Analyzing Neural Time Series Data

1.1 What is Cognitive Electrophysiology?

1.2 What is the purpose of this book?

- Gain a deeper understanding of data analysis, without requiring formal training in math and computer science.

1.3 Why You Shouldn't Use EEG Analysis Packages

- Lack of flexibility

1.4 Why Program Analysis, and Why in Matlab?

- Easy to use
- Matlab has many EEG analysis toolboxes
- Easily Sharable with others
- **Octave –** Free Matlab alternative
- Matlab Toolboxes for EEG:
    - Signal-processing Toolbox
    - Statistics Toolbox
    - Image-processing Toolbox

1.5 How to Best Learn from and Use This Book

- In front of a computer, running matlab
- In order from simple to more complicated analysis

1.6 Sample Data and Online Code

- www.mikexcohen.com/book

1.7 Terminology in this Book

- Always refer to as EEG, but also applies to other data collection techniques

1.8 Exercises

- Do them

1.9 Is Everything There is to Know about EEG Analysis in this Book?

- No, but it has the most useful, promising, and accepted approaches for linking EEG dynamics to cognitive processes.

2. Advantages and Limitations of Time- and Time-Frequency-Domain Analysis

2.1 Why EEG?

- Captures cognitive dynamics in the time frame the cognition occurs
    - Theta-band (4-8Hz)
        - Memory / Cognitive Control
        - Slower frequency
    - Gamma-band (30-80Hz)
        - Faster frequency
- Measures neural activity
    - Voltage fluctuations
- Multi-Dimentional
    - Voltage changes over time and space
        - Time
        - Space
        - Frequency
        - Power (strength of frequency-band-specific-activity)
        - Phase (timing of activity)

2.2 Why Not EEG?

- Not suited for studies where precise functional localization is important
- Not suited for testing hypotheses of deep brain structures
- Not suited for questions concerning slow processes with uncertain and variable time courses.

2.3 Interpreting Voltage Values from the EEG Signal

- Recorded in microvolts
    - Change in measured electrical potential between the electrode and a reference electrode placed elsewhere on the head
        - Readings change based on choice of reference and time period for baseline subtraction
        - Values differ across subjects because of

        - Skull shape / thickness
        - Scalp preparation
        - Orientation of dipole in brain
        - Cortical folding
        - If subject washed their had the morning of
    - Raw Values are difficult to compare and should not be overinterpreted
    - Interpret general pattern of effects and time-frequency-electrode characteristics of effects, rather than difference in microvolt values
- Analysis using scale transformations are advantageous
    - Individual differences in raw voltage values are eliminated

2.4 Advantages of Event-Related Potentials

1. Simple, fast to compute, require few analysis assumptions
2. High temporal precision and accuracy
    a. Applying low / high pass filters decreases precision
3. Extensive literature of ERP findings
4. Quick and useful data quality check of single subject data

Should be inspected for each subject to make sure data was properly collected.

2.5 Limitations of ERPs

1. Null results – many EEG data dynamics that aren't represented in ERP
2. Provide limited opportunities for linking results to physiological mechanisms
    a. Mechanisms that produce ERPs are less well understood than those producing oscillations

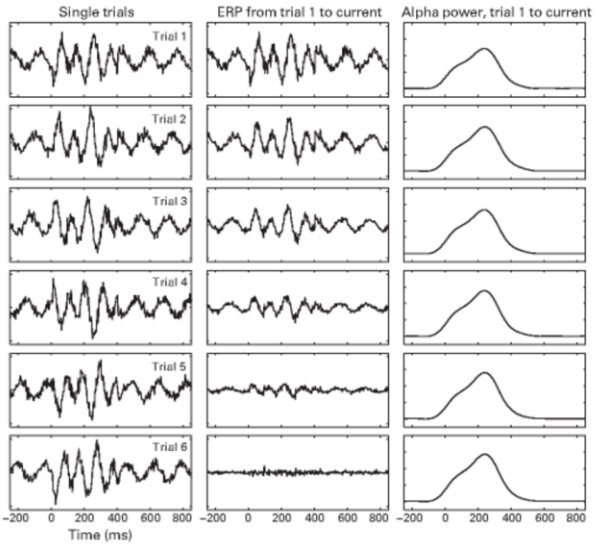

Figure 2.1
Simulated data showing how time-locked but not phase-locked activity (left column) is lost in ERP averaging (middle column) but is visible in band-specific power (right column). Each row in the left column shows a different trial, and each row in the middle and right columns shows averages from the first until the current trial.

