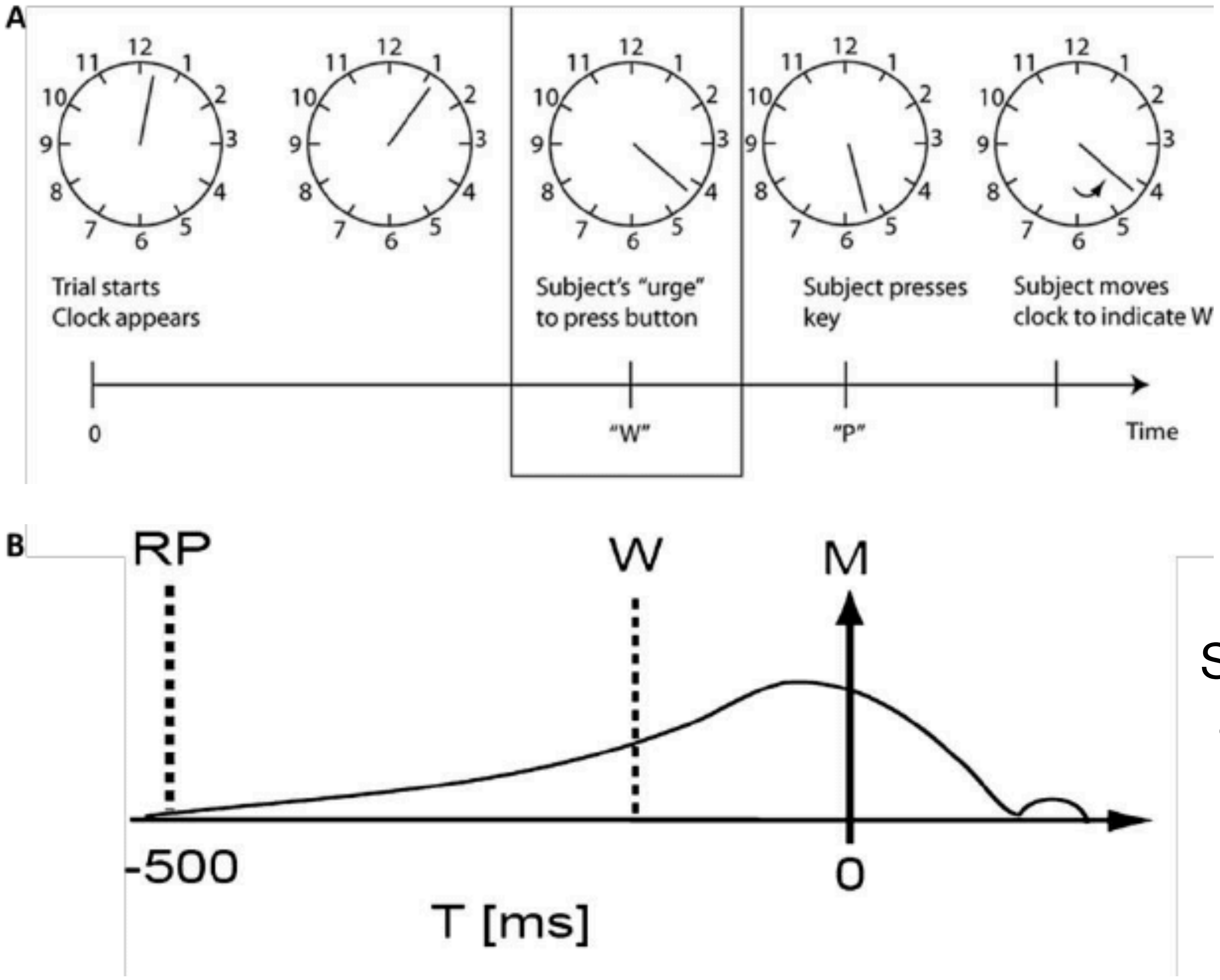
(C)overt attention and visual speller design in an ERP-based brain-computer interface

Matthias S Treder*[1,2] and Benjamin Blankertz[1,3]



Readiness Potential

“Libet Experiment”



Scalp potential shows preparatory activity hundreds of milliseconds prior to conscious intent.

General Event-Locked Analysis

This type of experimental paradigm can be generalized to different **signal modalities** (fMRI, spikes, etc.) and **trigger events** (internal vs. external).

List 3 examples of such experiments.

Summary

1. Understand conceptually signal vs. noise

2. List sources of noise in brain recordings

3. Event-related experimental design and analysis

https://tinyurl.com/cogs118c-att

Reading Discussion

Reading Senseless Sentences: Brain Potentials Reflect Semantic Incongruity

Abstract. *In a sentence reading task, words that occurred out of context were associated with specific types of event-related brain potentials. Words that were physically aberrant (larger than normal) elicited a late positive series of potentials, whereas semantically inappropriate words elicited a late negative wave (N400). The N400 wave may be an electrophysiological sign of the "reprocessing" of semantically anomalous information.*

MARTA KUTAS
STEVEN A. HILLYARD
Department of Neurosciences, University of California, San Diego, La Jolla 92093

Why?

