

An introduction to EEG

Neuroimaging workshop

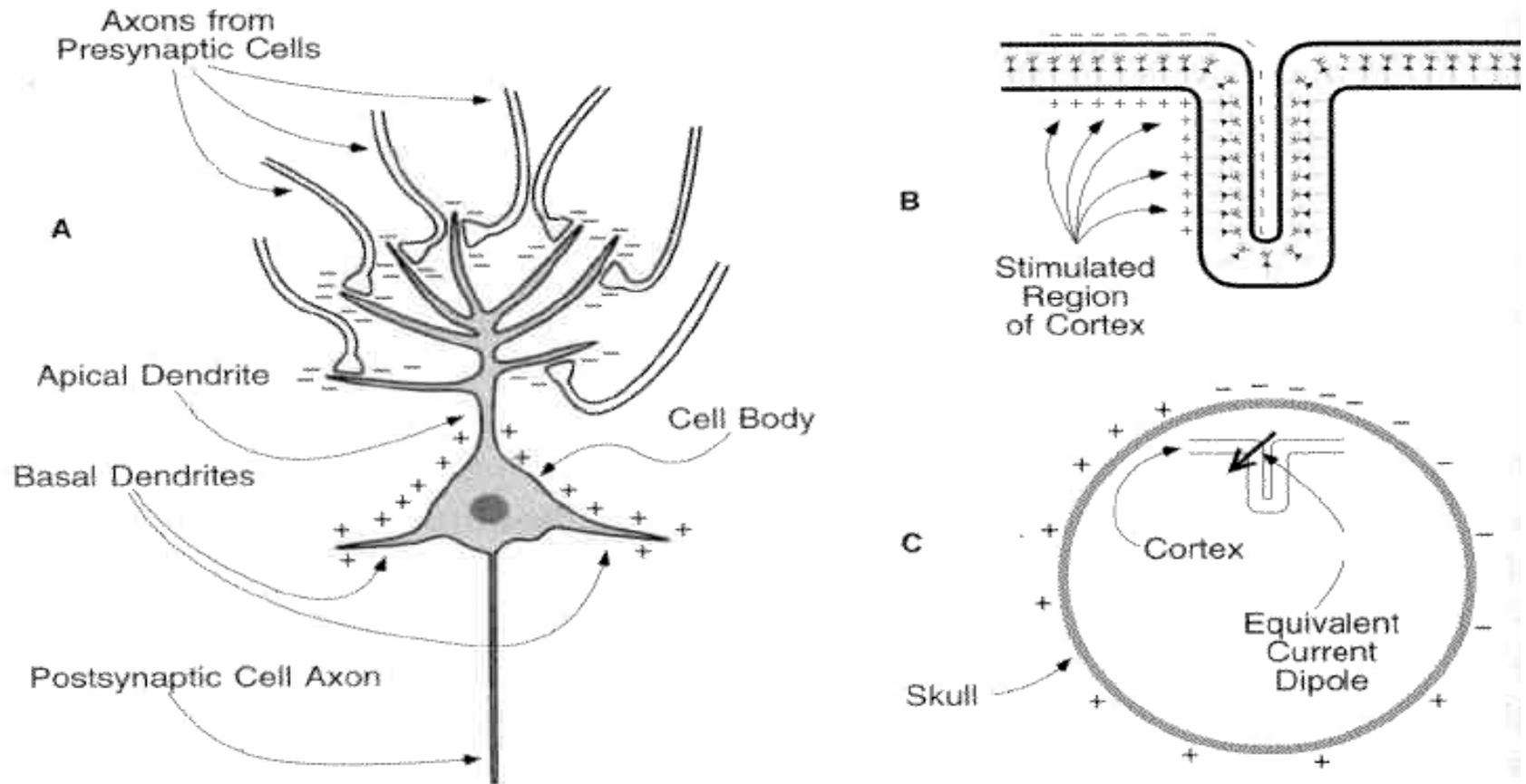
July 15, 2011

Benjamin Files

The plan

- EEG Basics:
 - What does it measure?
 - What is it good for?
- DNI's EEG equipment
- My advice for designing an EEG experiment
- A basic ERP analysis
- If time permits: advanced topics

EEG measures electric potentials

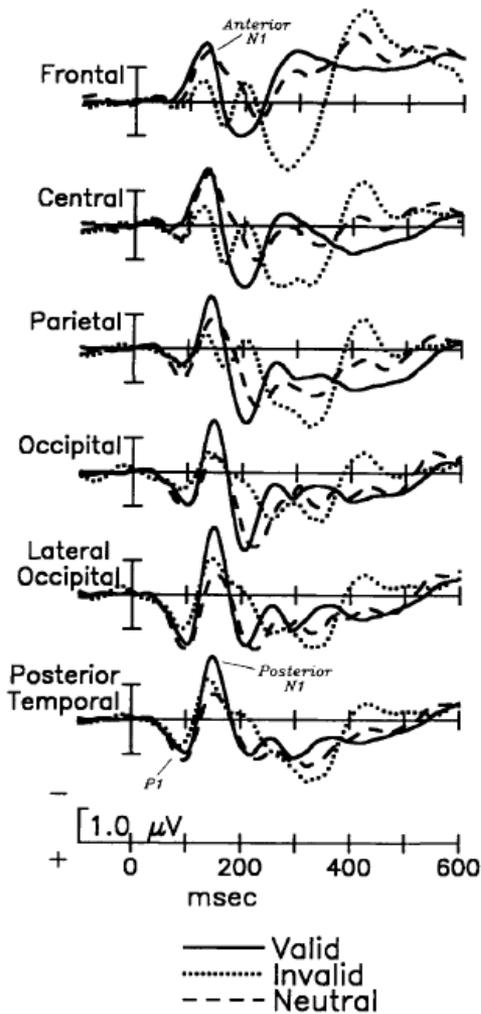


From Luck, S.J., (2005). *An Introduction to the Event-Related Potential Technique*. Cambridge, MA: MIT Press

The signal is weak, so averaging is required

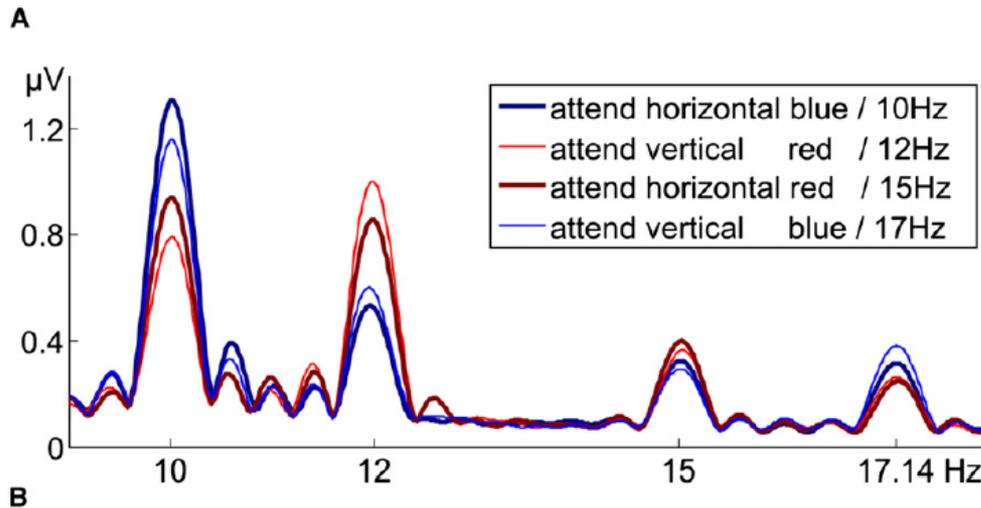
- Voltage relative to some time-locking event:
Event-related potential (ERP)
- Frequency spectrum
- Time/frequency transform:
 - Event-related spectral perturbation (ERSP)
 - Inter-trial Coherence (ITC)

Event-related potential



- erpology: the study of how experimental manipulations change ERP component latency/amplitude
 - Making the connection b/w an ERP effect and a brain effect can be tricky
- Recommended reading:
 - Luck, S. (2005). *An Introduction to the Event-Related Potential Technique: The MIT Press, Cambridge MA.*
- Some “Gotchas” while reading ERP papers:
 - Not everyone uses the same reference electrode
 - Sometimes negative is up
 - Beware of spatial claims
 - Cherry-picking is standard practice
 - Beware of biased measures

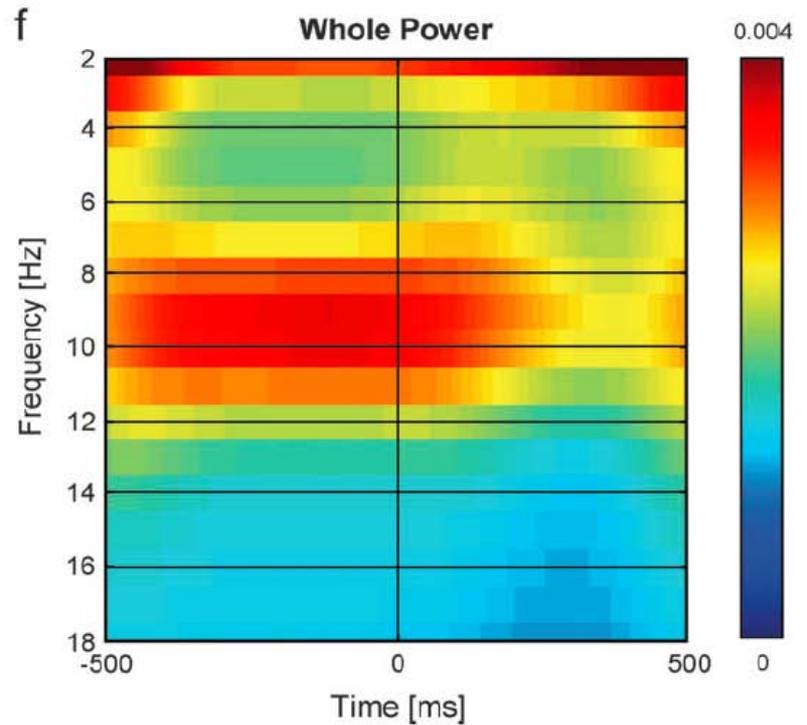
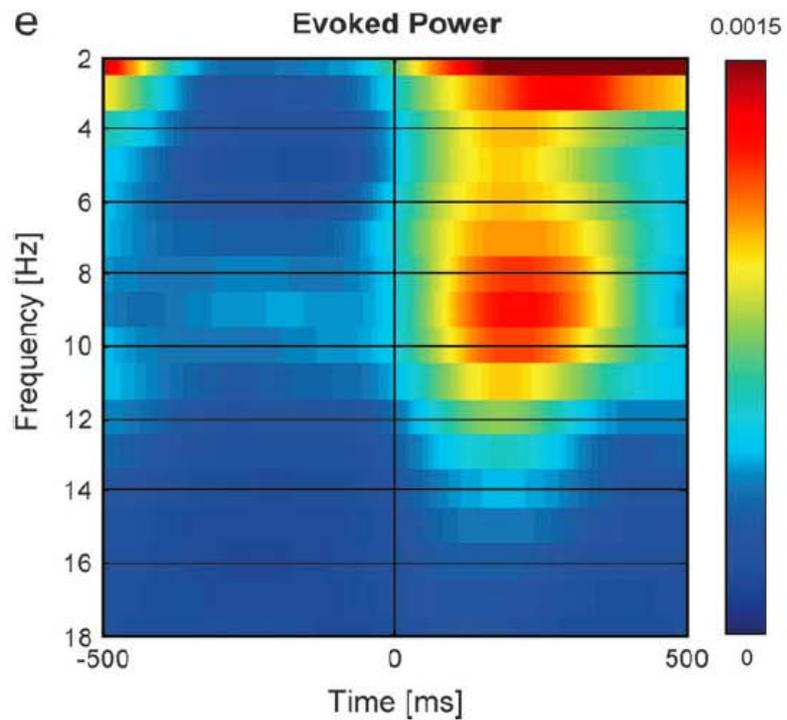
Frequency Spectrum



Andersen, S. K., Hillyard, S. A., & Müller, M. M. (2008). Attention facilitates multiple stimulus features in parallel in human visual cortex. *Current Biology*, 18(13), 1006-1009.

