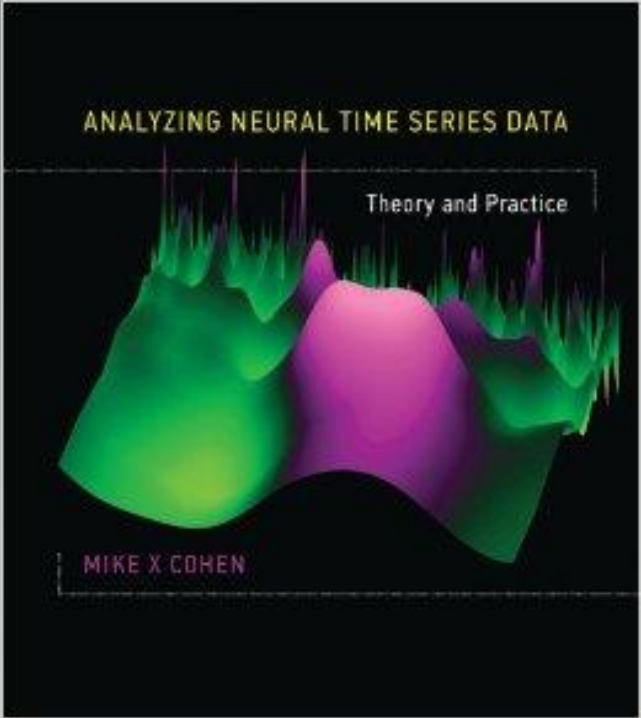


**PSYC596L:**  
*Analyzing Neural Time-series Data*

**Spring, 2022**  
**Mondays, 2<sup>00</sup>-4<sup>45</sup> p.m.**  
**Room 323 Psychology**

**Course Resources Online:**  
**[jallen.faculty.arizona.edu](http://jallen.faculty.arizona.edu)**

**Follow link to Courses**



Available from:

Amazon:

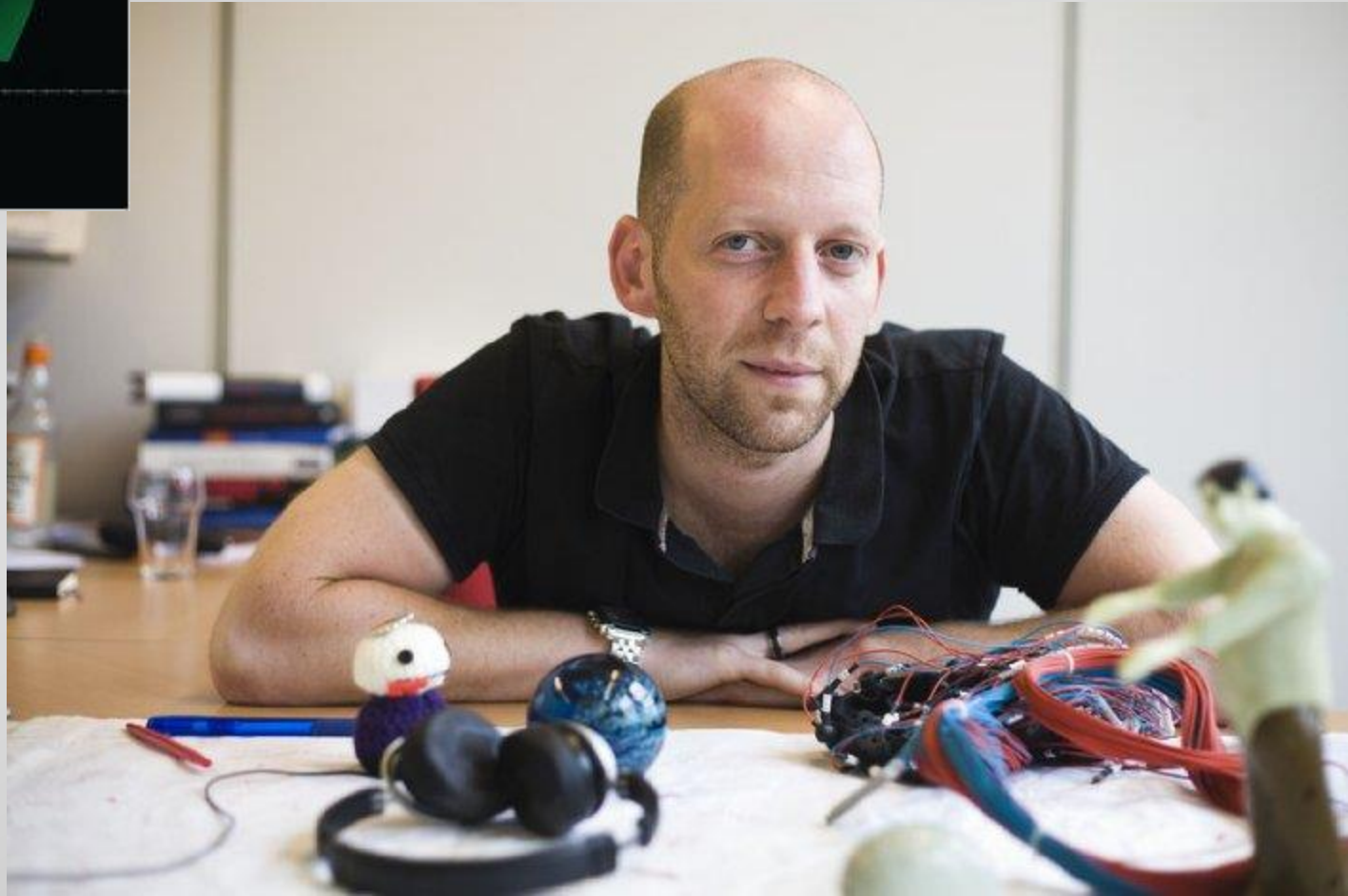
[http://www.amazon.com/gp/product/0262019876/ref=ox\\_ya\\_os\\_product](http://www.amazon.com/gp/product/0262019876/ref=ox_ya_os_product)

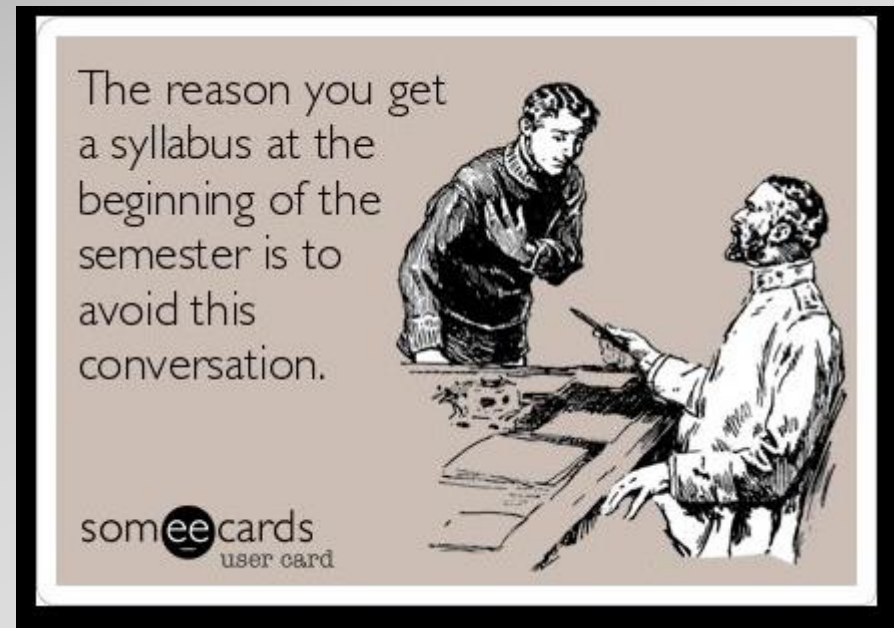
MIT Press:

<http://mitpress.mit.edu/books/analyzing-neural-time-series-data>

UA Library Online

<http://cognet.mit.edu.ezproxy1.library.arizona.edu/book/analyzing-neural-time-series-data>





But first...

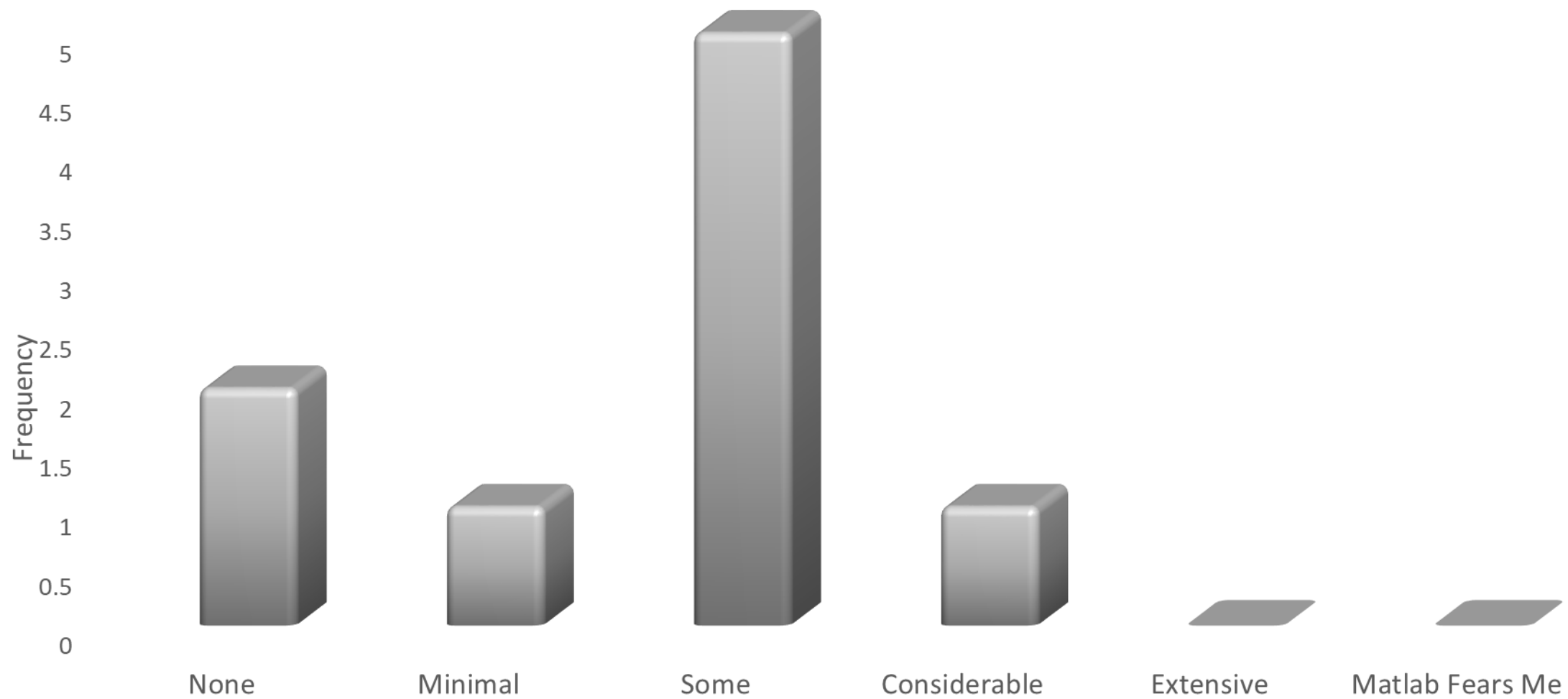
# SYLLABUS AND WEBSITE



# Roadmap

- ➡ **Classic (Time or Frequency) vs. Newer (Time-Frequency) Approaches**
- ➡ **Time Approaches**
- ➡ **Frequency Approaches**
- ➡ **Time-Frequency Approaches**
- ➡ **Brief discussion of Neural Sources and interpretation**
- ➡ **Guidelines for writing good code**
- ➡ **Code workshop part 1!**

## Previous Experience



# Expectations

- ◆ I'd like to learn how to analyze/interpret EEG data and learn how to use Matlab.
- ◆ I want to be able to understand EEG data at a level that would allow me to perform novel analyses with Polysomnographic EEG data.
- ◆ I am excited to make the best out of this class and have a good to great understanding of neural analysis.
- ◆ A goal I have for this course is to apply neural analyses to research methods.

# Expectations

- ◆ I have been working in a neuroscience lab since the last fall but I haven't been able to understand the data that we collect. ... I am hoping with this course I can understand neural data and learn how to deal with it.
- ◆ I hope to learn about different neural time series approaches in MATLAB, specifically in local field potential. I would also like to learn how to create figures of power and frequency that will help me analyze my own data. I would like to know how to filter, process, and analyze data (specifically brain signals). I want to become more familiar with Matlab and learn how to work with time Fourier series on Matlab.

# Expectations

- ◆ I used MATLAB and psychtoolbox to write some experiments before.
- ◆ The course 506 gave me a brief introduction about EEG, that is all I know about EEG. I hope that I could know more about how to use this technique and know how to analyze EEG data through this course.
- ◆ learn TFA, teach Matlab to fear me.