How?

What?

Reading Discussion

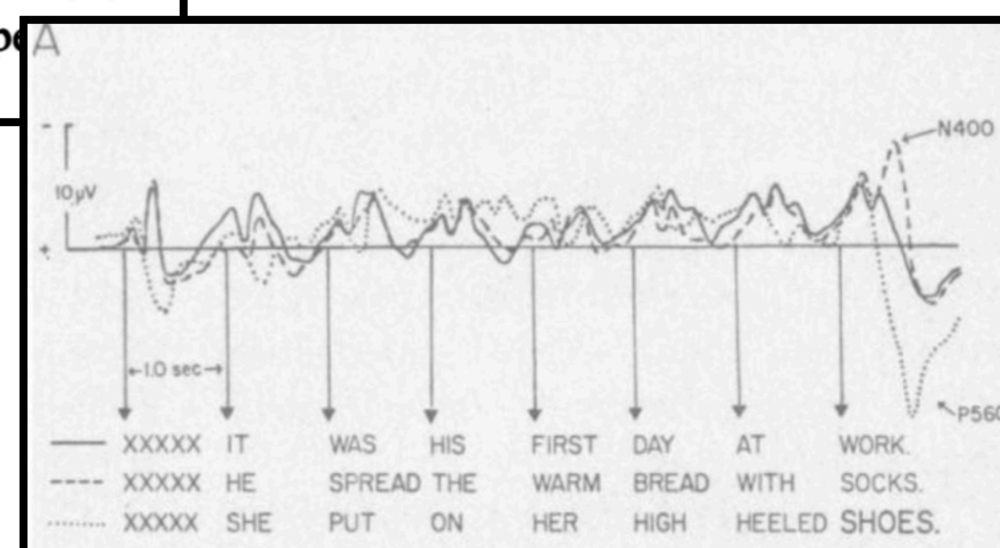
Why? (Background)

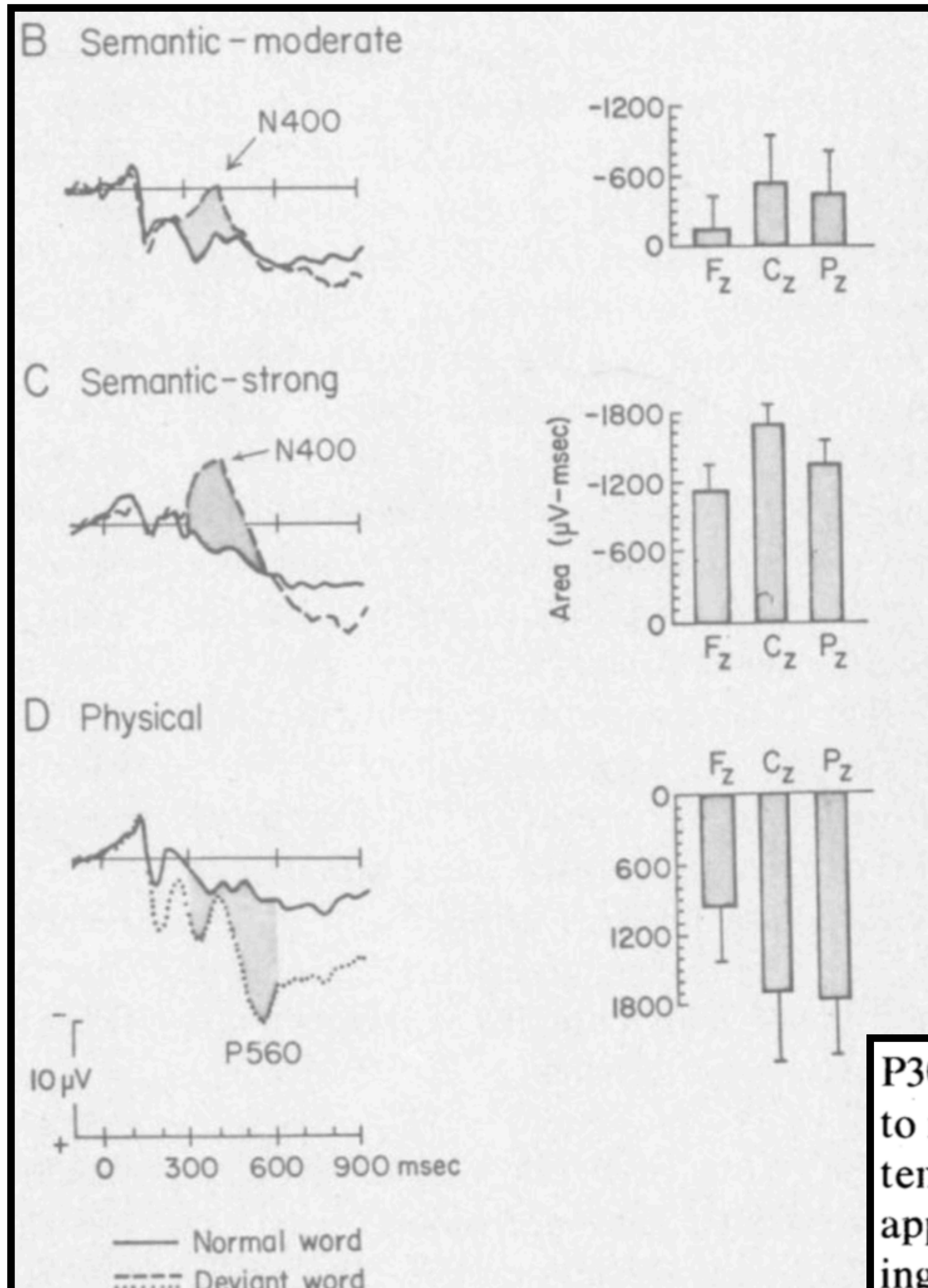
edly at the end of a sentence. This approach stemmed from extensive human research showing that certain components recorded from the scalp are sensitive to a person's expectations. In particular, unexpected or surprising stimuli are typically followed after some 300 to 600 msec by a positive ERP component known as the P300 (*3*). We now report,