- SSVEP
- Traditional frequency bands:
 - Delta (1-4 Hz)
 - Theta (4-8 Hz)
 - Alpha (8-12 Hz)
 - Beta (12-24 Hz)
 - Gamma (30 & up)

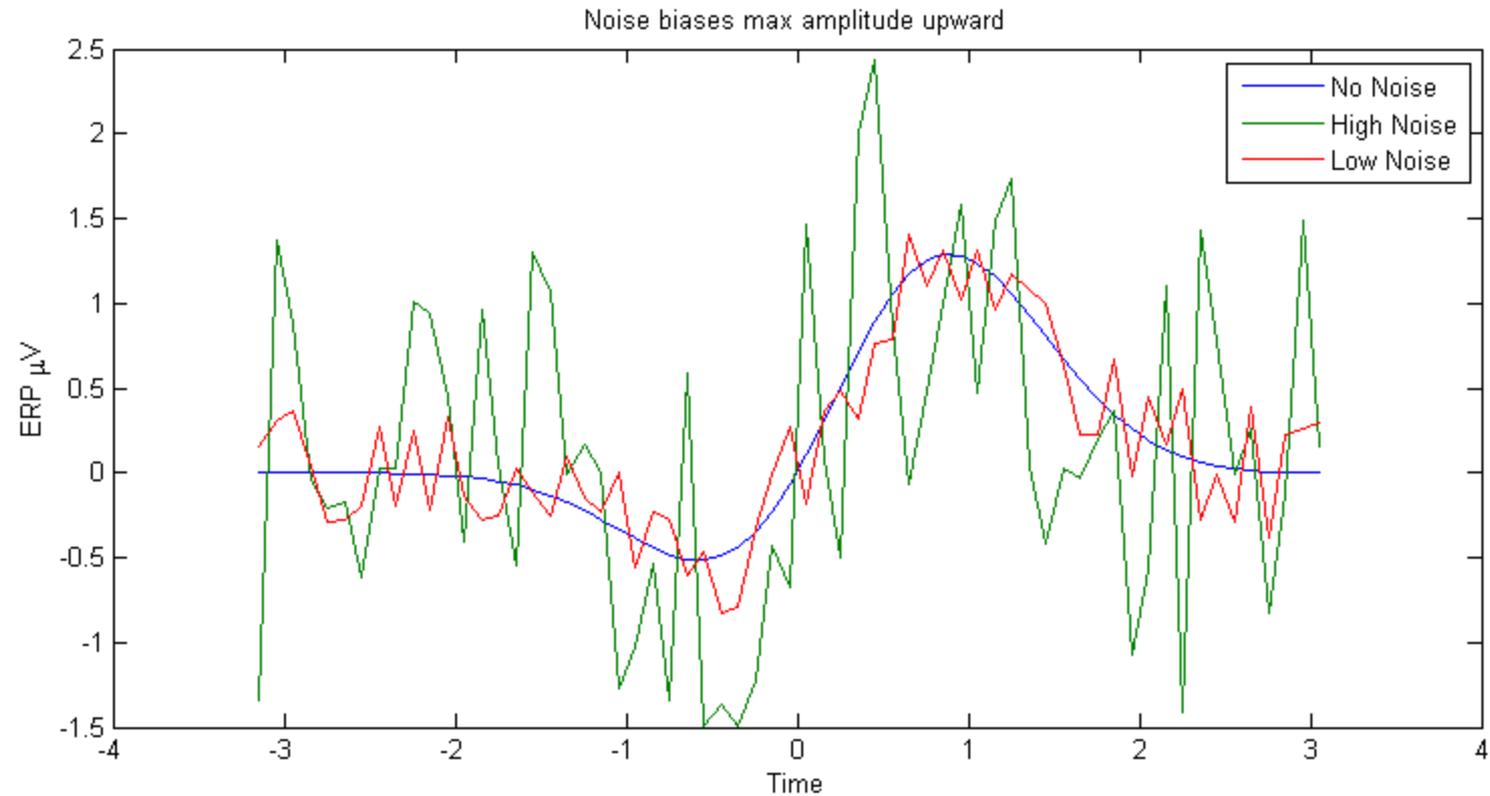
Time/Frequency



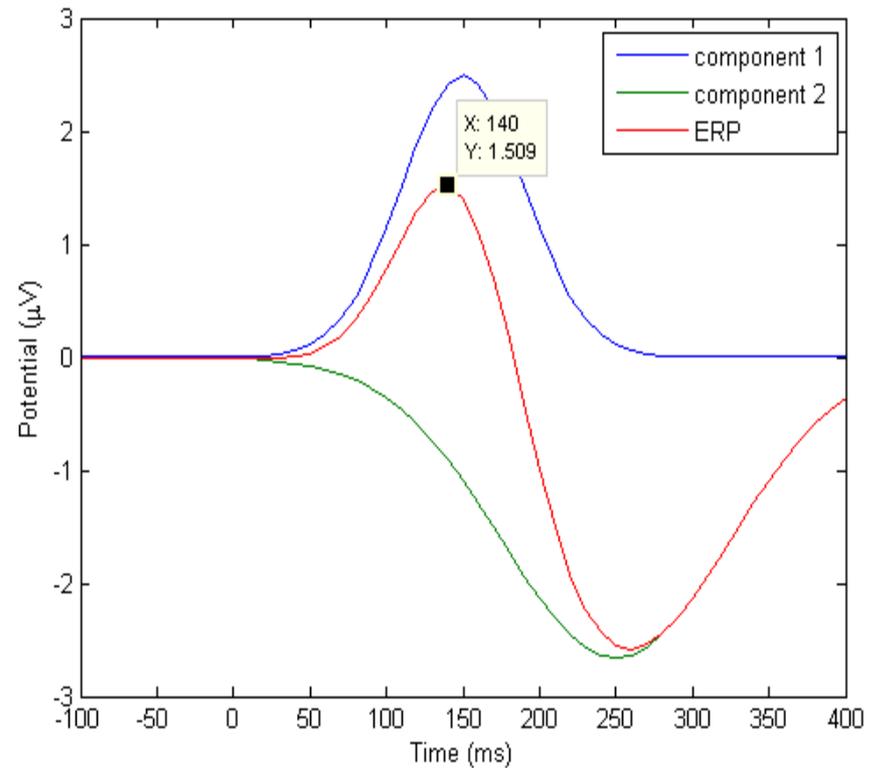
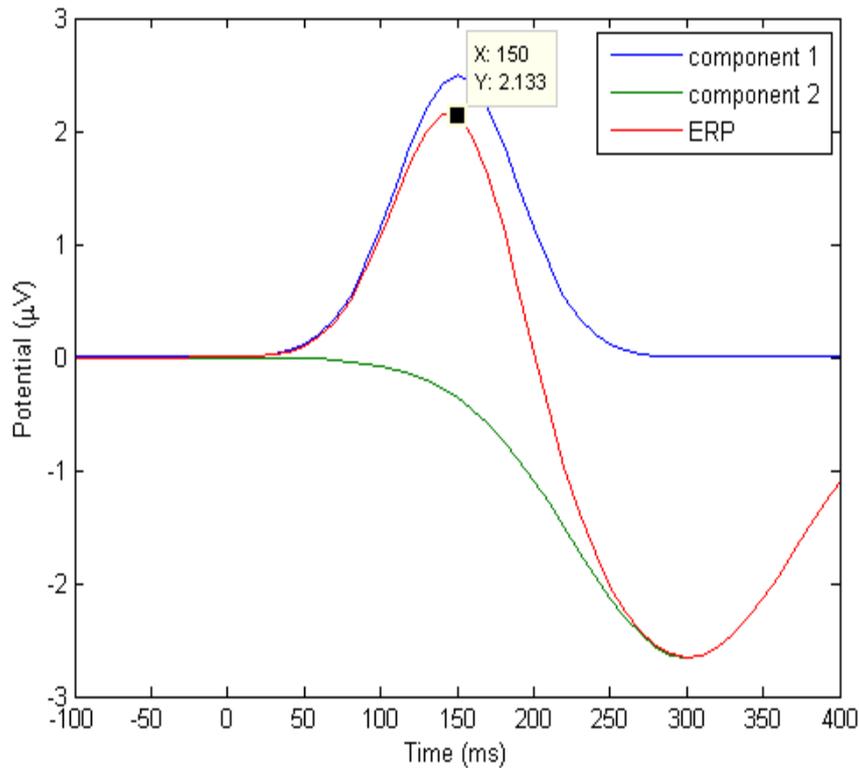
The strength of EEG is timing

- EEG has very high temporal resolution (typically 2 ms)
- EEG is best suited to hypotheses about time and frequency.
 - Speed of processing
 - Relative order of processes
 - Temporal relationships (correlation, functional connectivity)