2.6 Advantages of Time-Frequency-Based Approaches

1. Results can be interpreted in terms of neurophysiological mechanisms of neural oscillations
2. Oscillations are the most promising bridge that links findings from multiple disciplines within neuroscience and across multiple species
3. Many task-relavent dynamics that are retrievable using only time-frequency-based approaches

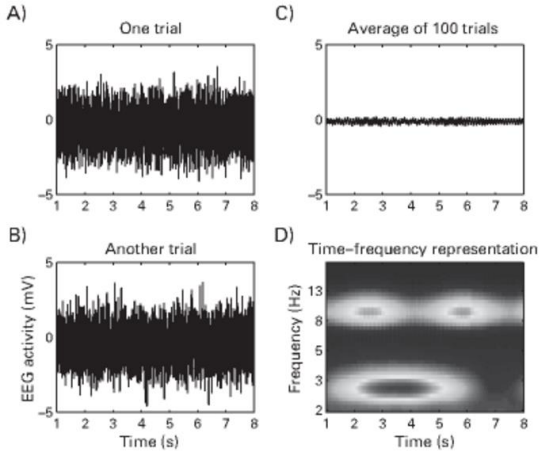

Figure 2.2
Simulated data showing that complex and multifrequency information contained in EEG data may have no representation in the ERP, if that information is non-phase-locked. One hundred trials were simulated; panels A and B show example trials. Panel C shows the ERP of those 100 trials, and panel D shows the time-frequency power. (This figure is adapted from Cohen 2011b).

2.7 Limitations of Time-Frequency-Based Approaches

1. Decrease of temporal precision → from time-frequency decomposition
    a. Lower frequency = more loss of temporal precision
    b. Low pass filtering of ERP data diminishes temporal precision
2. Large number of analyses that can be applied to EEG data
    a. Complexity of those analyses is intimidating

2.8 Temporal Resolution, Precision, and Accuracy of EEG

- Resolution → # of data samples per unit time
- Precision → certainty of measurement at each time point
- Accuracy → Relationship between timing of EEG signal and timing of biophysical events that lead to EEG signal
    - Distance of the dots to the center of the bull's eyes

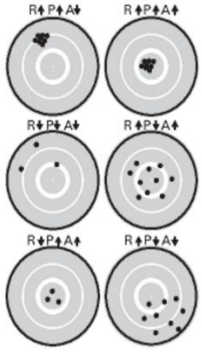

Figure 2.4
Bull's-eye illustration of the differences among resolution (R), precision (P), and accuracy (A). Up-and-down arrows indicate high and low levels. Resolution is illustrated by the number of dots, precision is illustrated by the spread of the dots, and accuracy is illustrated by the distance of the dots away from the center of the bull's-eye.

- Temporal resolution (Generally 250Hz – 1000Hz)
    - Determined by sampling rate of acquisition (100s – 1000s of samples per second)
    - Allows for extraction of frequency-band-specific information
    - Low temporal resolution
        - Extracting Delta-Band Power
    - High temporal resolution
        - Cross-frequency Coupling
- Temporal Precision
    - Depends on applied analysis / Selected Parameters / Frequency Band
        - Higher frequency (generally) = higher temporal precision
    - High Precision
        - Unfiltered ERPs
    - Low Precision
        - 1Hz bandpass-filtered activity
- When temporal precision is decreased by analysis, temporal resolution can decrease to match precision
- Temporal Accuracy – Is extremely high because
    - Brain electrical activity travels instantaneously from neurons to electrodes

2.9 Spatial Resolution, Precision, and Accuracy of EEG

- Spatial Resolution
    - Depends on # of electrodes
- Spatial Precision
    - Low, but can be improved by spatial filtering
        - Surface Laplacian / Adaptive source-space-imaging techniques
- Spatial Accuracy
    - Low
    - Electrodes collect data on cluster of neurons
- Organization of Brain networks
    - Microscoping Scale → less than a few cubic millimeters
    - Mesoscoping Scale → patches of cortex of several cubic (mm – cm)
    - Macroscopic Scale → large regions of cortex (many cubic cm)