# Time Approaches: ERPs

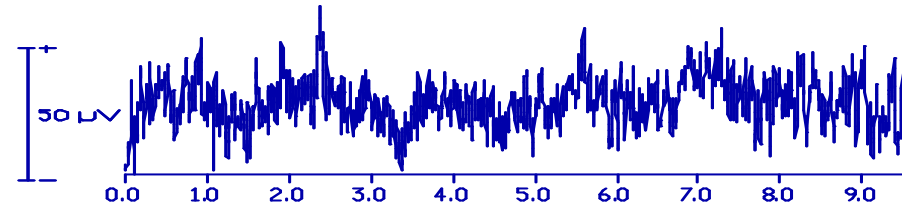
- ◆ What/how
- ◆ Advantages
- ◆ Disadvantages

# Overview

Event-related potentials are patterned voltage changes embedded in the ongoing EEG that reflect a process in response to a particular event: e.g., a visual or auditory stimulus, a response, an internal event



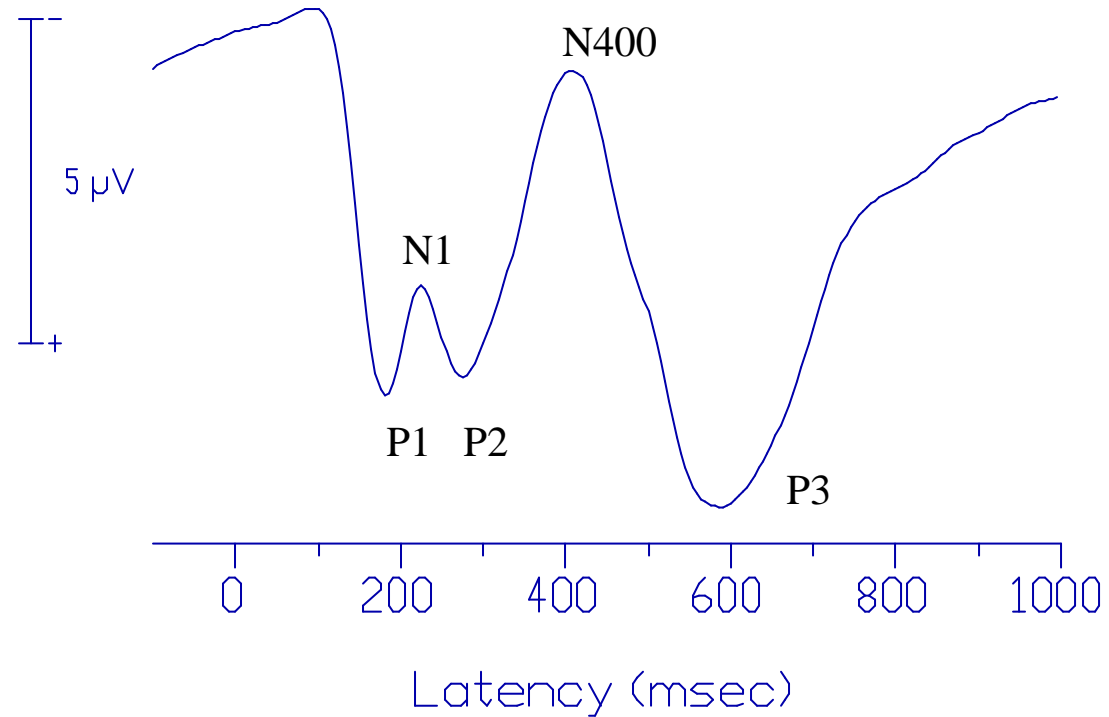
## Ongoing EEG

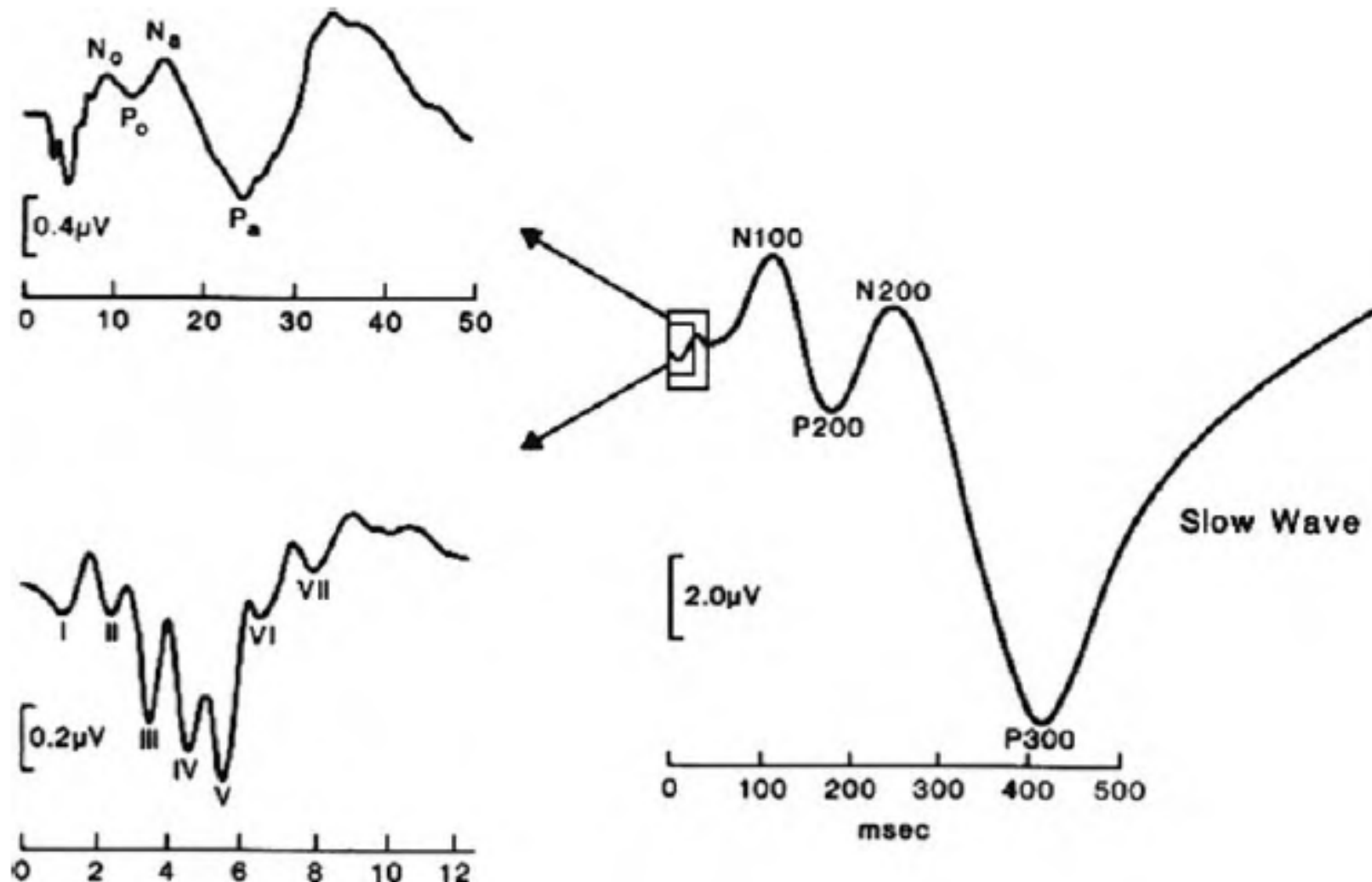


Stimuli



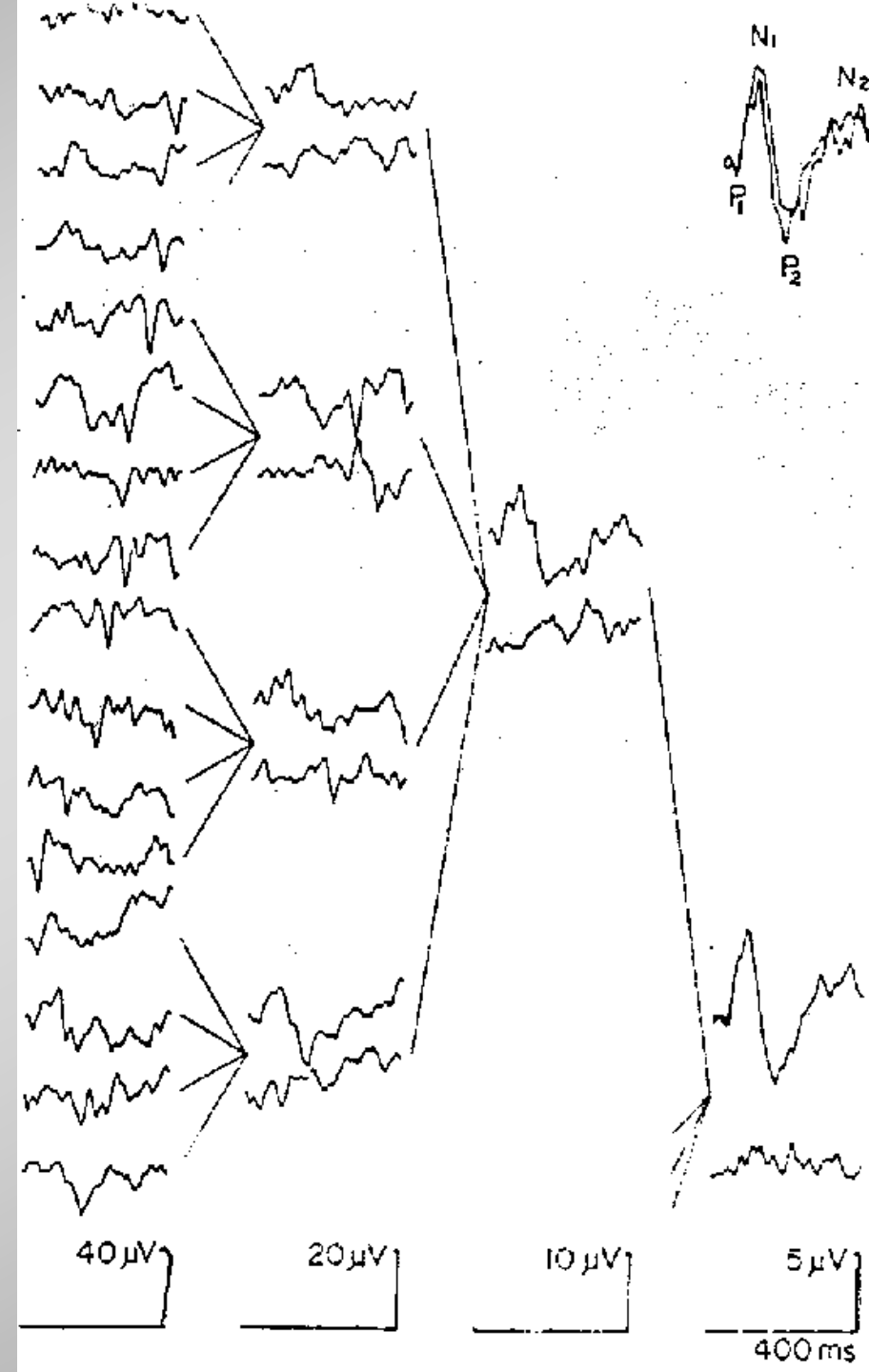
## Visual Event-related Potential (ERP)





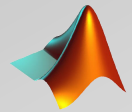
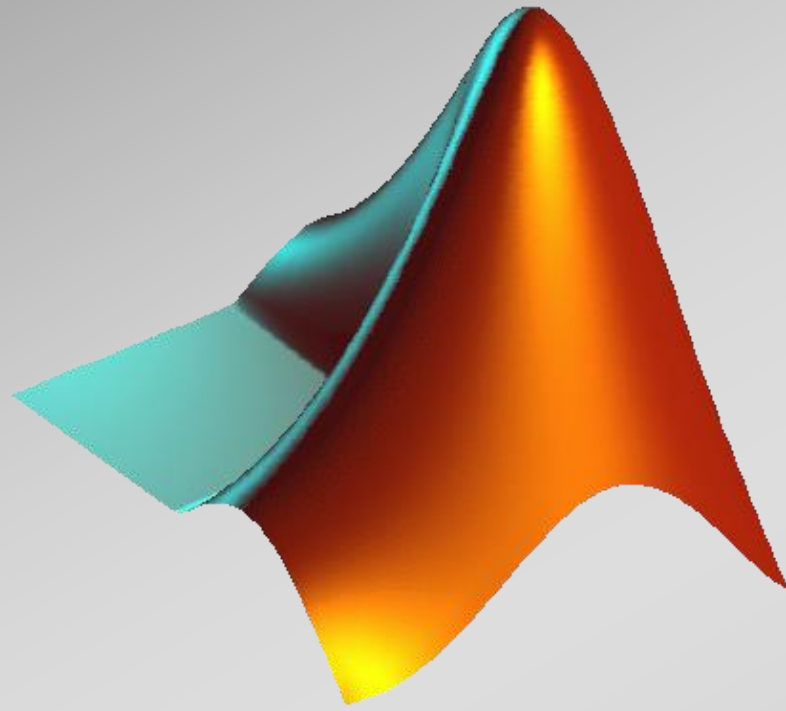
**Figure 4.2.** A schematic representation of ERP components elicited by auditory, infrequent target stimuli. The three panels represent three different voltage  $\times$  time functions: the left bottom panel shows the very early sensory components (with a latency of less than 10 ms); the left top panel shows the middle latency sensory components (with a latency of between 10 and 50 ms); and the right panel shows late components (latency exceeding 50 ms). Note the different voltage and time scales used in the three panels, as well as the different nomenclatures used to label the peaks (components). (Adapted with permission of the author from Donchin, 1979, with kind permission of Springer Science and Business media.)

Time-locked activity  
and extraction by  
averaging





# Matlab Demo!



Plus-Minus averaging to show impact of noise:

PlusMinus.m

Welcome to the Matlab Environment!