EEG can measure amplitude

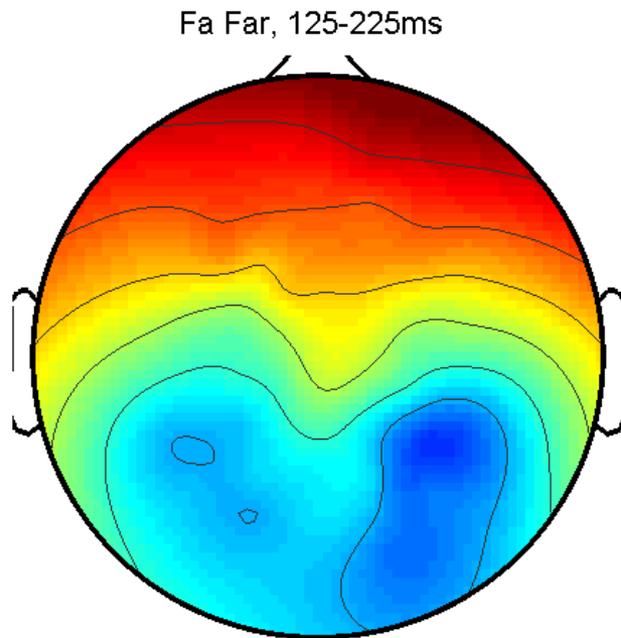


Amplitude can be tricky to interpret

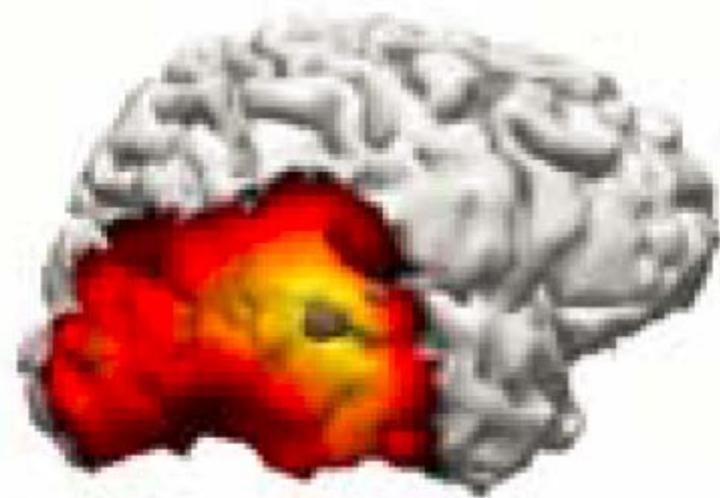


EEG can provide spatial information

Scalp Topography



Source localization



SNR = 9.48

Ponton, C. W., Bernstein, L. E., & Auer, E. T. (2009). Mismatch negativity with visual-only and audiovisual speech. *Brain Topography*, 21(3-4), 207-215.

End of EEG Basics!

- EEG measures electric potentials
- EEG signals can be used in many ways:
 - ERP
 - Frequency
 - Time/Frequency
- EEG is best-suited to hypotheses about time
- EEG can provide spatial information

DNI EEG equipment: Caps



Two caps, medium and small.
Cap layout, modified 10-20 system.
AFz ground, vertex ref
Drop electrodes: EOG*, mastoids, EMG(?)

Also some maglink caps

DNI EEG equipment: Headbox, Amps



DNI EEG equipment: Prep Options

“Quik-Gel” (Gloopy off-white paste)

- Pros:
 - Can achieve very low impedance
 - Long-lasting
- Cons:
 - Messy
 - Subject discomfort
 - Uneven quality/shelf life



“Quik-Cel” (sponges + electrolyte)

- Pros:
 - Pain-free, fast prep
 - Tidy
- Cons:
 - Higher impedance
 - Longer setup
 - Salt bridging more likely
 - Sponges dry out
 - Results depend on subject's hair type

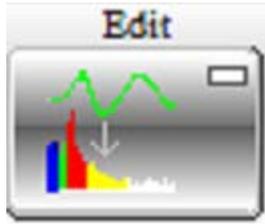


Advice for designing an experiment

- Have a solid time-locking signal
- Have a hypothesis about or including time
- You'll need a lot of trials for averaging
- Break your experiment into short blocks
- Build in lots of time for breaks

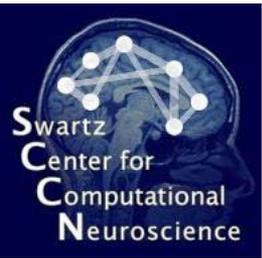
ERP analysis overview

- Available software
- The general workflow
- Demo: EDIT
- Demo: EEGLAB



Available Software: EDIT

- EDIT is commercial software from Neuroscan
 - Requires a hardware license dongle
- EDIT strengths:
 - Fairly easy point & click interface
 - Handles arbitrarily large files (*)
 - Has an associated scripting language (tcl)
- EDIT weaknesses:
 - Hodge-podge of outdated methods
 - Fills up your hard disk
 - Closed source
 - Weak user community



Available Software: EEGLAB

- EEGLAB is free software from SCCN (ucsd)
 - From the web: <http://sccn.ucsd.edu/eeglab/>
- EEGLAB strengths
 - Decent GUI
 - Runs in MATLAB
 - Open source
 - Strong user group
 - Lots of advanced methods
- EEGLAB weaknesses
 - Very RAM intensive
 - Developers very focused on ICA and T/F analyses

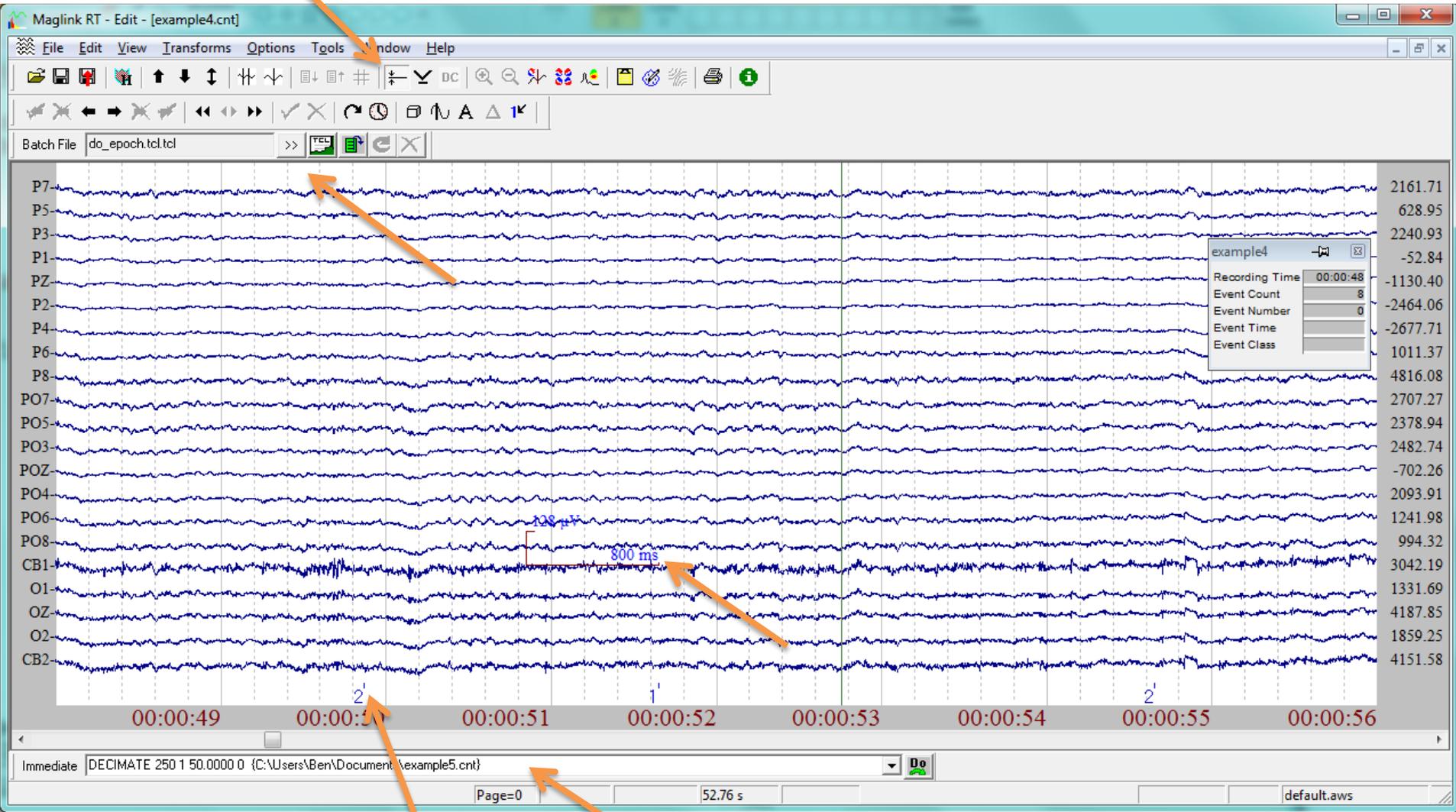
Demo analysis

- Thanks to Farhan Baluch for supplying demo data
- The example data:
 - Visual stimulus
 - Only posterior electrodes (21)
 - Vertex reference
 - 1000 Hz, 32 bits
 - Recorded here