2.10 Topographical Localization vs. Brain Localization

- Topographical → identify electrodes that show max effect
    - Description of observation
- Brain → identify regions in brain that generate activity (measured on scalp)
    - Interpretation of a result, supported by combination of theory, previous research, and data analysis in combination with spatial filtering

2.11 EEG or MEG?

- MEG → better at detecting high-frequency activity
    - Also better for source localization
- EEG → works better for radial sources

2.12 Costs of EEG Research

- Good EEG headsets are expensive
- If you have no equipment, the cost of EEG per subject gets close to, and sometimes supersedes the cost of MEG or MRI research

Interpreting and Asking Questions about Time-Frequency Results

3.1 EEG Time Frequency: Basics

- Rhythmic activity reflects neural oscillations
  - Fluctuations in excitability of populations of neurons
- Frequency
  - Speed of oscillation (Hz) – cycles per second
- Power
  - Energy in a frequency band that is squared amplitude of oscillations
- Phase
  - Position along sine wave at any given time point (Radians or Degrees)
- Power and phase are independent of eachother

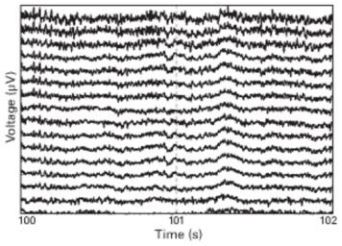

Figure 3.1
Raw EEG data (after 0.1-Hz high-pass filtering) showing oscillations at different speeds and for different lengths of time. Each line corresponds to an electrode.

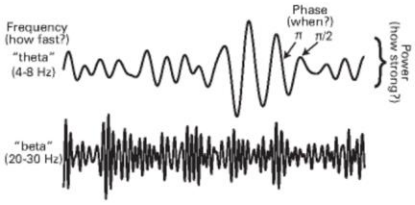

Figure 3.2
The three dimensions that define oscillations: frequency, power, and phase.

- EEG measures meso / macro – scopic cortical electrical activity
- Brain rhythms
  - Delta (2-4Hz)
  - Theta (4-8Hz)
  - Alpha (8-12Hz)
  - Beta (15-30Hz)
  - Lower Gamma (30-80Hz)
  - Upper Gamma (80-150Hz)
  - Subdelta (<600Hz)
- Generally: Better precision in time or frequency → Poorer precision on other domain

- Background activity exists
    - So we require baseline normalization
    - To remove artifacts that are consistently present, but not relevant to area of focus
    - Phase-locked
        - Phase is same or similar on each trial
    - Non-phase locked
        - Phase is different on each trial
- Spatial Autocorrection
    - Sometimes electrodes record activity from the same brain sources

3.2 Ways to View Time-Frequency Results

- Frequency Slice
    - Power (energy at each frequency band) vs. Frequency
    - No use of time
    - Useful when little time varying changes in frequency characteristics are expected
        - Ex. Resting State or Sleep Stage
- Time Slice
    - Select one frequency band
    - Plot its activity over time
    - Useful when comparing activity across multiple conditions or electrodes
        - And a prior reason to focus on a specific frequency
- Space Slice
    - One time-frequency point (or average over mult. Adjacent time freq. points)
    - Over electrodes on a topographical plot
    - Useful in visualizing topographical distribution of effect and facilities of topographical localization
- Time-Frequency Slice
    - Frequency vs. Time
    - Typically higher frequencies are plotted at the top
    - Color can be used to reflect:
        - Power
        - Phase clustering
        - Connectivity
        - Correlation Coefficient
- Other Slices
    - Activity of each electrode over time
    - Activity over different frequencies as a function of physical distance of subject to a target