# The Classic View:

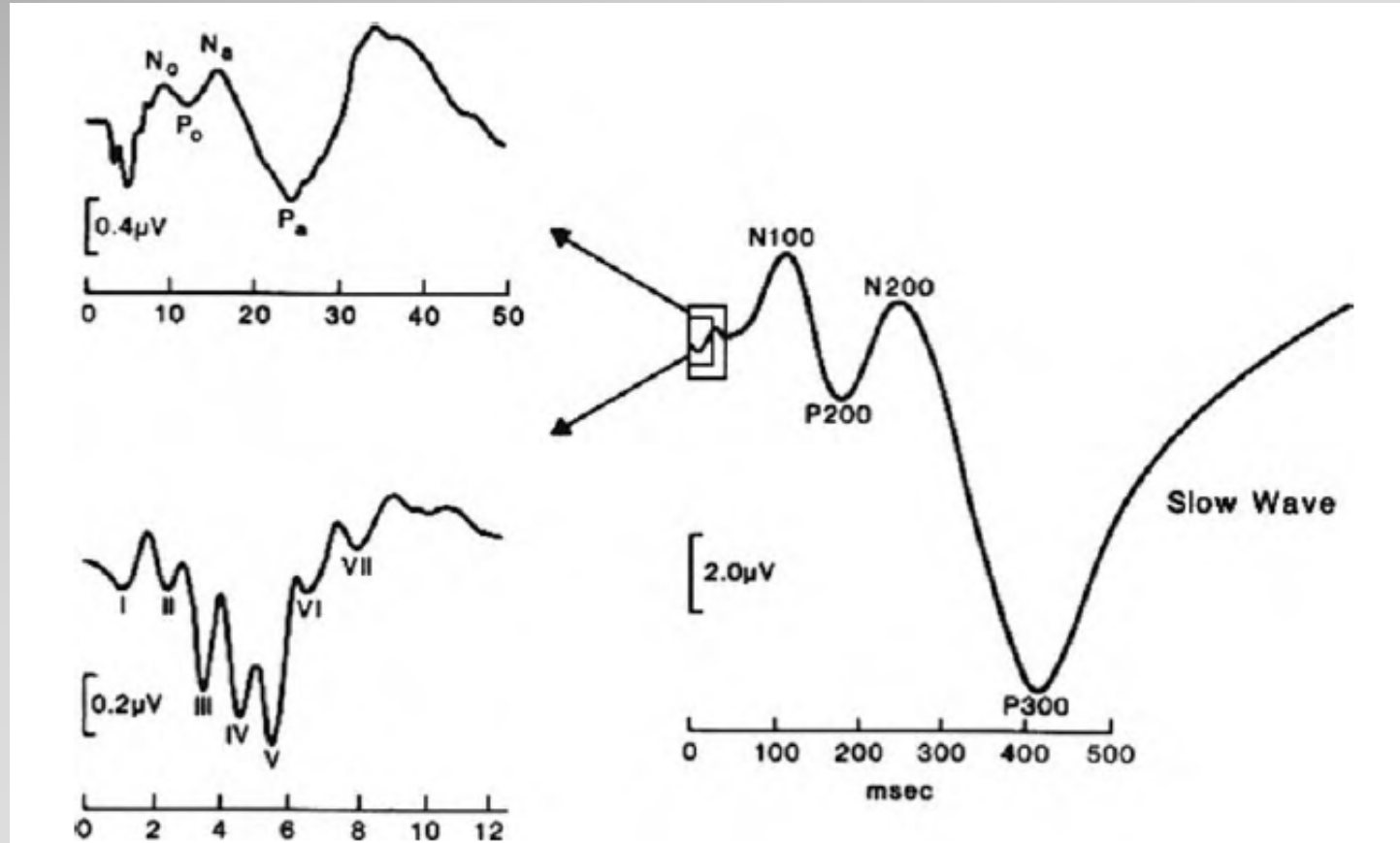
## Time-locked activity and extraction by signal averaging

- ◆ Ongoing activity reflects "noise"
- ◆ Activity that reflects processing of a given stimulus "signal"
- ◆ The signal-related activity can be extracted because it is **time-locked** to the presentation of the stimulus
- ◆ Signal Averaging is most common method of extracting the signal
  - ◆ Sample EEG for ~1 second after each stimulus presentation & average together across like stimuli
  - ◆ Time-locked signal emerges; noise averages to zero
  - ◆ Signal to noise ratio increases as a function of the **square root** of the number of trials in the average

# What does the ERP reflect?

- ◆ May reflect sensory, motor, and/or cognitive events in the brain
- ◆ Reflect the synchronous and phase-locked activities of large neuronal populations engaged in information processing

# Component is a "bump" or "trough"



**Figure 4.2.** A schematic representation of ERP components elicited by auditory, infrequent target stimuli. The three panels represent three different voltage  $\times$  time functions: the left bottom panel shows the very early sensory components (with a latency of less than 10 ms); the left top panel shows the middle latency sensory components (with a latency of between 10 and 50 ms); and the right panel shows late components (latency exceeding 50 ms). Note the different voltage and time scales used in the three panels, as well as the different nomenclatures used to label the peaks (components). (Adapted with permission of the author from Donchin, 1979, with kind permission of Springer Science and Business media.)

# Making Meaning from the bumps

Pores o'er the Cranial map with learned eyes,  
Each rising hill and bumpy knoll decries  
Here secret fires, and there deep mines of sense  
His touch detects beneath each prominence.



W. T. D. B. Esq. 40  
rue de la Harpe

## Bumpology

2nd Vol. 24th Nov. 1854  
25 St James's Rd London

Pores o'er the Cranial map with learned eyes,  
Each rising hill and bumpy knoll decries,  
Here secret fires, and there deep mines of sense  
His touch detects beneath each prominence.



# Time Approaches: ERPs

- ◆ What/how
- ◆ Advantages
- ◆ Disadvantages

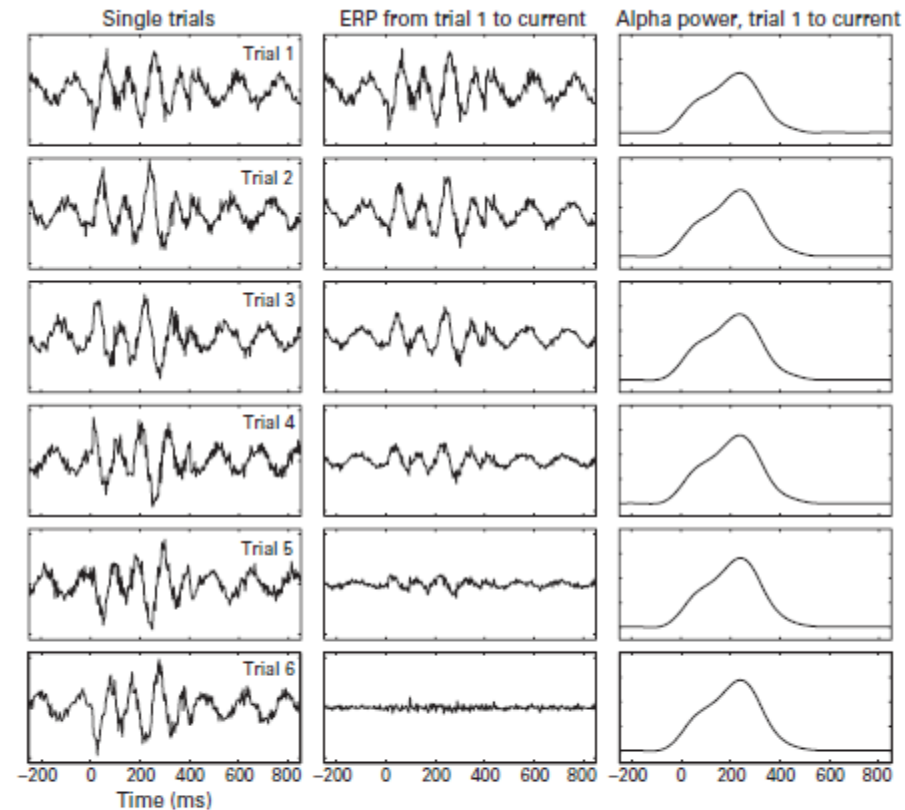
# ERPs Advantages

- ◆ Simple, easy to derive
- ◆ Exquisite temporal resolution
  - ◆ Time-freq approaches will blur temporal precision
  - ◆ Although ... time precision seldom realized with ERPs
- ◆ Extensive literature spanning decades
- ◆ Because of ease to compute, can provide check on single-subject data

# ERPs Disdvantages

- ◆ ERPs blind to non-phase-locked activity

# ERPs can be “blind” to activity



**Figure 2.1**

Simulated data showing how time-locked but not phase-locked activity (left column) is lost in ERP averaging (middle column) but is visible in band-specific power (right column). Each row in the left column shows a different trial, and each row in the middle and right columns shows averages from the first until the current trial.

# ERPs Disdvantages

- ◆ ERPs blind to non-phase-locked activity
- ◆ Limited basis for linking to physiological mechanisms
  - ◆ Time-frequency approaches assess oscillations
  - ◆ neurophysiological mechanisms that produce ERPs are less well understood than the neurophysiological mechanisms that produce oscillations



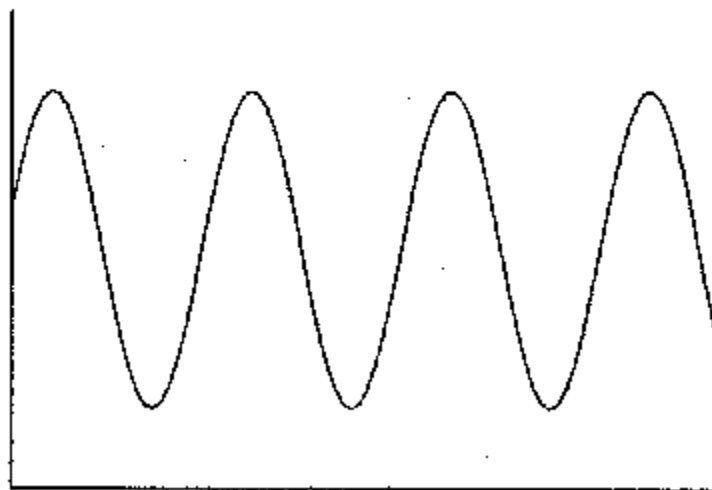
# Frequency Approaches: FFT etc

- ◆ What/how
- ◆ Advantages
- ◆ Disadvantages

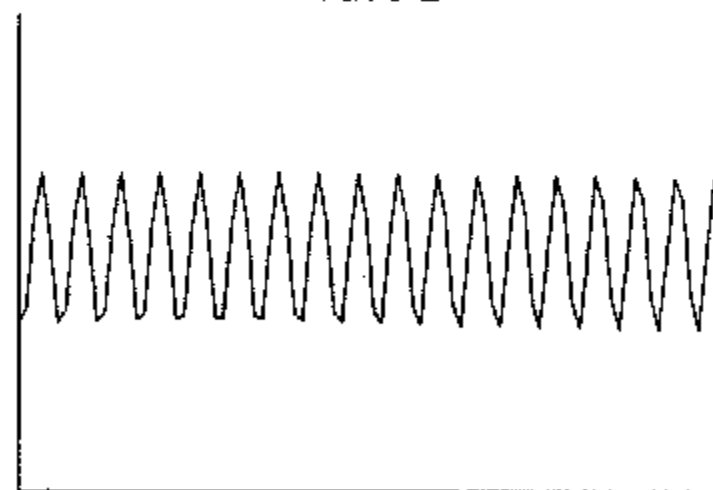
# Frequency Domain Analysis

- ◆ Frequency Domain Analysis involves characterizing the signal in terms of its component frequencies
  - ◆ Assumes periodic signals
- ◆ Periodic signals (definition):
  - ◆ Repetitive
  - ◆ Repetitive
  - ◆ Repetition occurs at uniformly spaced intervals of time
- ◆ Periodic signal is assumed to persist from infinite past to infinite future