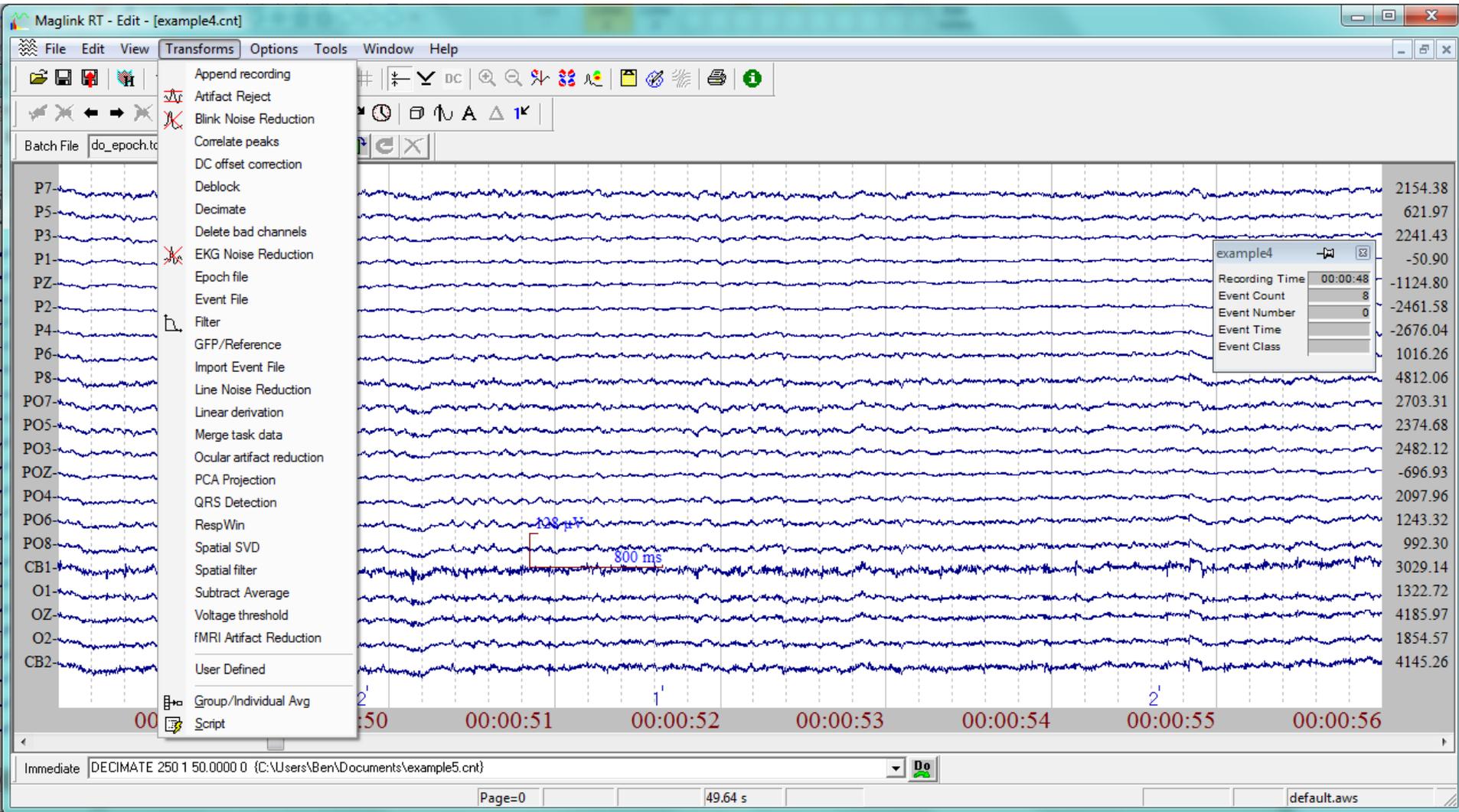
General Workflow

- Pre-process your CNT file*
 - Filtering, eyeblink artifact reduction
- Epoch
- Baseline correct
- Artifact reject
- Average
- Export measure of interest

Demo using EDIT: A CNT file



The action is in the transforms menu



Transforms -> epoch

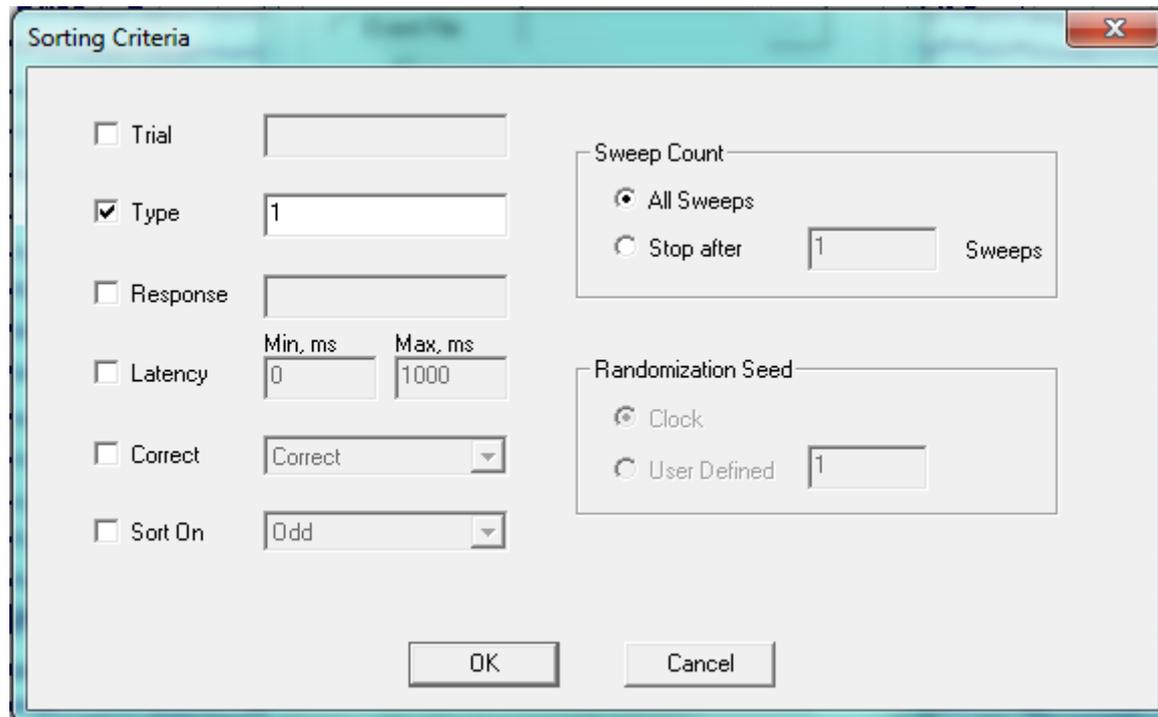
The screenshot displays the Maglink RT software interface. The main window shows a multi-channel EEG plot with channels labeled P7, P5, P3, P1, PZ, P2, P4, P6, P8, PO7, PO5, PO3, POZ, PO4, PO6, PO8, CB1, O1, OZ, O2, and CB2. The time axis at the bottom is marked from 00:00:01 to 00:00:08. A dialog box titled "Epoching Properties" is open in the center, with the following settings:

- Mode: Port/Internal, No Trigger, Event File (with an empty text field and a right arrow button). A checkbox below reads "Event file offsets are in seconds".
- Interval: Minimum: -100 ms, Points: 601; Maximum: 500 ms.
- Options: Shift Interval by Response Latency; Reject Epochs that Overlap Rejected Blocks.
- Event Types: Stimulus (with a "Set Sort Criteria..." button), Response, KeyBoard.
- Output file: C:\Users\Ben\Desktop\epoch1.eeg (with a right arrow button).
- Display Dialog During Script Execution.

At the bottom of the software window, the command line shows: Immediate DECIMATE 250 1 50.0000 0 {C:\Users\Ben\Documents\example5.cnt}. The status bar at the bottom indicates Page=0, 0.49 s, and default.aws.

Recording Time	00:00:00	-1038.22
Event Count	0	-2373.25
Event Number	0	-2694.49
Event Time		1044.48
Event Class		4832.39
		2795.70
		2474.61
		2561.75
		-590.23
		2164.84
		1351.06
		1053.54
		3092.91
		1113.80
		4270.35
		1948.39
		4222.04

Set sort criteria...



The image shows a 'Sorting Criteria' dialog box with the following settings:

- Trial
- Type: 1
- Response
- Latency: Min, ms: 0; Max, ms: 1000
- Correct: Correct
- Sort On: Odd
- Sweep Count:
 - All Sweeps
 - Stop after: 1 Sweeps
- Randomization Seed:
 - Clock
 - User Defined: 1

Buttons: OK, Cancel

An epoched file (*.eeg)

The screenshot displays the Maglink RT - Edit software interface for editing an epoched EEG file named [epoch1.eeg]. The interface includes a menu bar (File, Edit, View, Transforms, Options, Tools, Window, Help), a toolbar with various editing and analysis tools, and a main workspace. The workspace shows a topographic map of electrode positions labeled P7, P5, P3, P1, P2, P2, P4, P6, P8, PO7, PO5, PO3, PO2, PO4, PO6, PO8, CB1, O1, O2, and CB2. The P1 electrode is highlighted with a blue wavy line. A status window on the right shows the following data for epoch1:

Property	Value
Accepted	50
Rejected	0
Current	1
Status	Accept
Accuracy	0
Latency	0.000
Response	0
Type	1

The bottom status bar shows the command "Immediate DELETESORT SORT41" and a "Do" button. The page number is "Page=0" and the user is "default.aws".

Baseline correction

The screenshot shows the Maglink RT - Edit software interface. The main window displays an EEG epoch plot with various channels labeled: P7, P5, P8, PO7, CB1, O1, O2, and CB2. A 'Baseline Correction' dialog box is open in the center, with the following settings:

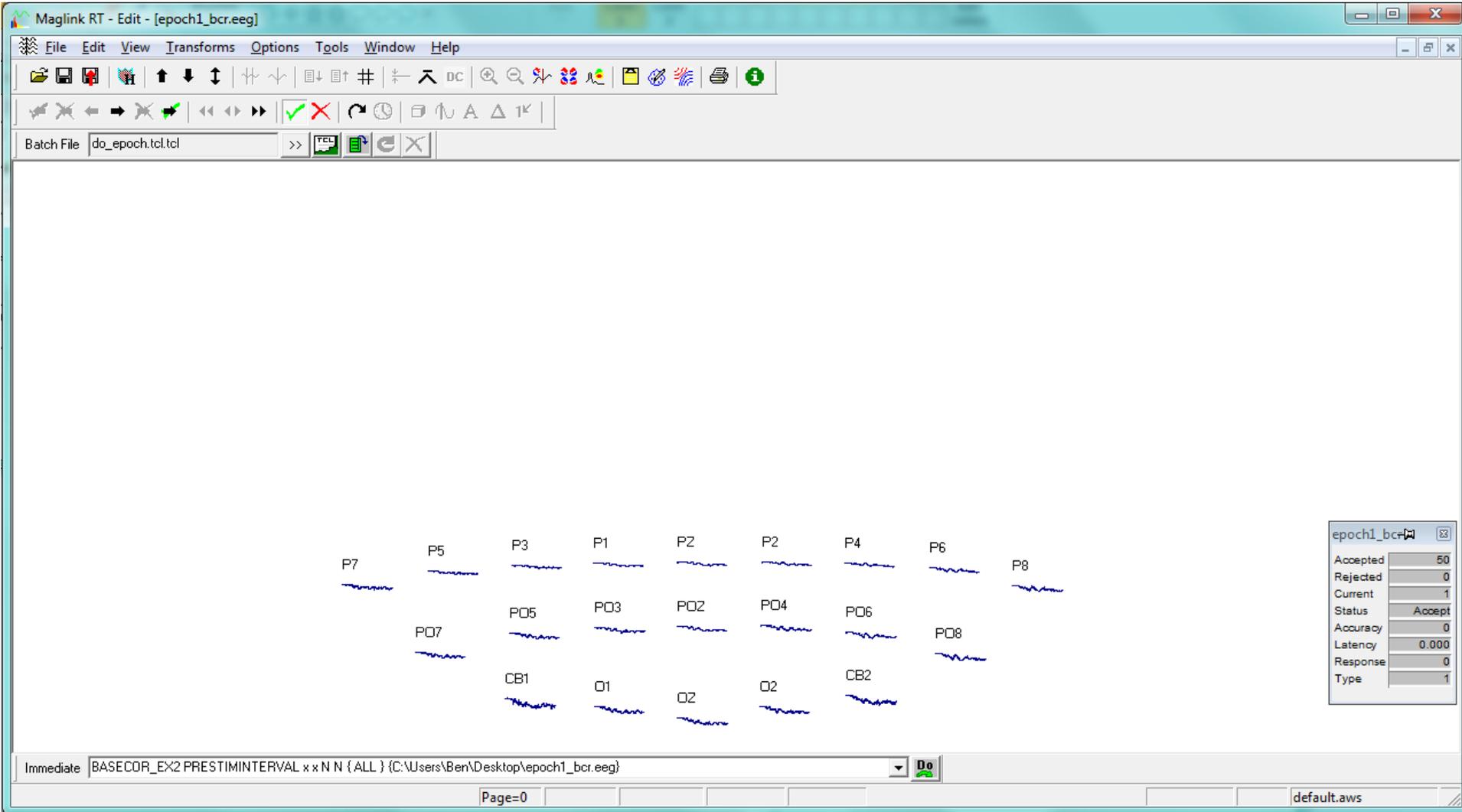
- Epoch Interval: -100.00 ... 500.00 ms
- Baseline Interval: First Point, Pre Stim Interval, Entire Sweep, User Defined
- Start (ms): End (ms):
- Channels: All, Specified (with a 'Select' button)
- Don't Correct: Bad Channels, Skipped Channels
- Output file: >>
- Display Dialog During Script Execution
- Buttons: OK, Cancel