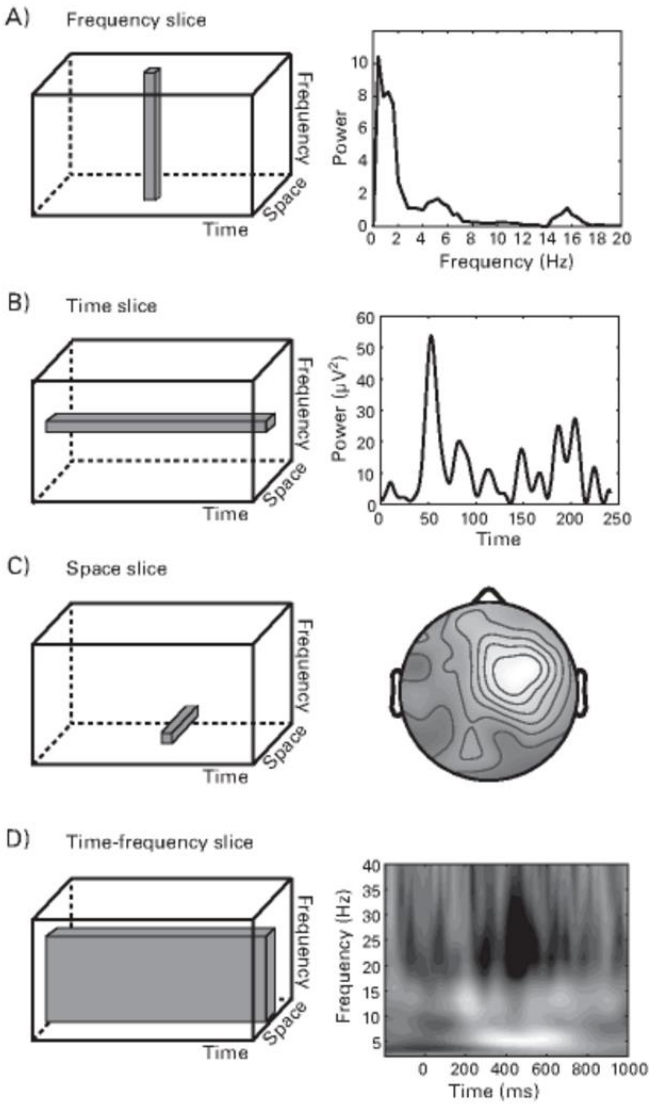

Figure 3.3
The data cube, containing information over time, frequency, and space, is difficult to view or conceptualize and therefore is sliced in different ways to illustrate 1-D or 2-D snapshots of the results.

3.3 Tfviewerx and erpviewerx

- Simultaneously shows time-frequency plot from one electrode and the topographical map at a selected time-frequency point

3.4 How to View and Interpret Time-Frequency Results

1. Determine what is shown in the plot
   - Power
   - Phase Clustering
   - Connectivity
   - Correlation with behavior
   - Understand conceptually what is being plotted
2. Inspect the ranges and limits of the plot
   - What are the time and frequency ranges?
   - Is there activity that is cutoff by boundaries?
   - Color limits? Symmetric or asymmetric or bounded by 0?
3. Inspect the Results
   - Activity at multiple freq. and time windows? Or all centered at one time-frequency?
   - Activity duration short or long? Freq. band-limited or spans multiple frequency bands?
   - Activity during prestimulus period?
   - Topographical specificity (are effects present selectively at some parts of scalp)?
   - Which electrode(s) are shown and why?
4. Link Results to Experiment
   - What does time = 0 refer to?
   - Mult. Events in experiment? How are they represented in time-freq. Results?
   - Results make sense? Are they consistent?
   - What do results suggest about cog. Process under investigation?
   - Results prove any new information about brain function?
5. Understand Statistical Procedures Used to Support the Interpretations
   - Statistical Threshold?
   - Hypothesis-driven or exploratory and data-driven?
   - Exploratory approaches generally require conservative statistical thresholds and corrections for multiple comparisons over time, frequency, and electrodes.
   - Hypothesis driven → increase sensitivity and theoretical relevance. Less stringent thresholds ($p < 0.05$ is acceptable)
   -If hypothesis driven, how were time-frequency-space windows selected for statistical analysis?

3.5 Things to Be Suspicious of When Viewing Time-Frequency Results

- Horizontal / Vertical stripes in Time-Frequency Plot
    - Ripple artifacts from poor filter construction
        - Filter widths are:
            - Too narrow
            - Applied to too little data
- Brief and large-power effects at high frequencies
    - EEG artifacts such as:
        - Amplifier saturation
        - Noise spike from bad electrode
- Broadband effects
    - Mechanical noise or excessive muscle activity from jaw or neck
- Fast color changes over time or frequency
    - Mistake in analysis – real part of analytical signal plotted instead of power
    - Fast change in lower frequencies are more suspect than in high frequencies
        - Increased temporal smoothing at lower frequencies
- Strange topographical distributions
    - Noisy or bad electrodes
    - Incorrect mapping between electrode label and physical location
    - High-pass spatial filters (Laplacian) increase topographical localization and highlight local spatial features
- High-frequency activity (over 100Hz)
    - Has low signal-to-noise ratio and may require many trials and special analysis techniques to enhance signal noise
- Low-Frequency Activity (<1z)
    - High pass filters that attenuate activity in lower frequencies
    - Apply high pass filter of 0.1 or 0.5 Hz to eliminate slow fluctuations