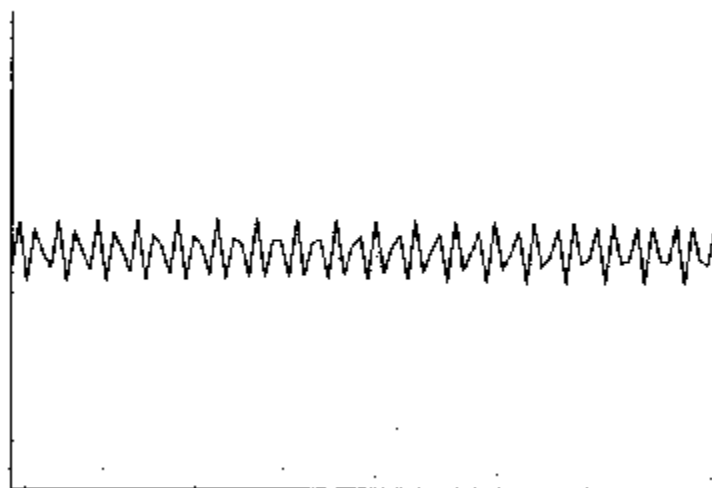
Wave 1



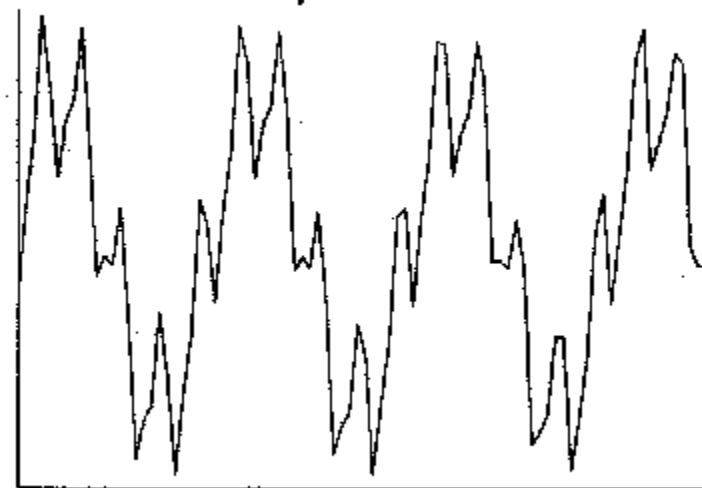
Wave 2



Wave 3

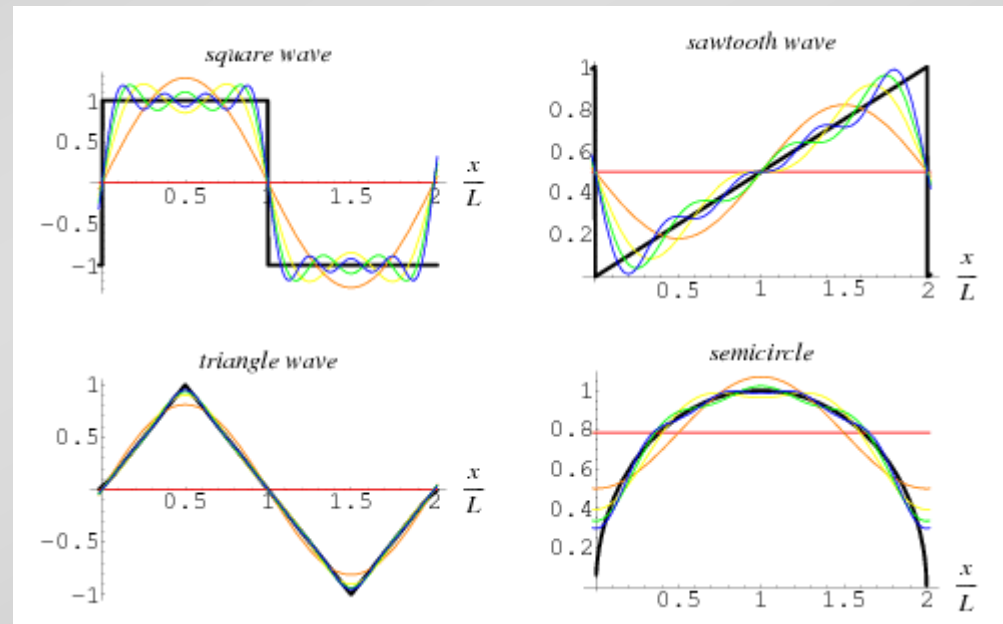


Composite Wave



# Fourier Series Representation

- ◆ If a signal is periodic, the signal can be expressed as the sum of sine and cosine waves of different amplitudes and frequencies
- ◆ This is known as the Fourier Series Representation of a signal



# Interactive Fourier!

◆ [Web Applet](#)

◆ [www.falstad.com/fourier/](http://www.falstad.com/fourier/)



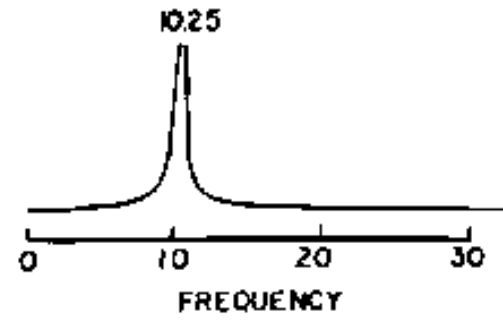
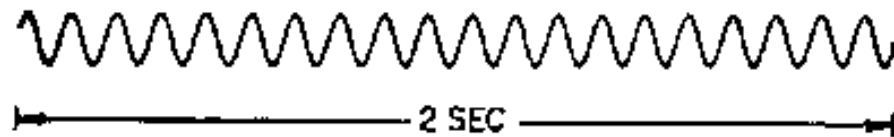
# Fourier Series Representation

## ◆ Pragmatic Details

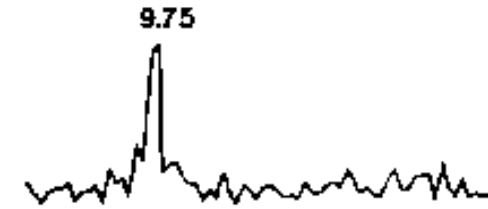
- ◆ Lowest Fundamental Frequency is  $1/T$
- ◆ Resolution is  $1/T$

## ◆ Phase and Power

- ◆ There exist a phase component and an amplitude component to the Fourier series representation
  - ◆ Using both, it is possible to completely reconstruct the waveform.



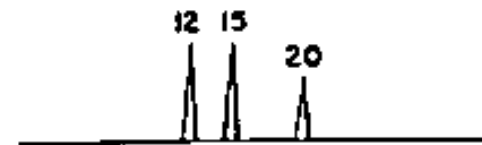
d



b



c



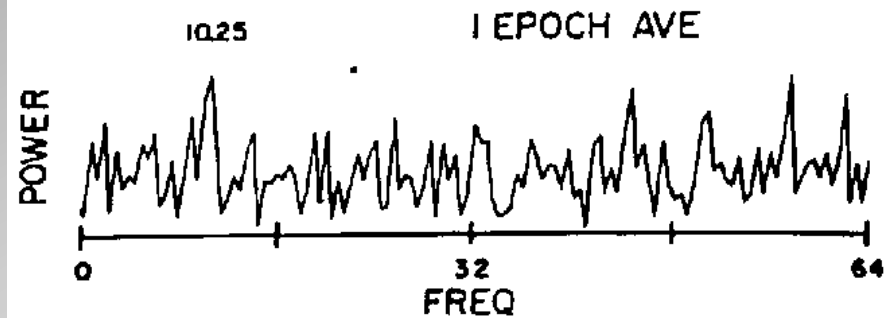
d

Time Domain

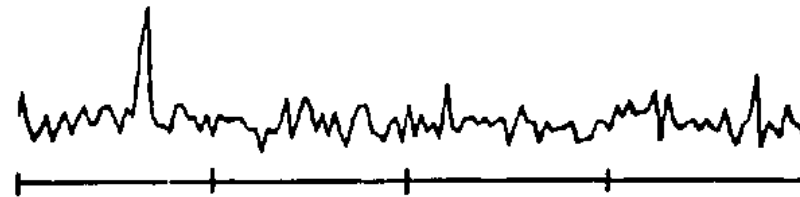
Frequency Domain

# Averaging Multiple Epochs improves ability to resolve signal

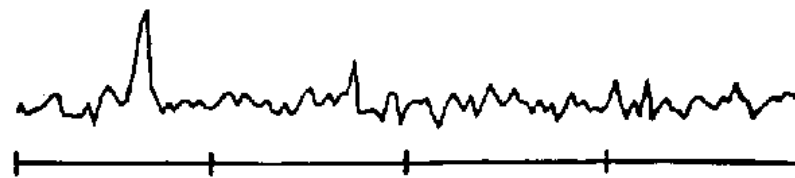
Note noise is twice  
amplitude of the signal



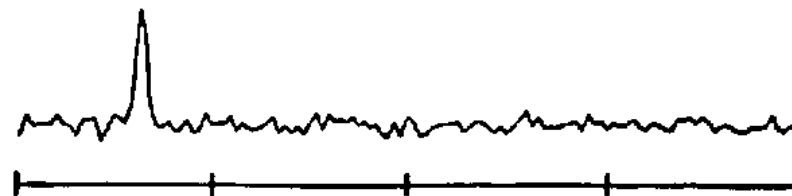
5



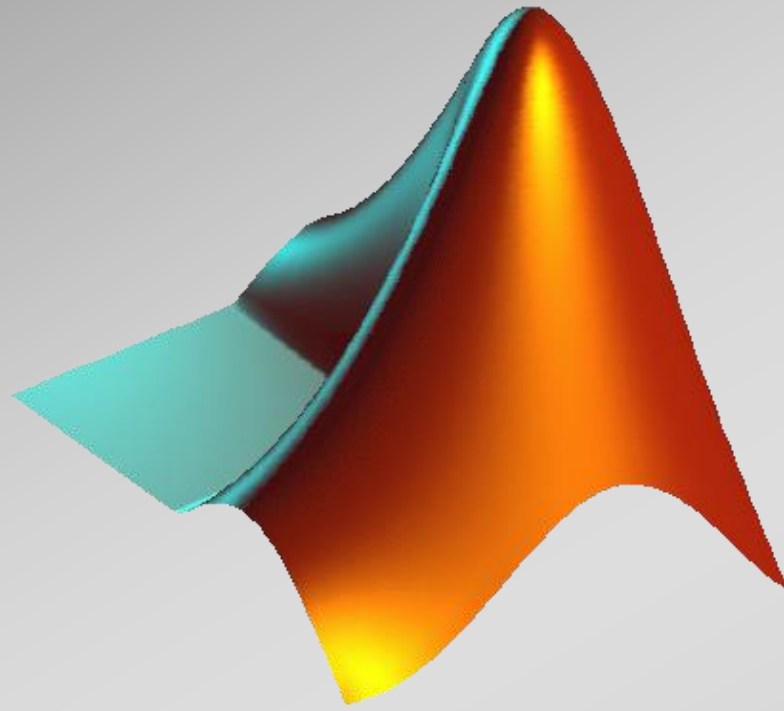
10

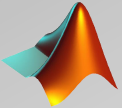


30



# Matlab Demo!



-  Advanced Coding Challenge:
- ◆ Find two snippets of the same song with different frequency characteristics
  - ◆ Use Audacity to create two wav files
  - ◆ Alter m code to plot spectra of these two snippets

# Frequency Approaches: FFT etc

- ◆ What/how
- ◆ Advantages
- ◆ Disadvantages

# Advantages of Frequency Approaches

- ◆ Sensitive to all frequencies below Nyquist
- ◆ Sensitive to phase-locked and non-phase-locked signals



# NYQUIST?

Small detour to discuss the nature of digital versus analog signals

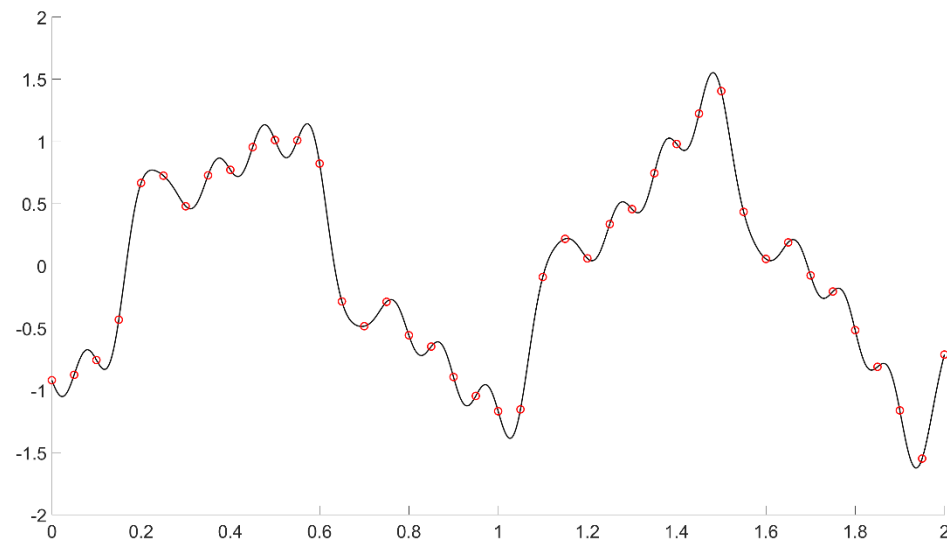


Figure 5: A signal sampled at 20 Hz. Discrete-time sampling (left panel) allows for continuous y-axis ( $\mu\text{V}$ ) values, whereas digitally-sampled signals (right panel) must use a limited number of y-axis values. The three bit converter illustrated here (right panel) allows for  $2^3=8$  distinct values, providing only a coarse approximation of the signal voltage. The right panel depicts the discrete sample value (red circle) and the 3-bit digital equivalent (red line), and the discrepancy (dashed vertical black lines).

From: Curham & Allen (in press)