On the right side of the plot, there is a small table for 'epoch1':

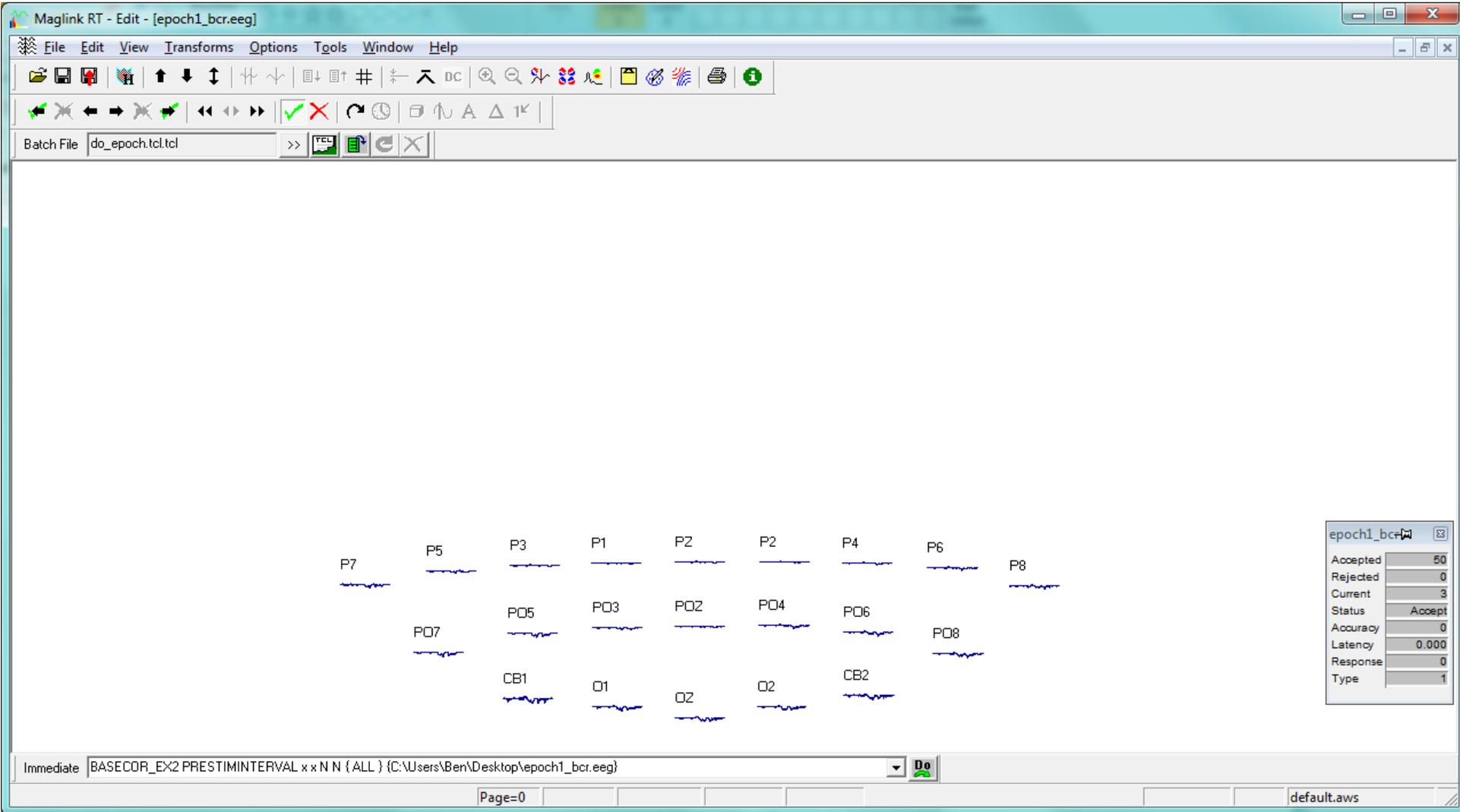
epoch1	
Accepted	50
Rejected	0
Current	1
Status	Accept
Accuracy	0
Latency	0.000
Response	0
Type	1

At the bottom of the window, the 'Immediate' command line contains 'DELETESORT SORT41'. The status bar at the very bottom shows 'Page=0' and 'default.aws'.

Epoch 1



Epoch 3



Artifact Rejection

Artifact Rejection

Epoch Interval

-100.00 ... 500.00 ms

Operation

Reject On Criteria Reject All Accept All Accept on Criteria

Reject Interval

Entire Sweep User Defined

Start (ms) End (ms)

Criteria

Time Domain

 Min (uV) Max(uV)

Frequency Domain

 Start [Hz] Stop [Hz] Max(uV)