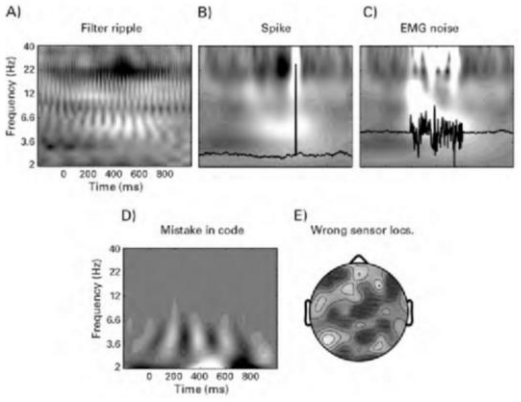

Figure 3.5
Some features of time-frequency results that should arouse suspicion, although they are not necessarily artifacts. In panels B and C, the offending single trial (out of 99 otherwise good-data trials) is superimposed on the time-frequency plot (EEG trace amplitude is arbitrarily scaled). The topographical map in panel E was produced by randomly swapping electrode label-location mappings.

3.6 Do Results in Time-Frequency Plots Men That There Were Neural Oscillations

- On one hand, EEG measures summed field potentials of populations of neurons
    - Strongly oscillatory
- On the other, Fourier's theorem specifies that any signal can be represented using sine waves, and thus, even nonoscillatory signals have a representation in a time-frequency plot

4 Introduction to Matlab Programming

4.1 Write Clean and Efficient Code

- Clean code is easy to read and understand
- 1. Write Brief Comments before the code
- 2. Group lines of code by their common purpose
- 3. Use sensible, interpretable variable names
- Perform matrix manipulations instead of loops when possible
- Verbally plan out your code on paper before coding it

4.2 Using Meaningful File and Variable Names

- Put “I” at end of counting variables in loops

4.3 Make Regular Backups of Your Code and Keep Original Copies of Modified Code

4.4 Initialize Variables

- Reserve space in Matlab buffer by creating variable before populating it with data
    - Helps avoid memory crashes
    - Helps prefent data from previous iterations of loop contaminating current iterations
    - Helps you think about size, dimensions, and contents of large and important variables in advance

5 Introduction to the Physiological Basis of EEG

5.1 Biophysical Events That Are Measurable with EEG

- Magnetic fields are perpendicular to electric fields and pass through skull/scalp unimpeded

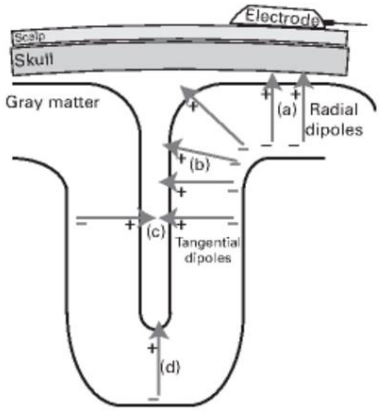

Figure 5.1
Illustration of dipoles in different orientations with respect to the skull. The dipoles illustrated in (a) will contribute the strongest signal to EEG, whereas the dipoles illustrated in (b) will contribute the strongest signal to MEG. The dipoles illustrated in (c) are unlikely to be measured 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.)

- Populations of neurons in subcortical structures are not arranged in geometrically parallel orientation
    - In synchronous population activity, electrical fields generated by individual neurons are likely to cancel eachother out at the macroscopic scale
- Slow fluctuations (<1Hz) are difficult to measure with EEG
    - Most amplifiers have built-in high-pass filters that attenuate very slow fluctuations because they may cause amplifier saturations
        - There are DC-coupled amplifiers for fluctuations below 1Hz
- Fast fluctuations (>100Hz)
    - High frequency activity generally has low power → difficult to distinguish from noise

5.2 Neurobiological Mechanisms of Oscillations

- Oscillation – Rhythmic alteration of states
    - Rhythmic fluctuations in excitability of neuron populations
- Interaction between inhibitory interneurons and excitatory pyramidal cells
    - Oscillations can be produced by excitatory or inhibitory neurons