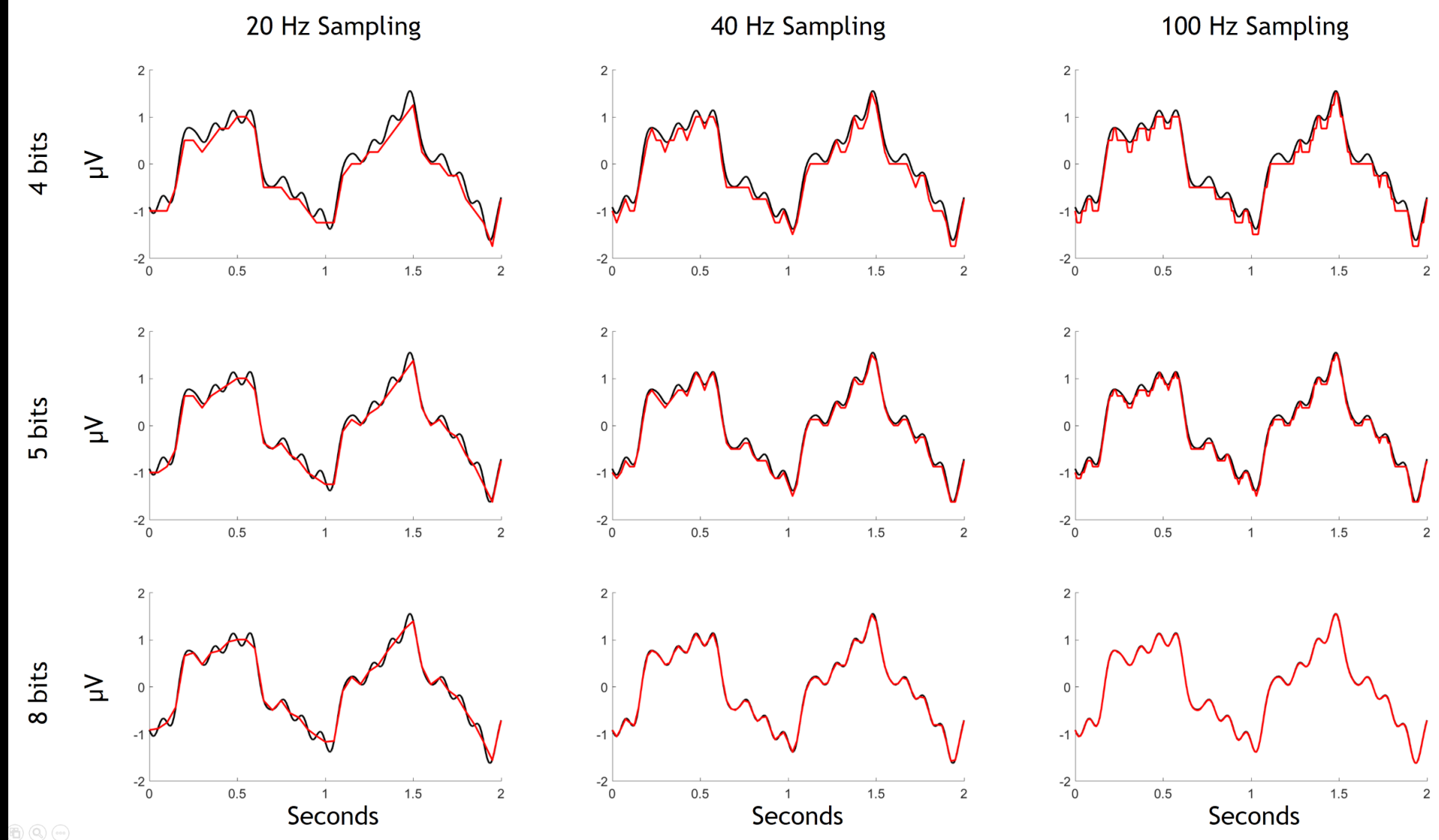


Figure 6: A comparison of a signal (black line) sampled (red line) at three sampling rates (20, 40, 100 Hz) and using three different converter resolutions (4-bit, 5-bit, and 8-bit) that allow for 16, 32, and 128 distinct  $\mu\text{V}$  values. Low bit-resolution was used here for illustrative purposes; commercial converters are typically 12-bit (4096 values) or 16-bit (65536 values).

From: Curham & Allen (submitted)

# The Problem of Aliasing

## ◆ Definition

- ◆ To properly represent a signal, you must sample at a fast enough rate.
- ◆ Nyquist's (1928) theorem
  - ◆ a sample rate twice as fast as the highest signal frequency will capture that signal perfectly
  - ◆ Stated differently, the highest frequency which can be accurately represented is one-half of the sampling rate
  - ◆ This frequency has come to be known as the Nyquist frequency and equals  $\frac{1}{2}$  the sampling rate

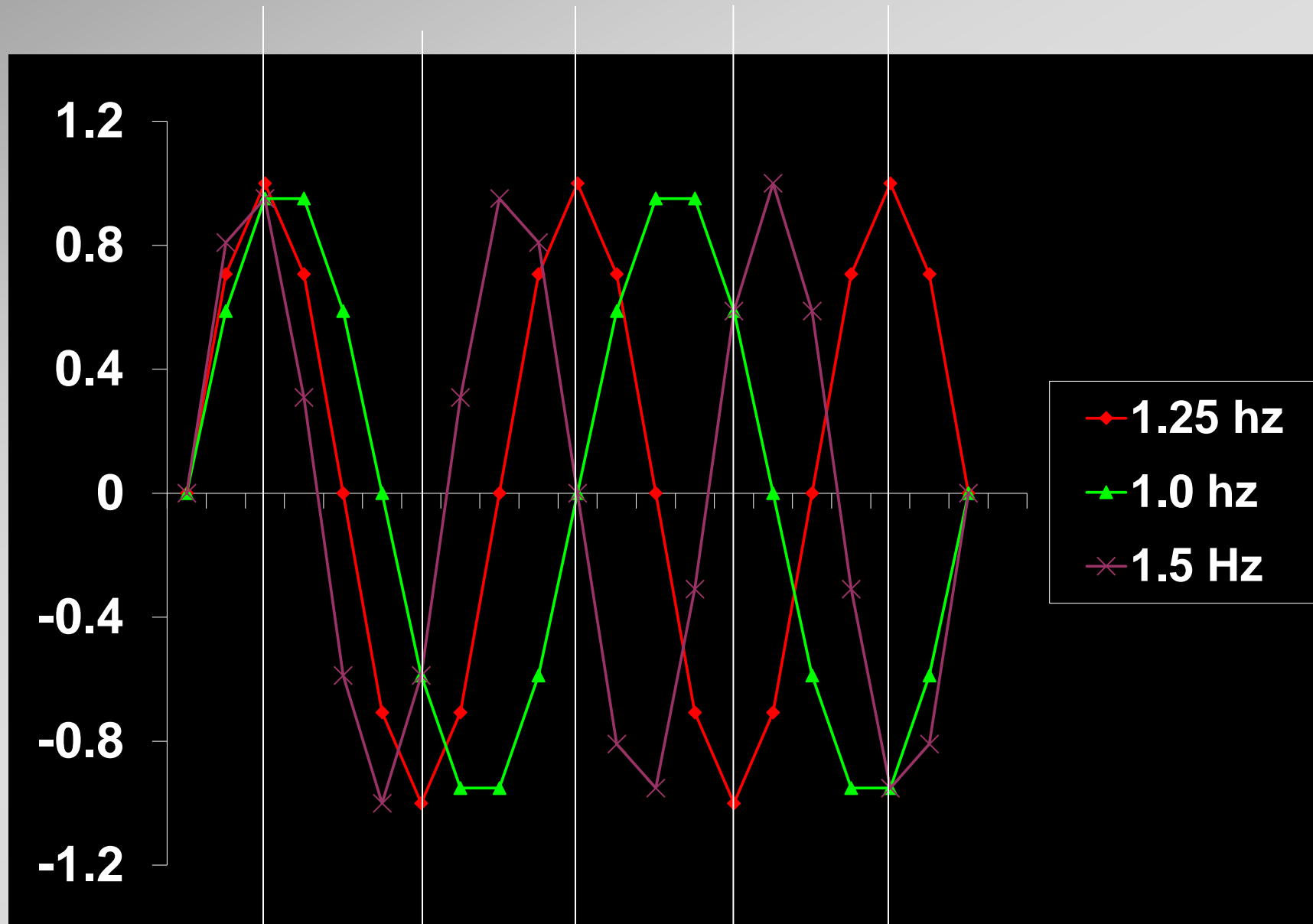
## ◆ Comments

- ◆ Wave itself looks distorted, but frequency is captured adequately.
- ◆ Frequencies faster than the Nyquist frequency will not be adequately represented
- ◆ Minimum sampling rate required for a given frequency signal is known as Nyquist sampling rate

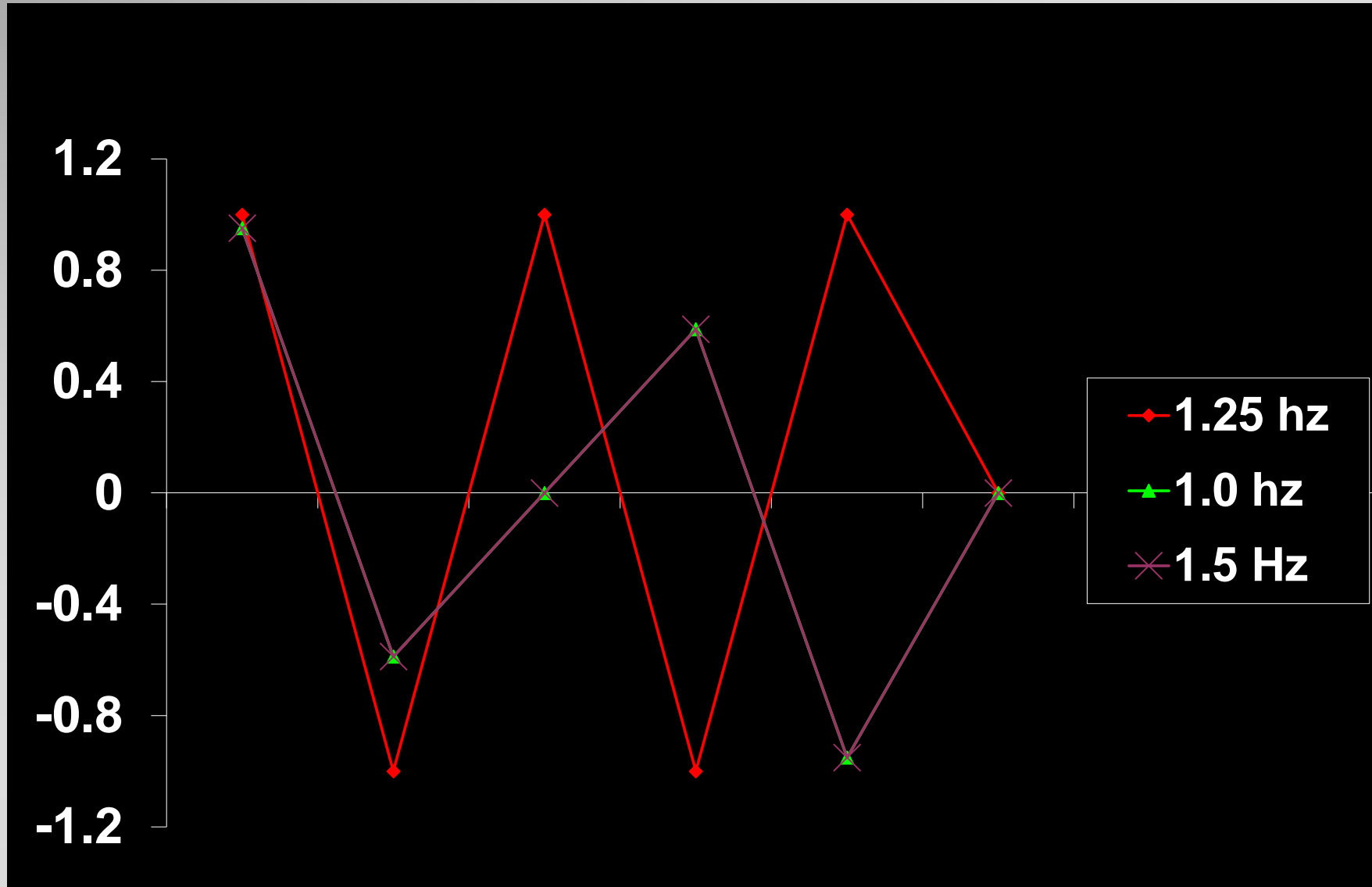


Harry Nyquist

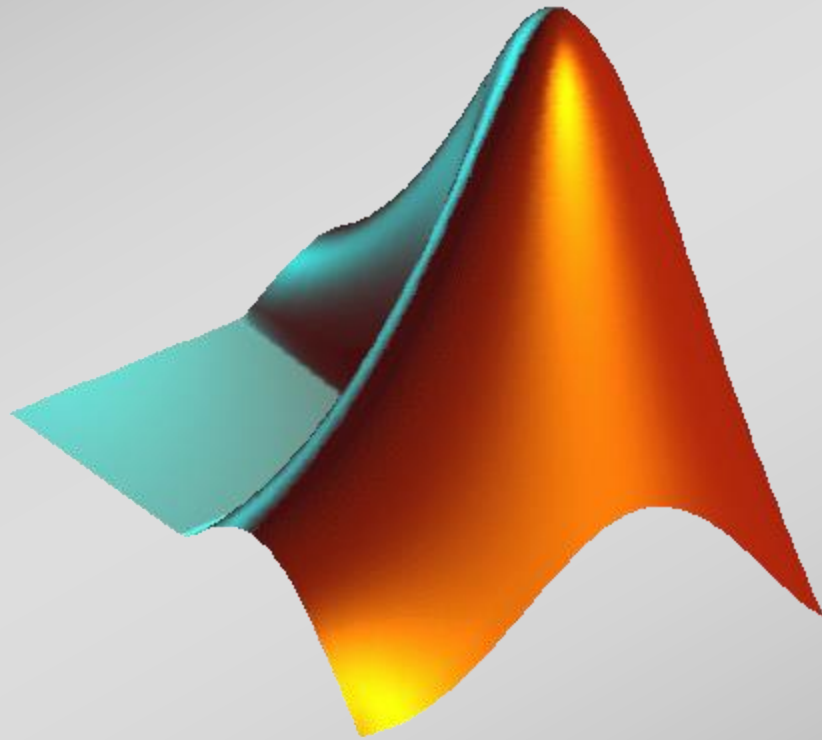
# Aliasing Demo (Part 1, 10 Hz Sampling Rate)



## Aliasing Demo (Part 2, 2.5 Hz Sampling Rate)



# Matlab Demo of Aliasing



# Solutions to Aliasing

- ◆ Sample very fast
- ◆ Use anti-aliasing filters to keep signals below **Nyquist Frequency**
- ◆ **KNOW YOUR SIGNAL!**



# Advantages of Frequency Approaches

- ◆ Sensitive to all frequencies below Nyquist
- ◆ Sensitive to phase-locked and non-phase-locked signals