Sweeps that do not meet criteria

Retain status Modify status

Channels

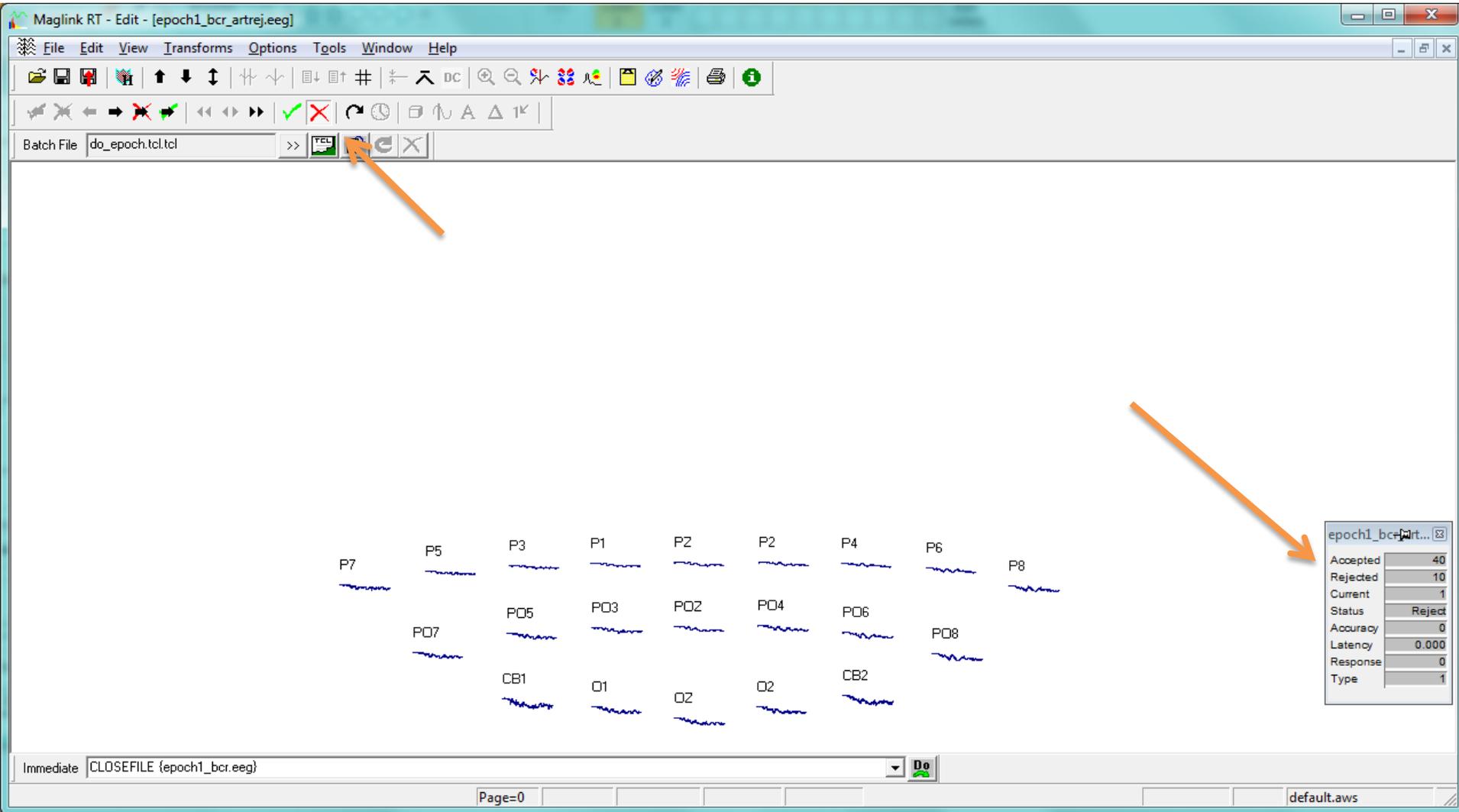
All Specified

Don't Reject On

Bad Channels Skipped Channels

Display Dialog During Script Execution

After artifact rejection



averaging

Averaging

Time Domain

Frequency Domain

Scaling

Amplitude Power

Window

Length [%] Resolution Duration

Type Range Points

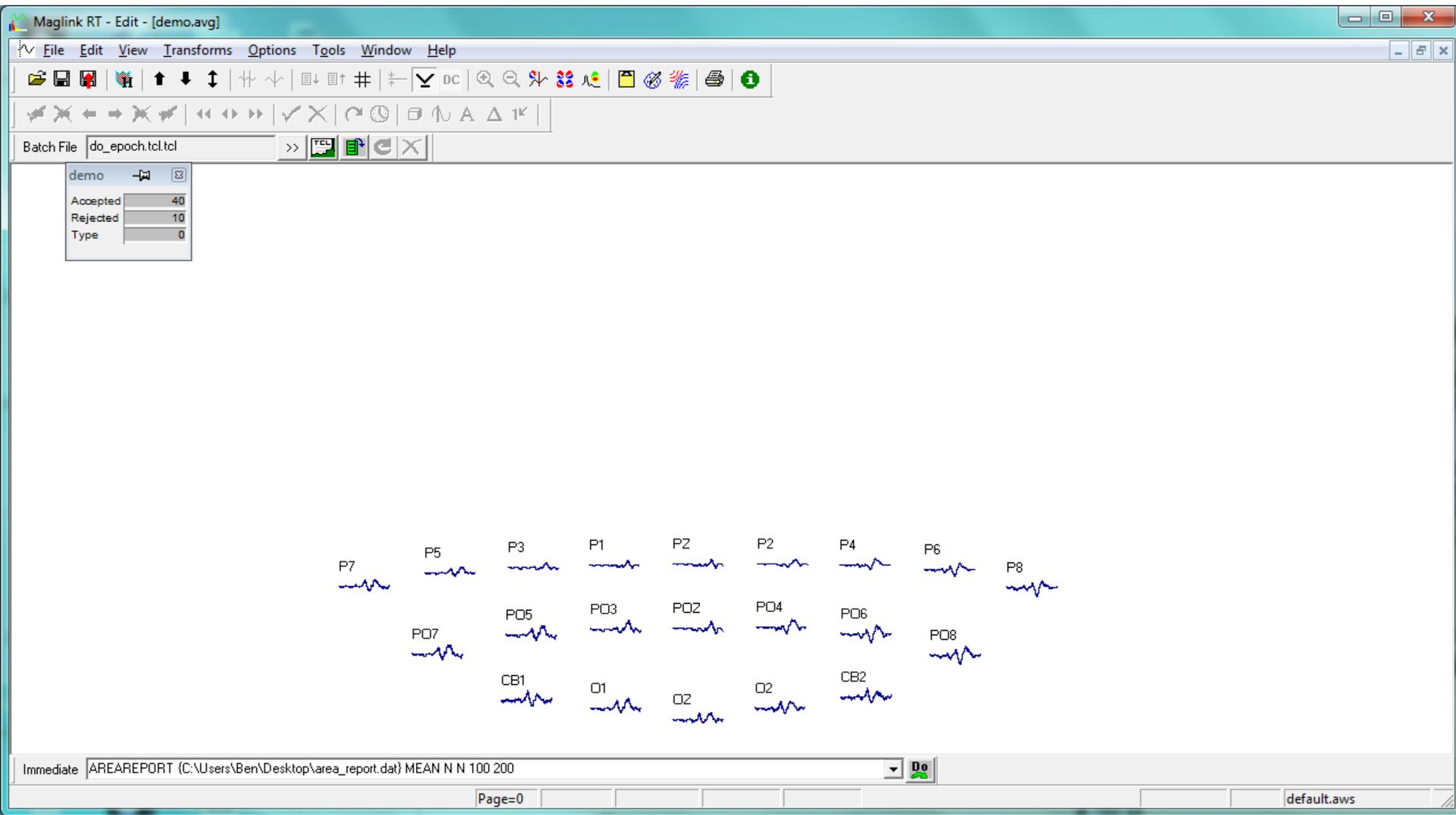
Options

Compute Standard Deviation

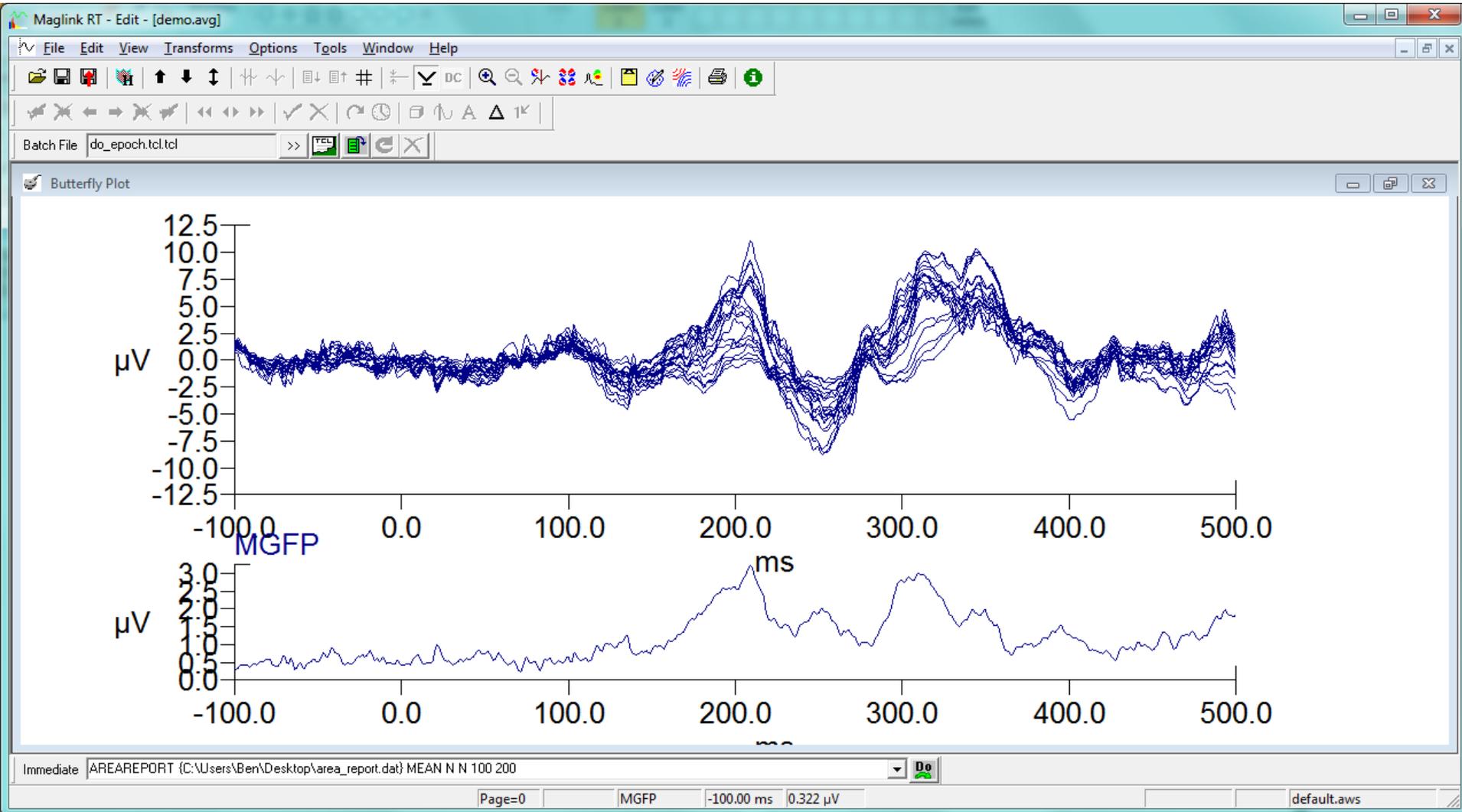
Output file

Display Dialog During Script Execution

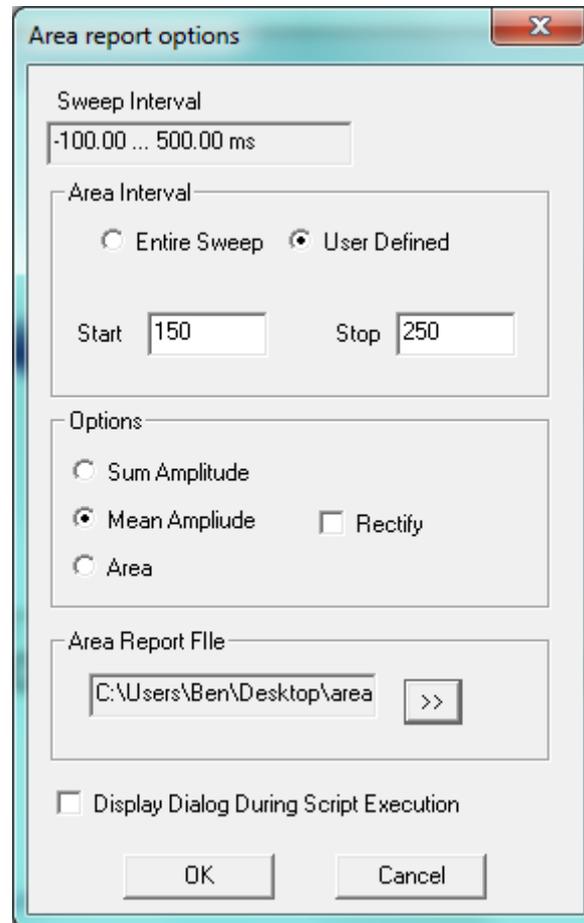
There's your ERP



Right-click -> butterfly plot