5.3 Phase-Locked, Time-Locked, Task-Related

- Phase-locked
  - Aligned with time = 0
  - Observed in time-domain averaging and in time-frequency-domain averaging
- Non-Phase-Locked
  - Time locked, but not phase locked with time = 0
  - Time-frequency-domain averaging
- Time and/or frequency characteristics change as a function of engagement in task events
  - Background activity does not
  - Apply baseline normalization to remove background activity

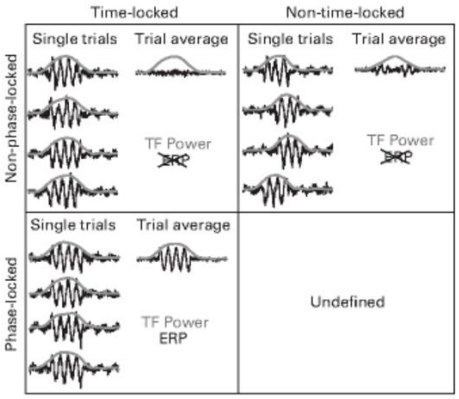

Figure 5.2
Illustration of whether time-frequency (TF) power and the ERP can measure phase-locked, non-phase-locked, time-locked, and non-time-locked activity. The left column of each cell shows four trials of simulated data, and the right column of each box shows the average of those four trials. Black lines show the raw time series, and gray lines show the time course of 10-Hz power. The ERP captures only phase-locked and time-locked activity. Time-frequency power can measure time-locked activity regardless of whether it is phase-locked or non-phase-locked. Activity that is not time-locked can be measured with time-frequency power, although the results will be smoothed and thus less temporally precise.

5.4 Neurophysiological Mechanisms of ERPs

- Additive
  - ERP reflects a signal elicited by an external stimulus (picture / sound)
  - Or internal event (manual response)
- Phase reset
  - ERP results from sudden alignment of phases of ongoing oscillations
  - Stimulus appears → ongoing oscillation at a particular frequency band is reset to a specific phase value
- Amplitude Asymmetry or Baseline Shift
  - Outward-going currents are less detectable from scalp
    - Producing asymmetry in oscillations measured by EEG
      - Unequally distributed peaks / troughs
  - Changes in overall power could produce asymmetries in ongoing oscillations

5.5 Are Electric Fields Causally Involved in Cognition?

- Theory 1: Long-term potentiation occurs at theta-band oscillations
- Theory 2: Timing of many neurons is constrained by local field potential
- Theory 3: Interregional oscillatory synchronization is a mechanism underlying the transmission of information across neural networks, and the synchronization-mediated connectivity is crucial for perceptual and cognitive processes

5.6 What if Electric Fields Are Not Causally Involved in Cognition?

- Doesn’t stop progress

6 Practicalities of EEG Measurement and Experiential Design

6.1 Designing Experiments: Discuss, Pilot, Discuss, Pilot

- Discuss with colleagues before data collection
- Test run without EEG headset
- Perform on 2 people and fully analyze those datasets

6.2 Event Markers

- Square-wave pulses sent from stimulus-delivering computer to EEG amplifier
- Recorded as separate channel in raw data file
    - Amplitude used to encode specific events (stimulus onset or response)
    - During data importing, markers are converted to labeled time stamps
        - Indicate when different events occurred
- Used to time lock EEG data
- Used to reconstruct different conditions and responsebetters
    - **Better more detail in these markers, More =**

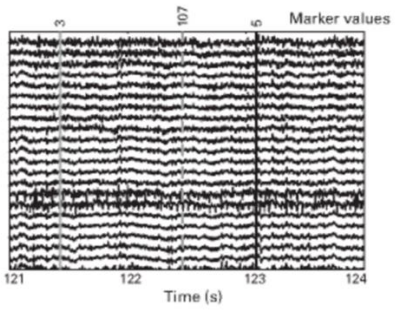

Figure 6.1
Example EEG data showing 3 s of data and three experiment markers. The experiment markers are represented as vertical lines, and the numbers on top of the vertical lines correspond to particular events. In this case the numbers 3 and 5 refer to two response buttons being pressed by the subject, and the number 107 corresponds to a particular stimulus. This picture was made using the eeglab lab function `eegplot`.