# Frequency Approaches: FFT etc

- ◆ What/how
- ◆ Advantages
- ◆ Disadvantages

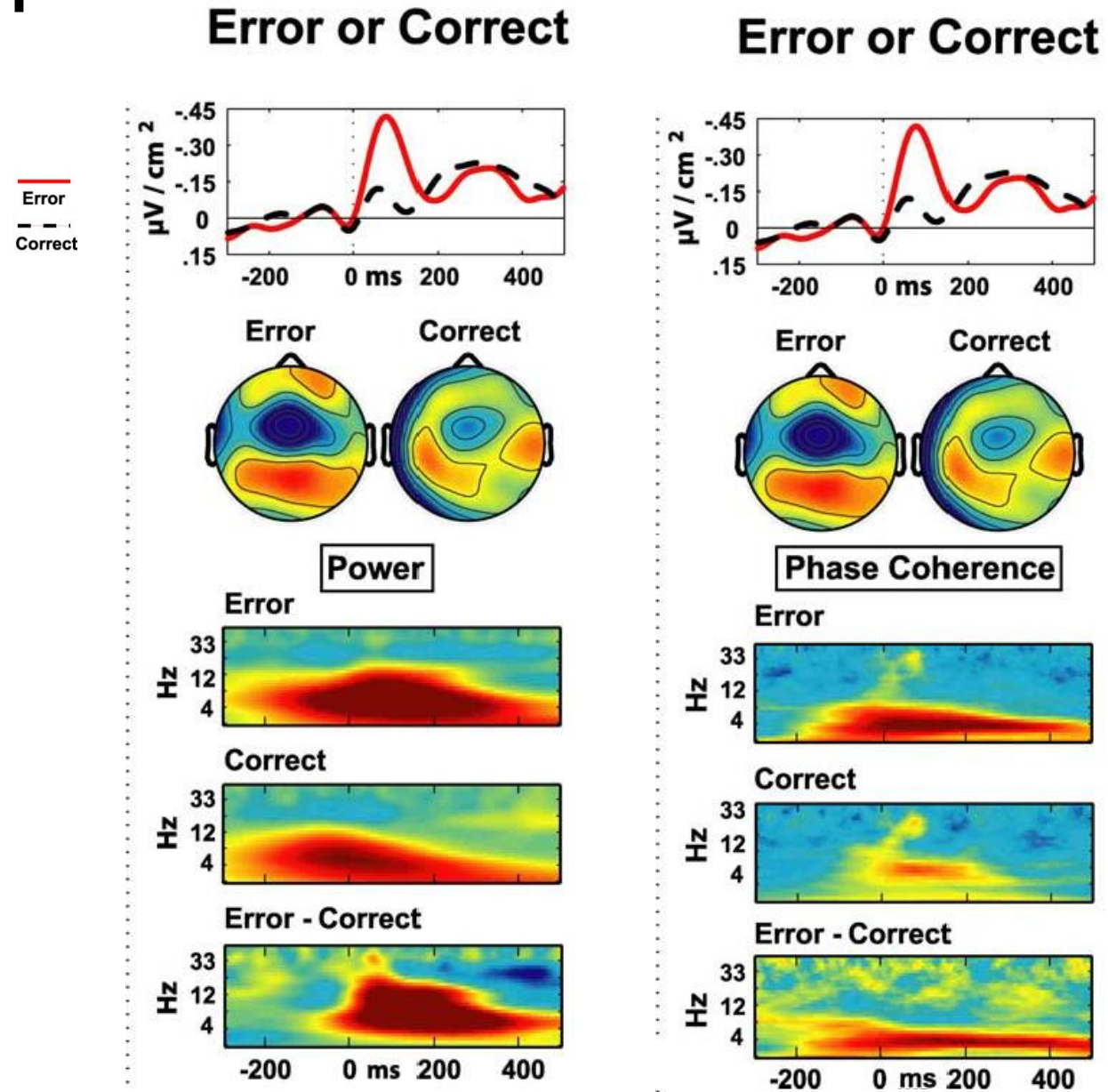
# DisAdvantages of Frequency Approaches

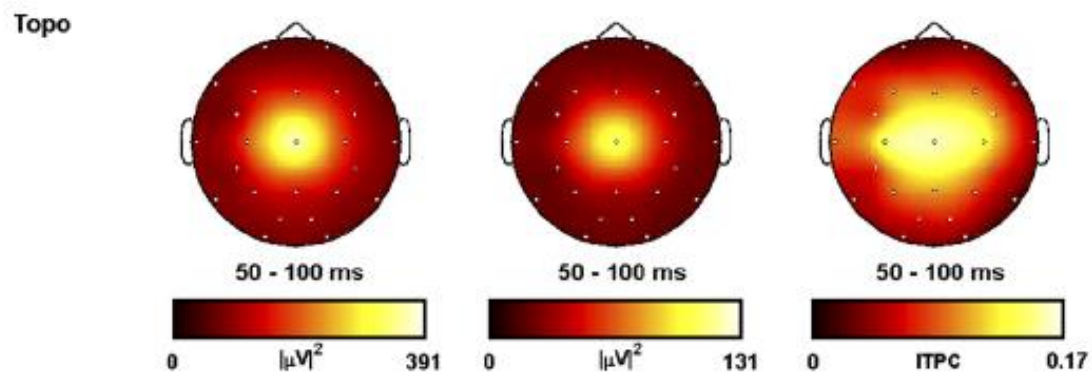
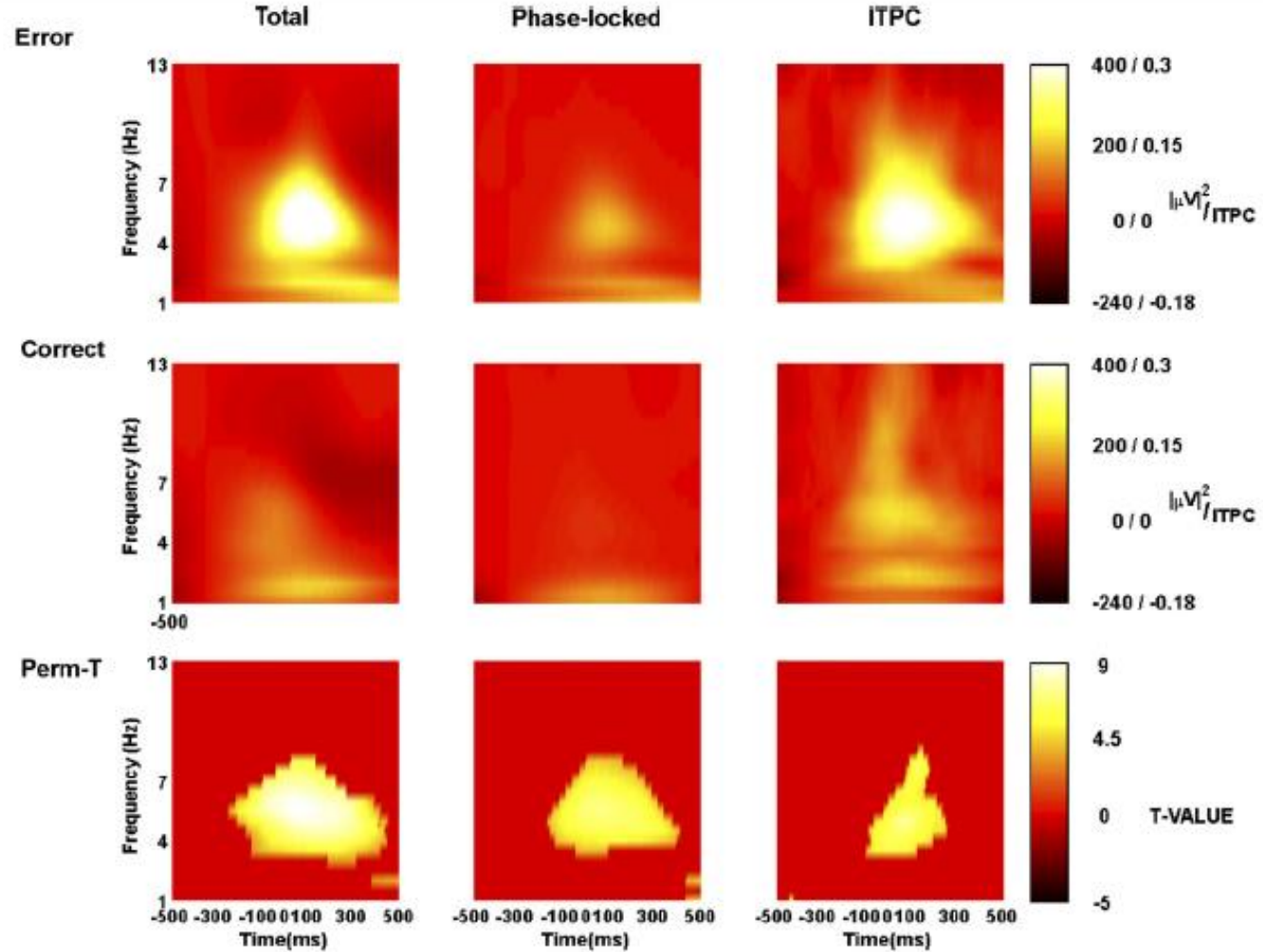
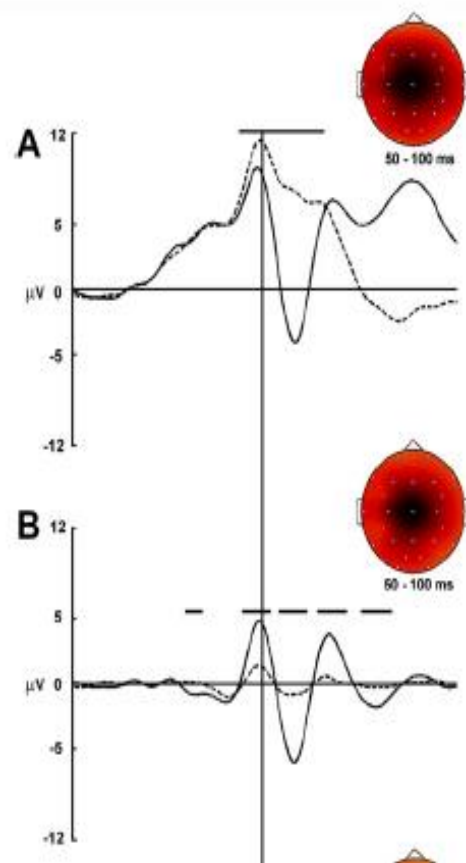
- ◆ Temporally nonspecific
- ◆ Power interpretation is ambiguous:
  - ◆ More is more?
  - ◆ More is more often?

# Time-Frequency Approaches

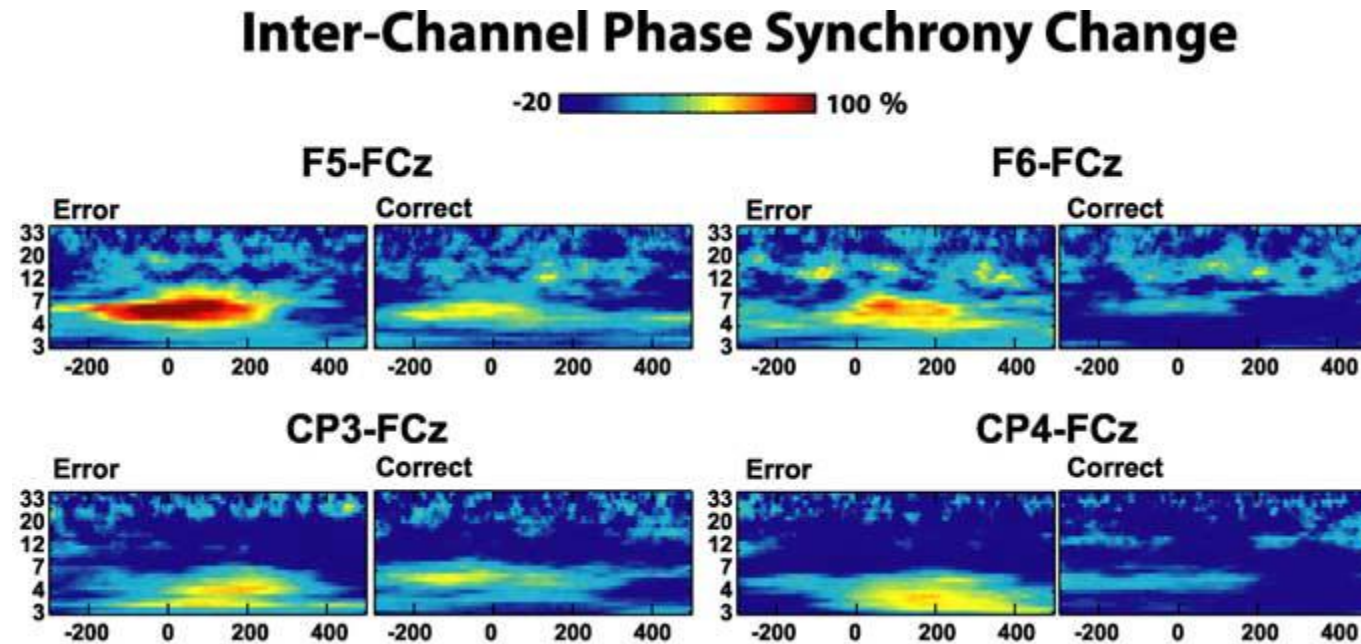
- ◆ What/how
- ◆ Advantages
- ◆ Disadvantages