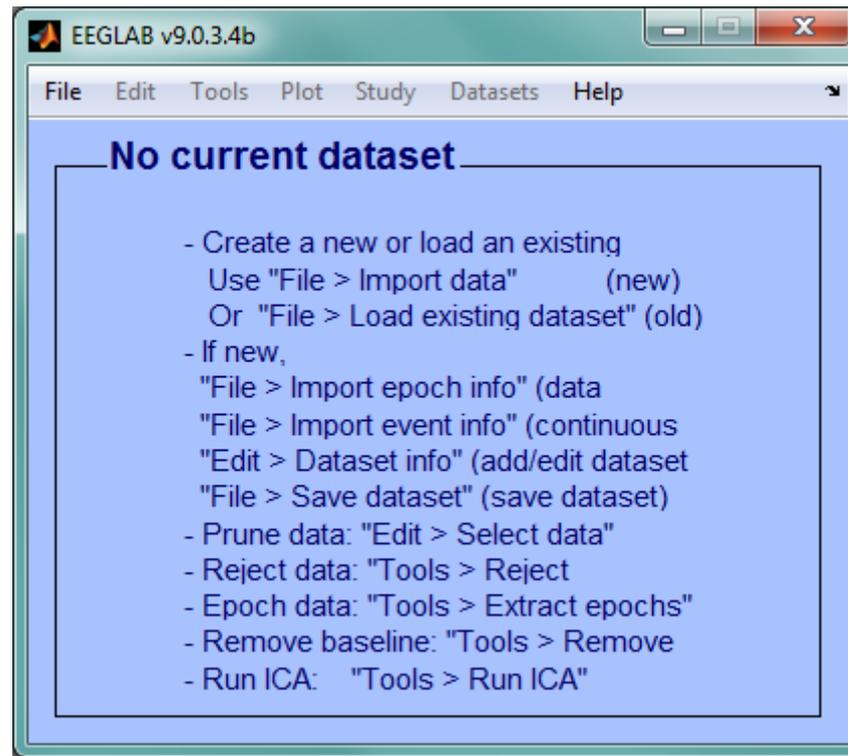
Export for hypothesis testing



Here's an area report

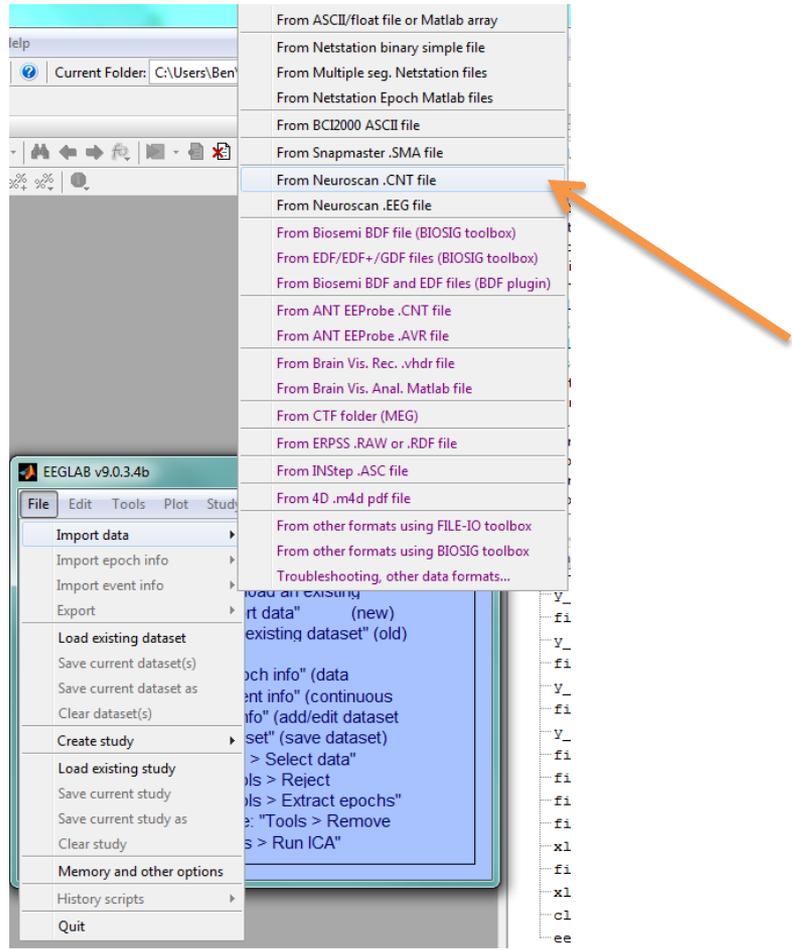
Sweep Number	Channel	Mean (175.00->225.00ms)
1	P7	4.690564
1	P5	3.174123
1	P3	0.730975
1	P1	-0.231918
1	PZ	-1.183108
1	P2	-0.863040
1	P4	0.089758
1	P6	1.402170
1	P8	2.635723
1	PO7	4.648739
1	PO5	4.478690
1	PO3	1.482446
1	POZ	-0.636791
1	PO4	0.022323
1	PO6	1.946077
1	PO8	3.224173
1	CB1	5.995599
1	O1	5.090222
1	OZ	3.403352
1	O2	4.255494
1	CB2	4.972079

Demo using EEGLAB

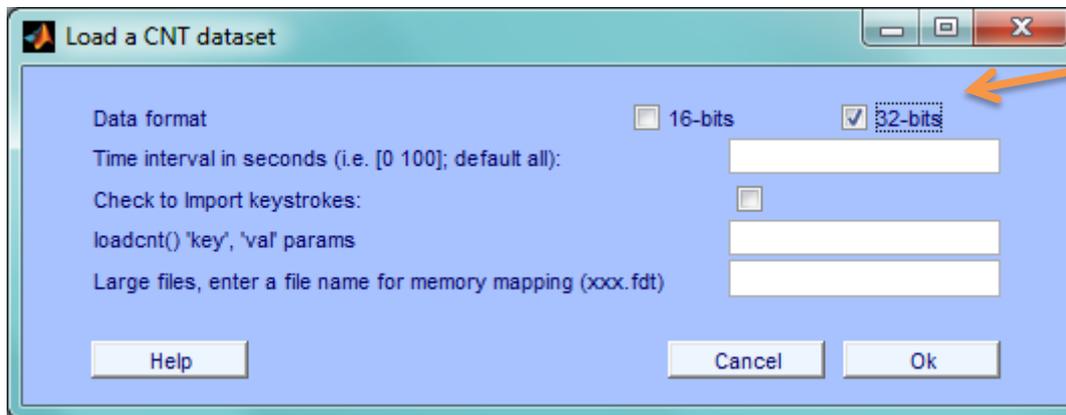


Matlab:
>>eeglab

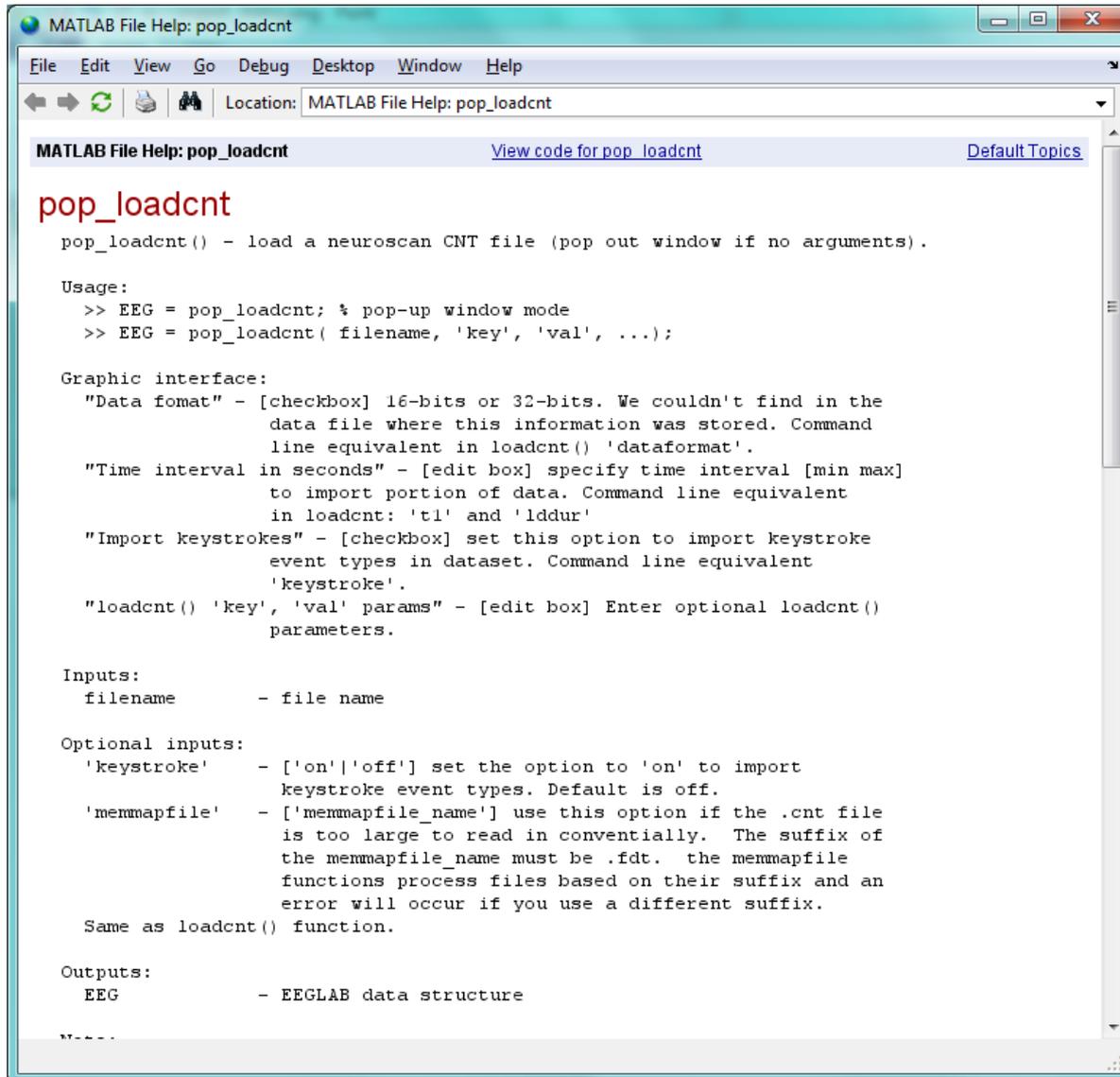
File>import data>from neuroscan .cnt



32 bits!