- Check for overlapping and dropped markers
- Temporal duration
    - Time when marker has non-zero value
    - (Should be at least a few samples ~5 ms)
- Data is useless without markers
    - Test by:
    - Sending codes 1-256 with 10ms spaces between markers

6.3 Intera- and Intertrial Timing

- Space out time between tasks by a few seconds (Intertrial Interval ~1000ms)
    - Allow brain response to subside after a task
    - Different tasks will take different times to subside
        - Ex. Pictures that evoke emotion
- Period of time for baseline normalization of task related data?
- What frequencies to analyze.
- Time Freq. Decomposition
    - End before trial onset (-500 to -200ms)
        - Bc. Temporal filtering may cause early poststimulus activity to leak into the prestimulus baseline period
- ERPs
    - End at time = 0
- Subjects nearly always generate temporal expectations about when the next trial will occur
- Constant Time Intervals
    - People can mentally prepare for an upcoming event
- Random Time Intervals
    - People can try to guess when the next event is upcoming

6.4 How Many Trials You Will Need

- Depends on:
    - Signal-to-noise ratio (how clean vs. how noisy) of the data
    - Size of the effect
    - Type of analysis to be performed
- Usually minimum of:
    - 50 trials per condition per subject
    - But there are unique cases where less is needed

6.5 How Many Electrodes You Will Need

- Depends on Experiment and what you're looking for:
    - Brain Source Reconstrucion Analysis
        - 100+ electrodes
    - Measure P3 Amplitude
        - 3 electrodes
            - Central parietal cortex for P3
            - Reference
            - Ground
    - At least 64 usually
        - Consider time to prepare the subject with an EEG cap
        - Storage and processing capacity required for more data

6.6 Which Sampling Rate to Use When Recording Data

- Times per second the data are acquired
- Defines data's temporal resolution
- Depends on:
    - Type of analysis
    - Frequencies to analyze
    - Available desk space
    - Processor Speed
- Nyquist Theorem
    - Only frequencies below half the sampling rate can be recovered
        - Looking at 50Hz, need to sample 100Hz
- Generally use (500Hz to 2000Hz) sampling rate
    - Better higher sampling rate and then downsizing
- Make it easy to convert between time in samples and time in ms
    - 1000Hz is optimal
        - 14ms is 14 samples

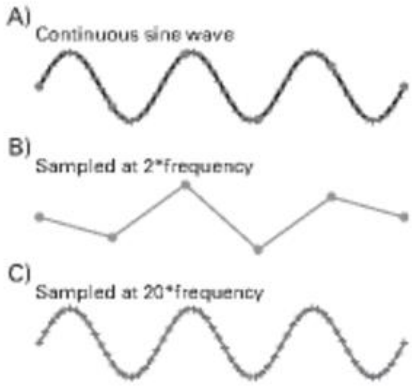

Figure 6.2
A continuous sine wave (panel A) and an illustration of the effect of subsampling that sine wave. Panel B shows that sampling the sine wave at twice its frequency (see gray dots along the sine wave in panel A) can reconstruct some features of the sine wave but fails to reconstruct the finer features, in particular the precise peak and trough times and the ongoing phases. Panel C shows that sampling at 20 times the frequency (see gray plus signs in panel A) can reconstruct the time-varying features of the sine wave with much higher accuracy.

6.7 Other Optional Equipment to Consider

- Response EMG or Force Grips
    - Provide data on muscular movement
- Eyetracker
    - Lets you remove trials where subjects looked away from the fixation spot
    - Use saccades and looking times as dependent measures
    - Remove oculomotor artifacts from EEG data
    - Changes in pupil dilation

- Electrode Localization Equipment
    - Have the precise location of the electrodes on the dead
- Comfortable Chair for Subject to Sit In
    - More comfort = less movement artifacts
- Good Response Device
    - Response device with good timing, comfortable, and intuitive
    - Easy to hold, intuitive layout
    - Not too easy to press (subjects must know that response was registered)
    - Not too hard to press (subject gets tired)
    - Clicks to show that a response was registered
        - Might also create artifacts

7 Preprocessing Steps Necessary and Useful for Advanced Data Analysis

7.1 What is Preprocessing?

- Any processing between collecting and analyzing the data
    - Organize data
        - Extract epochs from continuous data
    - Removing bad or artifact-ridden data w/ out changing clean data
        - Remove bad electrodes
        - Reject epochs with artifacts
    - Modifying Clean Data
        - Temporal filters
        - Spatial transformations
- Keep track of all details of preprocessing for each subject
    - Trials rejected
    - Electrodes interpolated
    - Independent components removed from the data