How (did they do it)?

In these experiments, each subject read 160 different seven-word sentences presented one word at a time. Subjects were instructed to read silently, "in order to answer questions about the contents of the sentences at the end of the experiment." In the first two experiments, a random 25 percent of the sentences ended in a semantically inappropriate (but syntactically correct) word. The degree of semantic incongruity was "moderate" in experiment 1 (for example, "He took a sip from the *waterfall*") and "strong" in experiment 2 ("He took a sip from the *transmitter*") (*5*). In experiment 3, all sentences ended with semantically appropriate words, but a random 25 percent of these were larger in letter size than the preceding words (*6*). Different subjects were used in each exp
(*7*).

Data from all channels were stored on FM tape for off-line signal averaging with a PDP-11/45 computer.





What (did they find)?

P300 wave (*19*). Rather, the N400 seems to reflect the interruption of ongoing sentence processing by a semantically inappropriate word and the "reprocessing" or "second look" (*20*) that occurs when people seek to extract meaning from senseless sentences. The extent to

Discussion Questions

Harry Potter and the Chamber of *What*?: the impact of what individuals know on word processing during reading

Melissa Troyer & Marta Kutas

To cite this article: Melissa Troyer & Marta Kutas (2018): Harry Potter and the Chamber of *What*?: the impact of what individuals know on word processing during reading, Language, Cognition and Neuroscience, DOI: 10.1080/23273798.2018.1503309

Discussion Questions

Could the effect be due to unfamiliarity with the vocabulary?

Discussion Questions

At the end of the article, the authors say that the N400 wave could be used in the diagnosis/evaluation of reading impairments and language disorders, however, how are these finding helpful in finding ways to treat and help these partients? For instance, in the article, there is no mention of a particular region of the brain that is more impacted than the others. Though this is not the main concern of their research and just a possible application, what form of imaging would be the most effective in giving us this information? EEG perhaps since it's the least invasive? Or what would be the next logical step to discovering more about the physiological source of these brain reactions?

Discussion Questions

It is maintained that the element of surprise is a large ingredient in humor. Some theorize that the humor in a joke arises from the delay that comes with reprocessing the shift in direction. Given that the researchers in this study discovered that semantically inappropriate words at the end of a sentence induced the N400 wave, and infer that this late negative wave could be tied to the reprocessing of the semantically unexpected information, could this be the biological basis for the delay that occurs in jokes?

Discussion Questions

Given that this study finds that the N400 wave may be an electrophysiological sign of "reprocessing", could the N400 wave be a wave of learning in general? In other words, could the brain be outputting the N400 wave due to underlying mechanisms of plasticity/LTP, or is this wave a highly specialized wave in the reprocessing of language only?

Discussion Questions

Why did they use different subjects for the 3 different experiments?

What if the last word was misspelled, instead of semantically aberrant?

What if the last word was physically and semantically aberrant?

Do these results hold in another language other than English?

Measure of incongruity is ambiguous; could the effect be due to unfamiliarity?

Why were the words separately presented, one at a time?

P300 = physical surprises; N400 = semantic surprises; does the brain have different prediction areas for specific tasks, rather than a general "prediction hub"?

What would happen if you used a semantically ambiguous word, e.g., "I threw a rock into a bank"

Distinction between automatic vs. requires conscious switching of attention.

What if words were heard instead of read?