# Time-Frequency Representation: Power





# Time-Frequency Representation: Power





# Time-Frequency Approaches

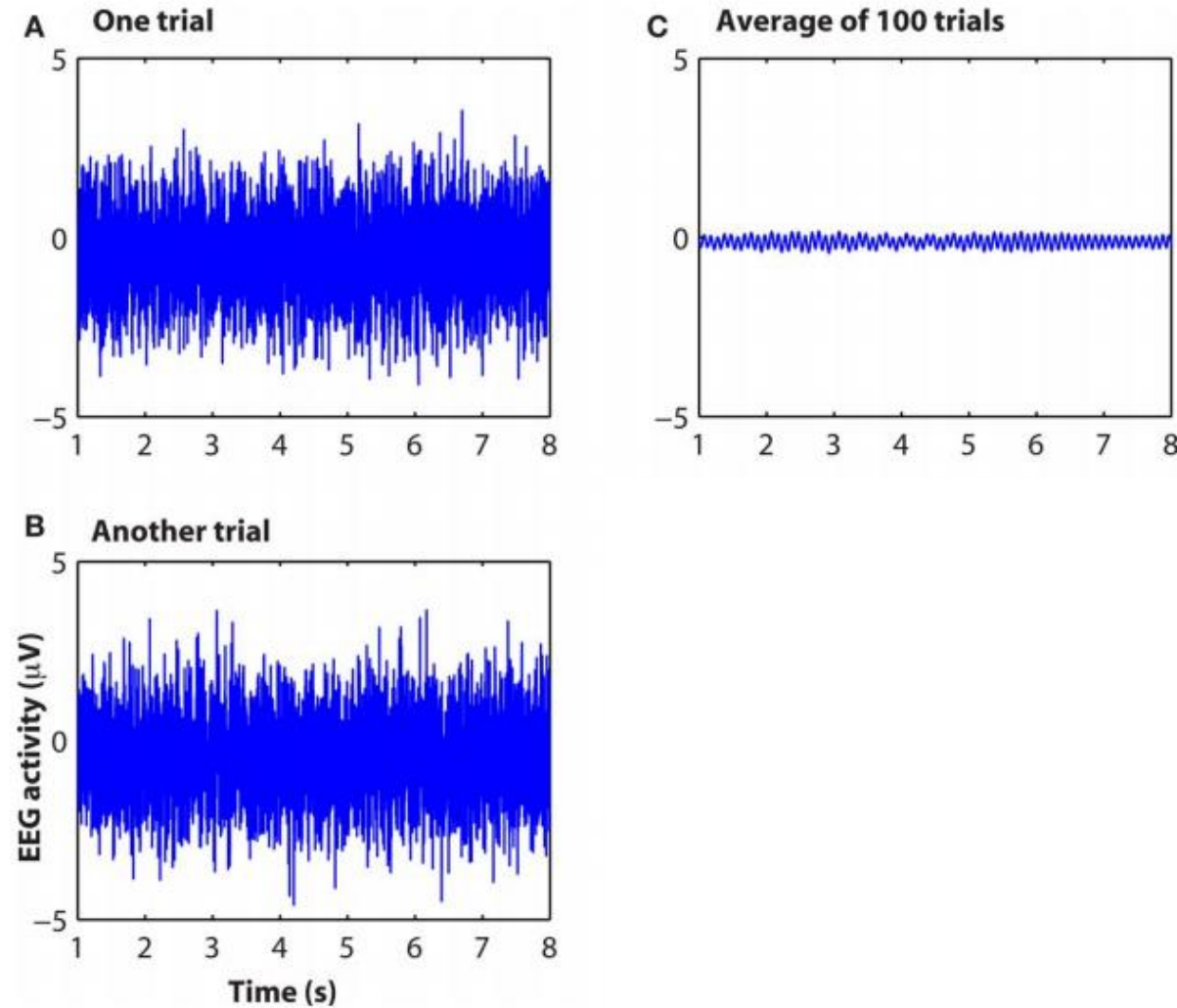
- ◆ What/how
- ◆ Advantages
- ◆ Disadvantages



# Time-Frequency Advantages

- ◆ Results can be interpreted in terms of neurophysiological mechanisms of neural oscillations.
  - ◆ Oscillations are a fundamental neural mechanism that supports aspects of synaptic, cellular, and systems-level brain function across multiple spatial and temporal scales (Cohen, 2014)
- ◆ Oscillations studied across multiple species and levels of analysis (single cell, LFP, intra-cranial, scalp)
- ◆ Captures more of brain dynamics than ERPs

# Power increase in the absence of any phase locking



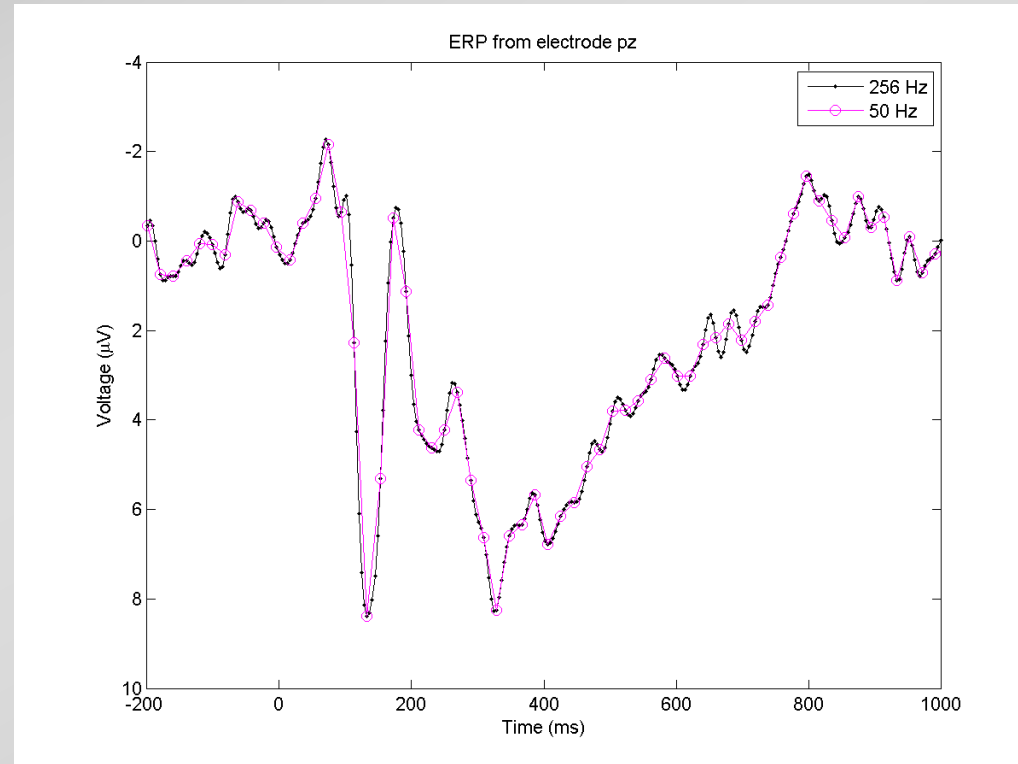
**FIGURE 3 |** Simulated data showing how information contained in raw EEG data [(A,B): single “trials”] is not apparent in the event-related potential (C) but is readily observable in the time–frequency representation (D). Matlab code to run this simulation is available from the author.

# Time-Frequency Approaches

- ◆ What/how
- ◆ Advantages
- ◆ Disadvantages

# Time-Frequency Disadvantages

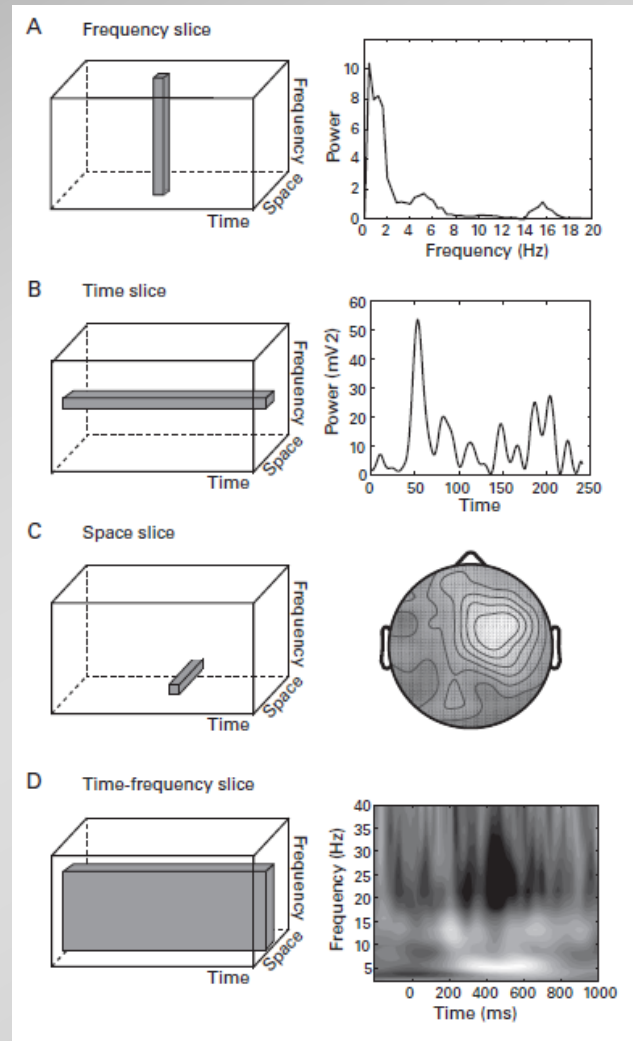
- ◆ Decreased temporal precision vs ERPs
  - ◆ Must observe a full oscillation to capture it
  - ◆ Greater loss of temporal precision at lower frequencies
  - ◆ BUT NOTE (Time-frequency proponents take heart!)



# Time-Frequency Disadvantages

- ◆ Decreased temporal precision vs ERPs
  - ◆ Must observe a full oscillation to capture it
  - ◆ Greater loss of temporal precision at lower frequencies
  - ◆ BUT NOTE (Time-frequency proponents take heart!)
- ◆ Diverse range of analysis possibilities leads combinatorial explosion of possible ways to screw up!
  - ◆ Running analyses improperly
  - ◆ Running improper analyses
  - ◆ Rendering inappropriate interpretations
  - ◆ Multiple comparisons problem
    - ◆ Time-frequency space is large
    - ◆ Multiplied by many electrodes!
  - ◆ The “paralysis of analysis” (Cohen, 2014)
- ◆ TF approaches are *relatively* new, but growth in use is exponential!

# How to view Time-Frequency Results



# How to view Time-Frequency Results

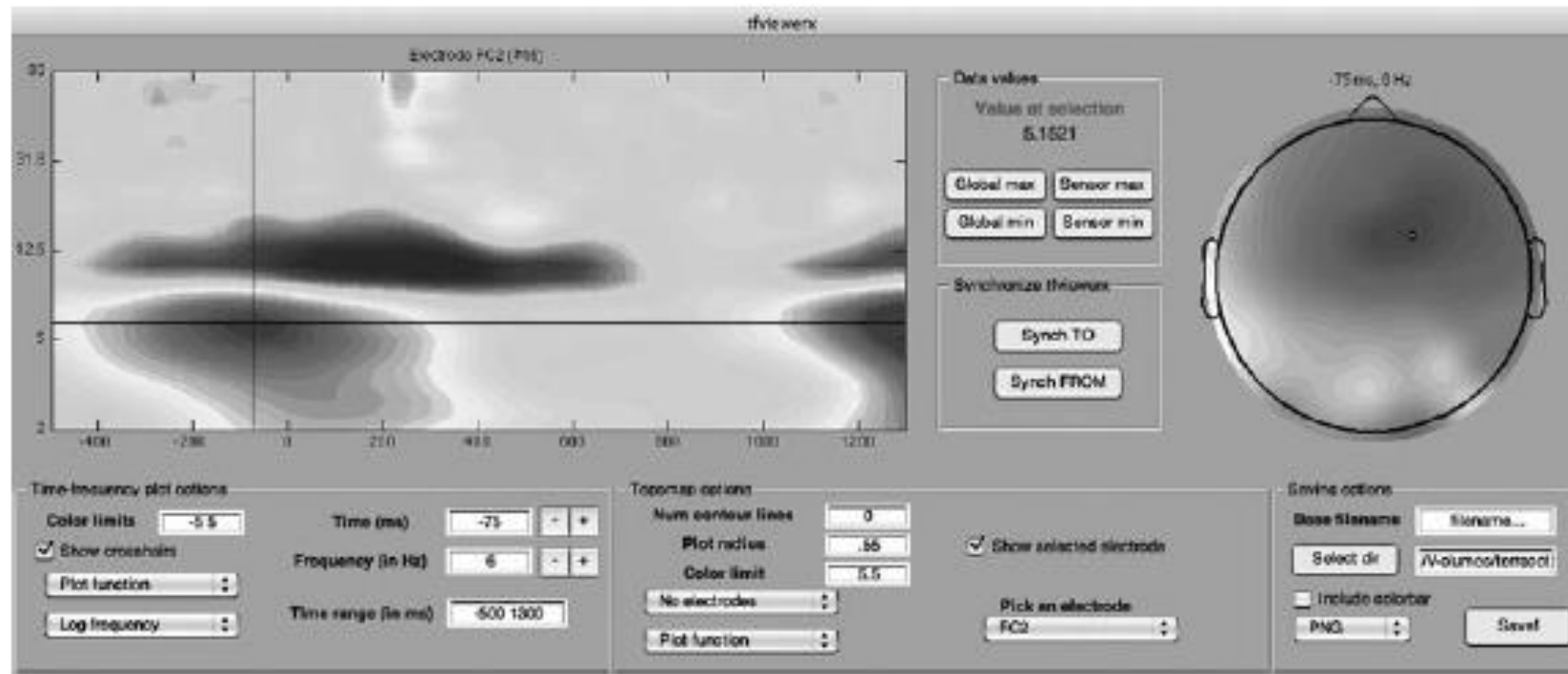


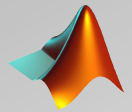
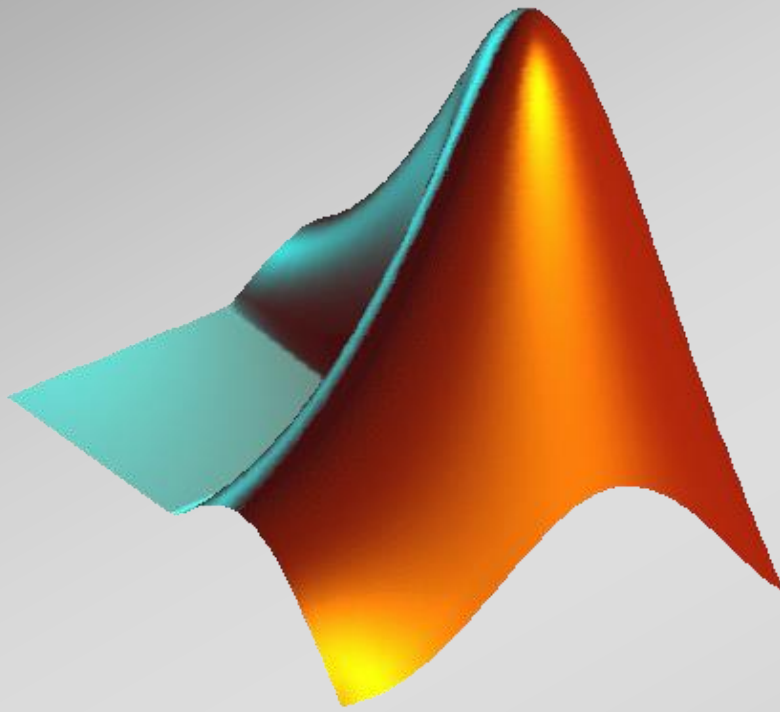
Figure 3.4

A screen-shot of the data-cube-viewing utility `tfviewerx`, which is available online with the Matlab code. Mouse clicks on the time-frequency plot update the topographical map to show the scalp distribution at that time-frequency point, and mouse clicks on the topographical map update the time-frequency plot to show the time-frequency dynamics at the nearest electrode. Multiple `tfviewerx` windows can be opened (e.g., to view results from different conditions) and can be synchronized to show the same time-frequency-electrode point across plots. Type “`help tfviewerx`” in Matlab to learn about how to use this utility.