7.2 Balance Between Signal and Noise

- Signal and noise overlap, so it is hard to remove noise without removing signal too
- Noise example:
    - Amplifier Saturations (produce spikes)
- Threshold for noise depends on the experiment at hand

7.3 Creating Epochs

- Continuous data are cut into segments surrounding particular experimental events
- Must decide what to call “time = 0”
    - Options:
        - Time-lock to earliest event in each trial
        - Time-lock to the data of focus
- Must decide how much time before and after the “time = 0” event
    - Epoch must be at least as long as duration of trial
- Compute only ERPs
    - Epoch as long as time period to analyze + a baseline period
- Time-Frequency-Based Analysis
    - Longer epochs to avoid contaminating results with edge artifacts
        - Edge artifact:
            - Apply temporal filters to sharp edges → producing a high-amplitude broadband power artifact lasting hundreds of ms

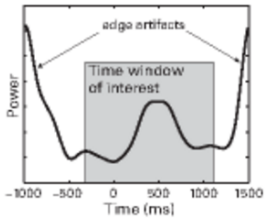

Figure 7.2
Edge artifacts resulting from discontinuous breaks in the time series between trials can contaminate the results if there are insufficient buffer zones to allow those edge artifacts to subside. In this case the edge artifacts are easily identifiable, and it is also clear that those artifacts subside before the time window of interest (gray area). In general, edge artifacts will contaminate up to three cycles of activity, but this could be less or more depending on the magnitude of the edges.

- The buffer zone you choose to include depends on frequencies you intend to extract
    - Longer epochs allow for edge artifacts to subside before and after experiment events
    - Lower frequency band to extract = more buffer zone to avoid edge artifacts
- Analyze one subject closely
    - Check if artifacts affect time period of interest
- General Rule:
    - 3 Cycles at the lowest frequency
    - Ex. 1500 ms for 2Hz activity
- Caveat: Large Epochs
    - Overlapping data in each epoch
    - A problem for Independent Component Analysis
        - Don't expose ICA to the same data more than once
- Sufficient Buffer Required for:
    - Time-Frequency-Decomposition via:
        - Complex Morlet Wavelet Convolution
        - Filter-Hilbert Method
- Sufficient Buffer Not-Required:
    - Time-Frequency Decomposition via:
        - Short-Time FFT
        - Multitaper
- If analyzing data that's already EEG epoched
    - Use Reflection – only when necessary
        - EEG data from each trial and electrode are reversed and put in beginning and end of trial
    - Makes Epoch 3 times longer
    - Discard reflected data after analysis
- NEVER – Taper the entire epoch time period

7.4 Matching Trial Count across Conditions

- Ideal for all conditions to have the same number of trials
- Analysis backed on phase:
    - More sensitive to trial count
    - Small # of trials introduces positive bias
- Analysis based on power or ERP
    - Less sensitive to trial count
    - Low trials ERP
        - Mean amplitude in time range is more robust to noise compared to peak times
- Large Differences in Trial Count Across Conditions
    - (less than 30 trials) – consider matching trial count across conditions
- Matching Trial Count
    - Identify condition with fewest trials
    - Selecting trials from other conditions
        - All conditions end up with equal # of trials
    - Method 1:
        - Select 1st N trials from each condition
        - N is # of trials in smallest condition
        - Biases conditions to have more trials earlier in experiment (when subjects are less tired, more patience/motivated)
    - Method 2:
        - Select trials at random
        - No bias in terms of when trial occurred in experiment
        - But reanalyzes same data multiple times (unless store which trials were used already)
    - Method 3:
        - Select trials based on relevant behavioral or experimental variable (ex. Reaction time)
        - Select subset of trials from all conditions
            - Distributions of reaction times from the retained trials are similar across conditions
        - Disadvantage:
            - If there are reaction time differences between conditions, matching reaction times across conditions may bias trial selection from different regions of the reaction time trial distribution
        - Selective sampling based on any relevant behavioral measure:
            - Saccade speed
            - Pupil response
            - Subject difficulty rating
            - Luminance
            - Location of stimulus
- Trial matching when comparing EEG results across subjects with a behavioral variable that might be related to trial count