# Matlab Demo!

◆ tfviewerx



A Non-coding Challenge:

- ◆ Explore the time-frequency-topography space using the preloaded data in tfviewerx



# Be suspect: Time-Frequency Results

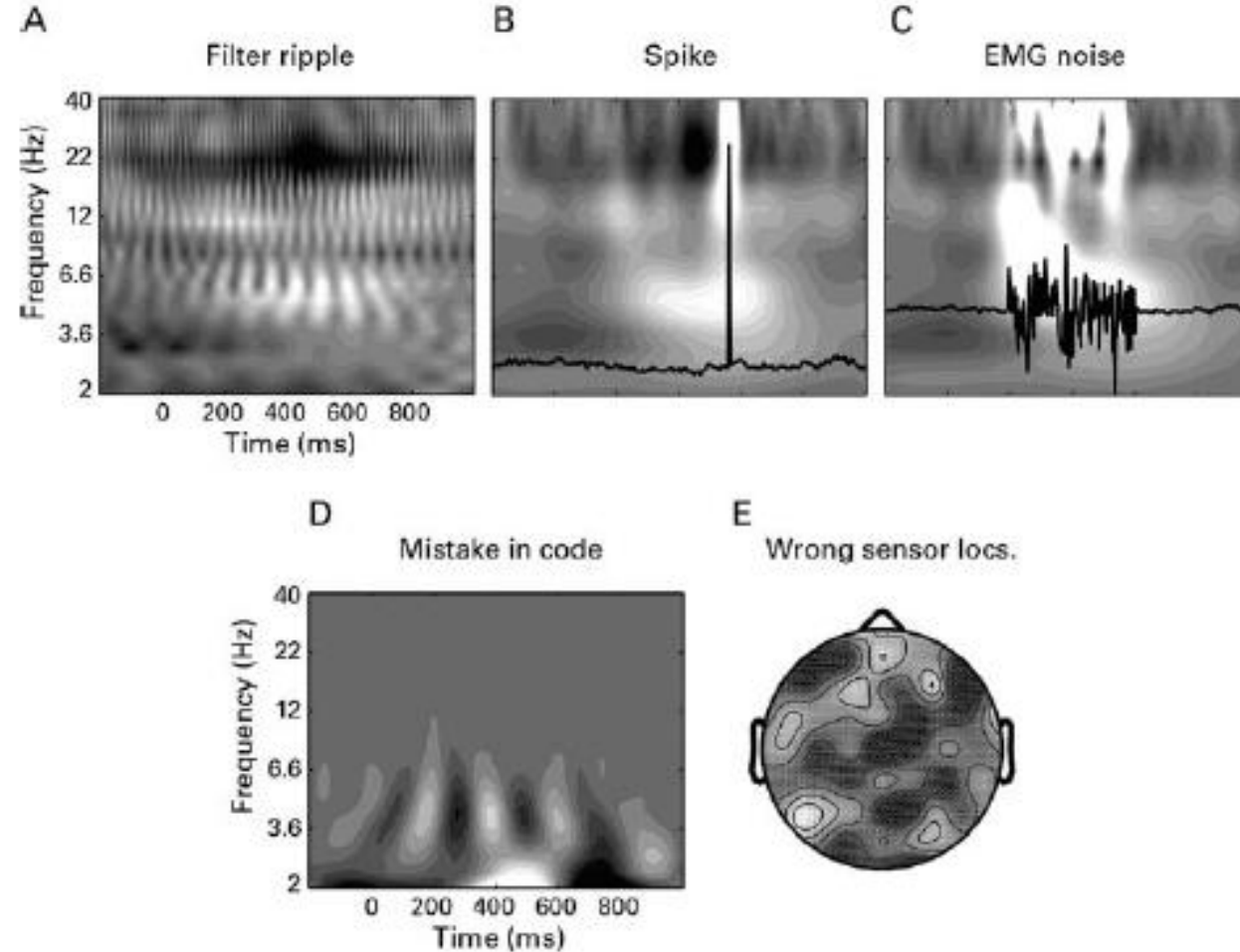


Figure 3.5

Some features of time-frequency results that should arouse suspicion, although they are not necessarily artifacts. In panels B and C, the offending single trial (out of 99 otherwise good-data trials) is superimposed on the time-frequency plot (EEG trace amplitude is arbitrarily scaled). The topographical map in panel E was produced by randomly swapping electrode label-location mappings.

# Roadmap



➡ **Classic (Time or Frequency) vs. Newer (Time-Frequency) Approaches**

➡ **Time Approaches**

➡ **Frequency Approaches**

➡ **Time-Frequency Approaches**

➡ **Brief discussion of Neural Sources and interpretation**

➡ **Guidelines for writing good code**

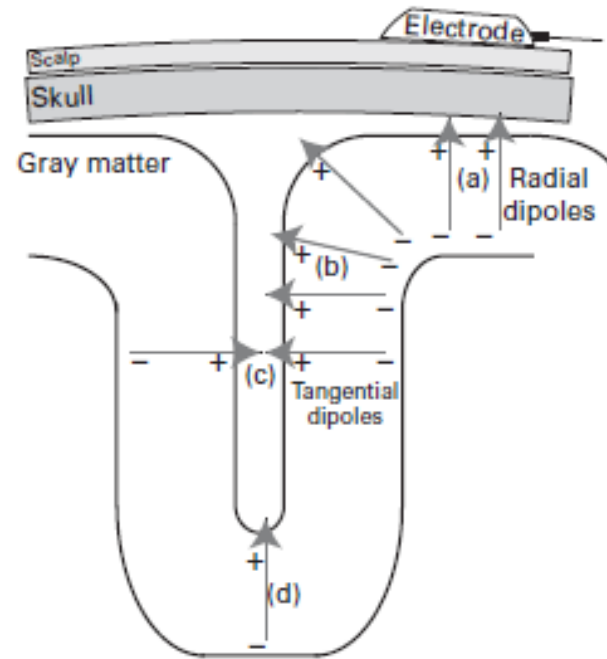
➡ **Code workshop!**

# Brief comment on Neural Sources of EEG

## ◆ EEG blind to many signals

- ◆ Insufficient number of neurons synchronously active
- ◆ Electrical field geometry

# Electrical Field Geometry



**Figure 5.1**

Illustration of dipoles in different orientations with respect to the skull. The dipoles illustrated in (a) will contribute the strongest signal to EEG, whereas the dipoles illustrated in (b) will contribute the strongest signal to MEG. The dipoles illustrated in (c) are unlikely to be measured because the dipoles on opposing sides of the sulcus produce electrical fields that are likely to cancel each other. The dipole illustrated in (d) will make a smaller contribution to EEG than dipole (a) because it is further away from the electrode. (This figure is inspired by figure 1 of Scherg 1990.)



# Brief comment on Neural Sources of EEG

- ◆ EEG blind to many signals
  - ◆ Insufficient number of neurons synchronously active
  - ◆ Electrical field geometry
  - ◆ Cortical Sources predominate for electrodes on the scalp (deep sources “buried”)
    - ◆ Field strength decreases exponentially from source

# Brief comment on Causation

- ◆ EEG is only direct noninvasive measure of neural activity
- ◆ BUT... is the measured activity causal to the psychological process of interest?

# Roadmap

➡ **Classic (Time or Frequency) vs. Newer (Time-Frequency) Approaches**

➡ **Time Approaches**

➡ **Frequency Approaches**

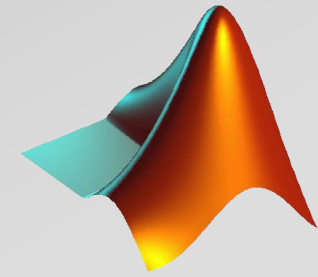
➡ **Time-Frequency Approaches**

➡ **Brief discussion of Neural Sources and interpretation**

➡ **Guidelines for writing good code**

➡ **Code workshop!**

# Writing Matlab Code



- ◆ Write Clean and Efficient Code
- ◆ Comment your code!
  - ◆ One comment per three lines of code
- ◆ Use Meaningful File and Variable Names
- ◆ Make Regular Backups of Your Code
  - ◆ Keep Original Copies of Modified Code
- ◆ Initialize Variables; pre-allocate matrices/cells
- ◆ Make functions!
- ◆ Test small segments and built outward
  - ◆ Use cells within code
- ◆ Read (and critique) other people's code



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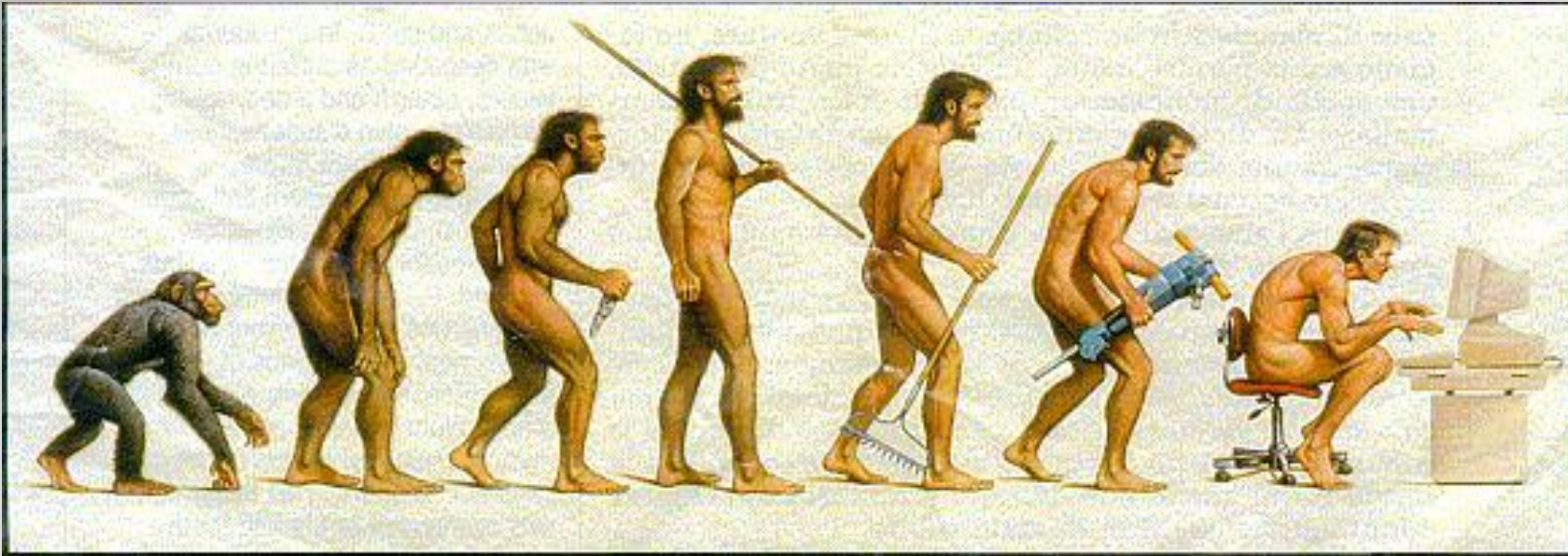
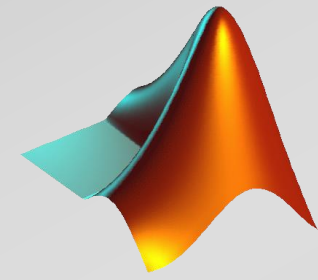
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# Let's Code!





# How to access Self-study Materials or Additional Training if you wish

- ◆ Workshops for Matlab, EEGLab, and R are available from my website [resources and downloads page](#).
  - ◆ The link for *Matlab and R Tutorials from Summer 2011* will prompt you for a password, and you can access the page with this password: U2CanzBeGeekz
  - ◆ Full instructions and links to all resources are available on that page.
  - ◆ Lessons 1-3 most relevant for basic coding mastery; Lesson 4 for EEG-specific coding
- ◆ Mike Cohen's very accessible book on Matlab ([FunTF](#)) is just \$9.99 on Kindle