Help tells you how to do it with scripts



The image shows a screenshot of the MATLAB File Help window for the `pop_loadcnt` function. The window title is "MATLAB File Help: pop_loadcnt". The menu bar includes File, Edit, View, Go, Debug, Desktop, Window, and Help. The location bar shows "MATLAB File Help: pop_loadcnt". The main content area displays the function name `pop_loadcnt` in red, followed by a description: "pop_loadcnt() - load a neuroscan CNT file (pop out window if no arguments).". Below this, the "Usage:" section shows two command-line examples: `>> EEG = pop_loadcnt; % pop-up window mode` and `>> EEG = pop_loadcnt(filename, 'key', 'val', ...);`. The "Graphic interface:" section lists several options: "Data format" (checkbox), "Time interval in seconds" (edit box), "Import keystrokes" (checkbox), and "loadcnt() 'key', 'val' params" (edit box). The "Inputs:" section lists "filename" as the file name. The "Optional inputs:" section lists "keystroke" (set to 'on' or 'off'), "memmapfile" (use if file is too large), and "Same as loadcnt() function." The "Outputs:" section lists "EEG" as the EEGLAB data structure.

```
MATLAB File Help: pop_loadcnt
File Edit View Go Debug Desktop Window Help
Location: MATLAB File Help: pop_loadcnt
MATLAB File Help: pop_loadcnt View code for pop_loadcnt Default Topics
pop_loadcnt
pop_loadcnt() - load a neuroscan CNT file (pop out window if no arguments).

Usage:
>> EEG = pop_loadcnt; % pop-up window mode
>> EEG = pop_loadcnt( filename, 'key', 'val', ...);

Graphic interface:
"Data format" - [checkbox] 16-bits or 32-bits. We couldn't find in the
data file where this information was stored. Command
line equivalent in loadcnt() 'dataformat'.
"Time interval in seconds" - [edit box] specify time interval [min max]
to import portion of data. Command line equivalent
in loadcnt: 't1' and 'lddur'
"Import keystrokes" - [checkbox] set this option to import keystroke
event types in dataset. Command line equivalent
'keystroke'.
"loadcnt() 'key', 'val' params" - [edit box] Enter optional loadcnt()
parameters.

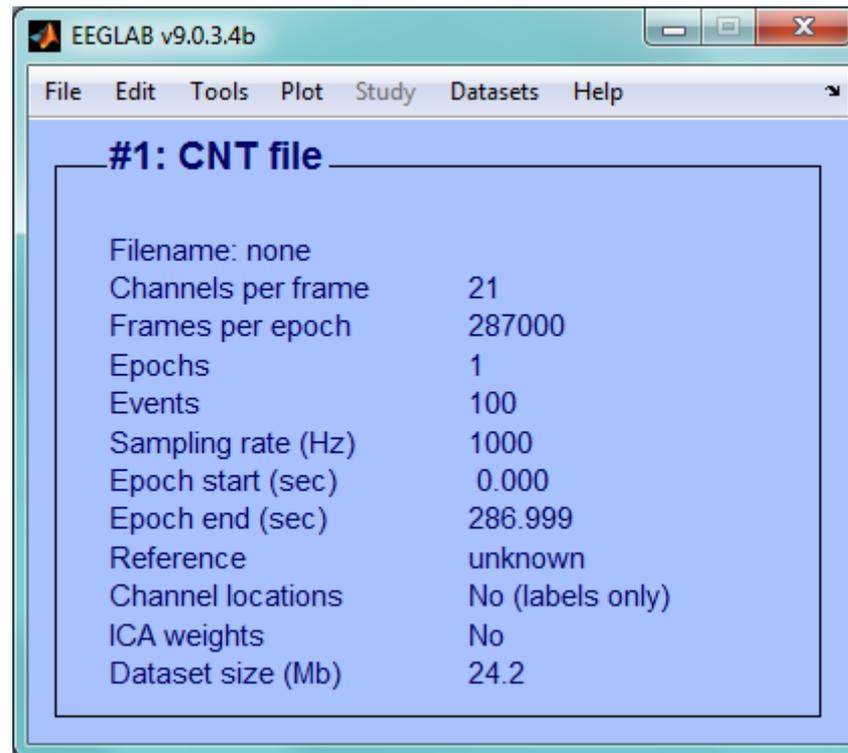
Inputs:
filename - file name

Optional inputs:
'keystroke' - ['on'|'off'] set the option to 'on' to import
keystroke event types. Default is off.
'memmapfile' - ['memmapfile_name'] use this option if the .cnt file
is too large to read in conventionally. The suffix of
the memmapfile_name must be .fdt. the memmapfile
functions process files based on their suffix and an
error will occur if you use a different suffix.

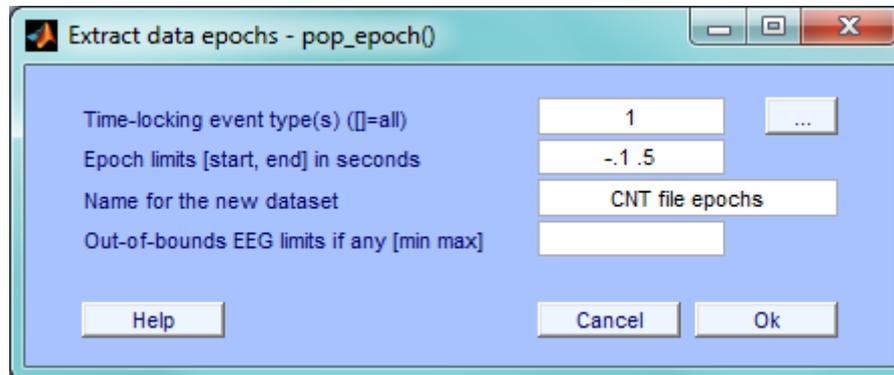
Same as loadcnt() function.

Outputs:
EEG - EEGLAB data structure
```

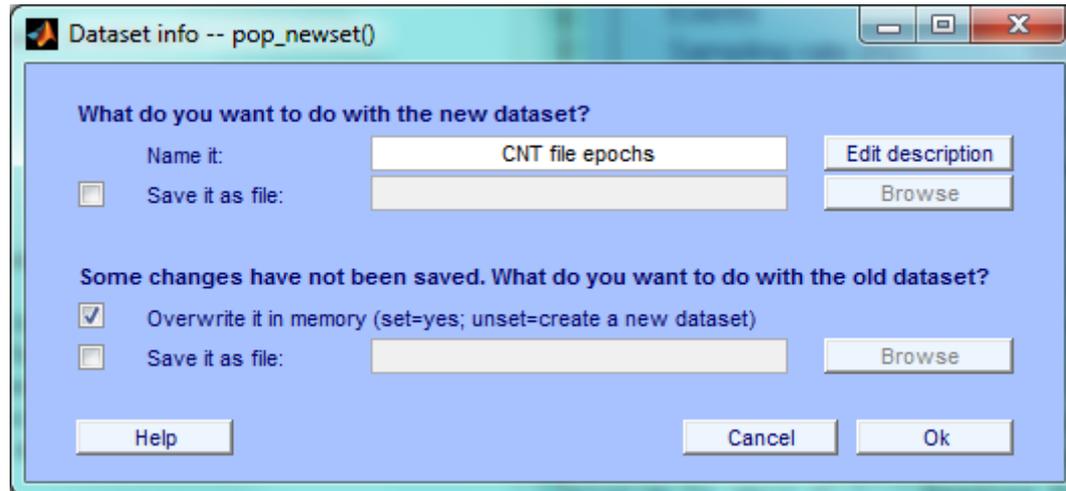
Now the data's in.



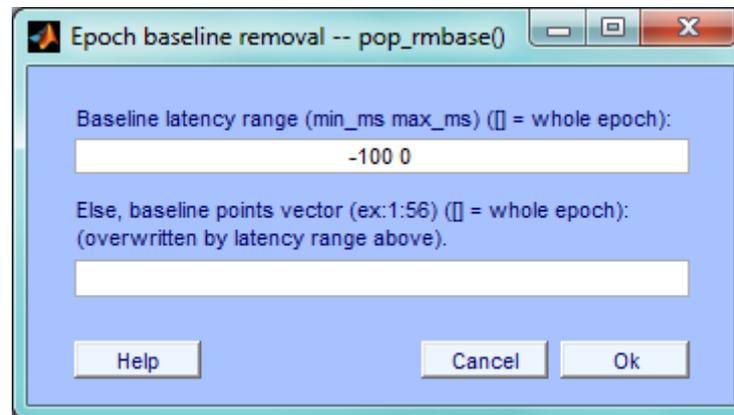
Tools > extract epochs



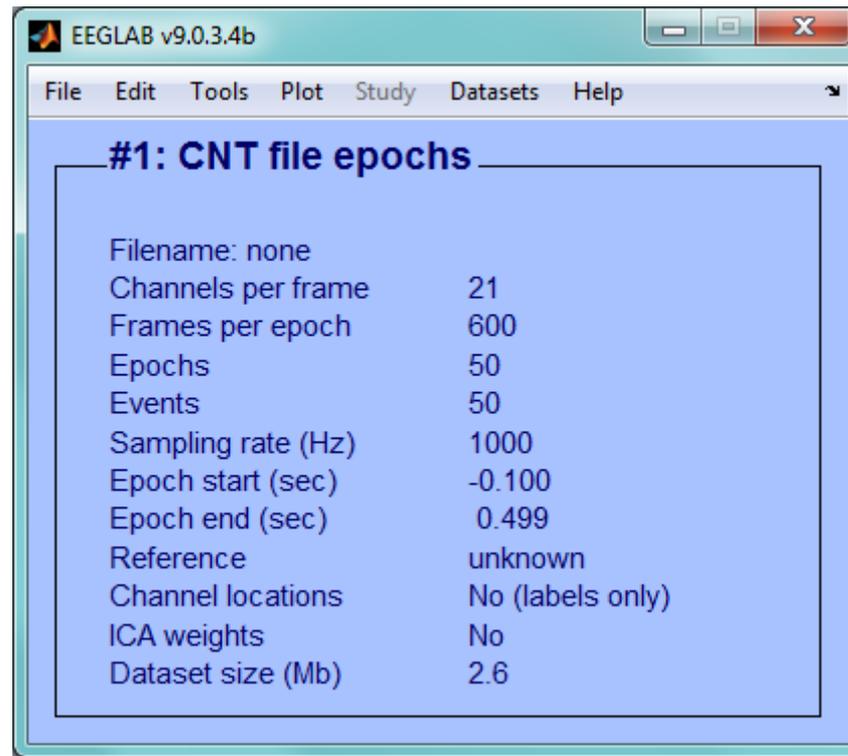
You can choose to overwrite, save, rename etc.



It knows baseline correction is next



Check number of sweeps etc.



The screenshot shows the EEGLAB v9.0.3.4b software interface. The window title is 'EEGLAB v9.0.3.4b'. The menu bar includes 'File', 'Edit', 'Tools', 'Plot', 'Study', 'Datasets', and 'Help'. The main content area displays the parameters for '#1: CNT file epochs'.

Filename:	none
Channels per frame	21
Frames per epoch	600
Epochs	50
Events	50
Sampling rate (Hz)	1000
Epoch start (sec)	-0.100
Epoch end (sec)	0.499
Reference	unknown
Channel locations	No (labels only)
ICA weights	No
Dataset size (Mb)	2.6

Tools > reject data epochs > reject extreme values

Rejection abnormal elec. values -- pop_eegthresh()

Electrode (number(s), Ex: 2 4 5):	1:21
Lower limit(s) (uV, Ex: -20 -10 -15):	-50
Upper limit(s) (uV, Ex: 20 10 15):	50
Start time(s) (seconds, Ex -0.1 0.3):	-0.1
End time(s) (seconds, Ex 0.2):	0.499
Display with previously marked rejections? (YES or NO)	NO
Reject marked trial(s)? (YES or NO)	YES

Help Cancel Ok

Plot > channel erp image

(many plots are unavailable w/o locations)

Channel ERP image -- pop_erpimage()

Channel: 1
Smoothing: 10
Downsampling: 1
Time limits (ms): -100 499

Figure title:

Plot scalp map
 Plot ERP
 Plot colorbar

ERP limits (uV):
Color limits (see Help):

Sort/align trials by epoch event values

Epoch-sorting field: Event type(s): Event time range: Rescale: no Align:

Don't sort by value
 Don't plot values

Sort trials by phase

Frequency (Hz | minHz maxHz): 8 12
Percent low-amp. trials to ignore: 0
Window center (ms): 200
Wavelet cycles: 3

Inter-trial coherence options

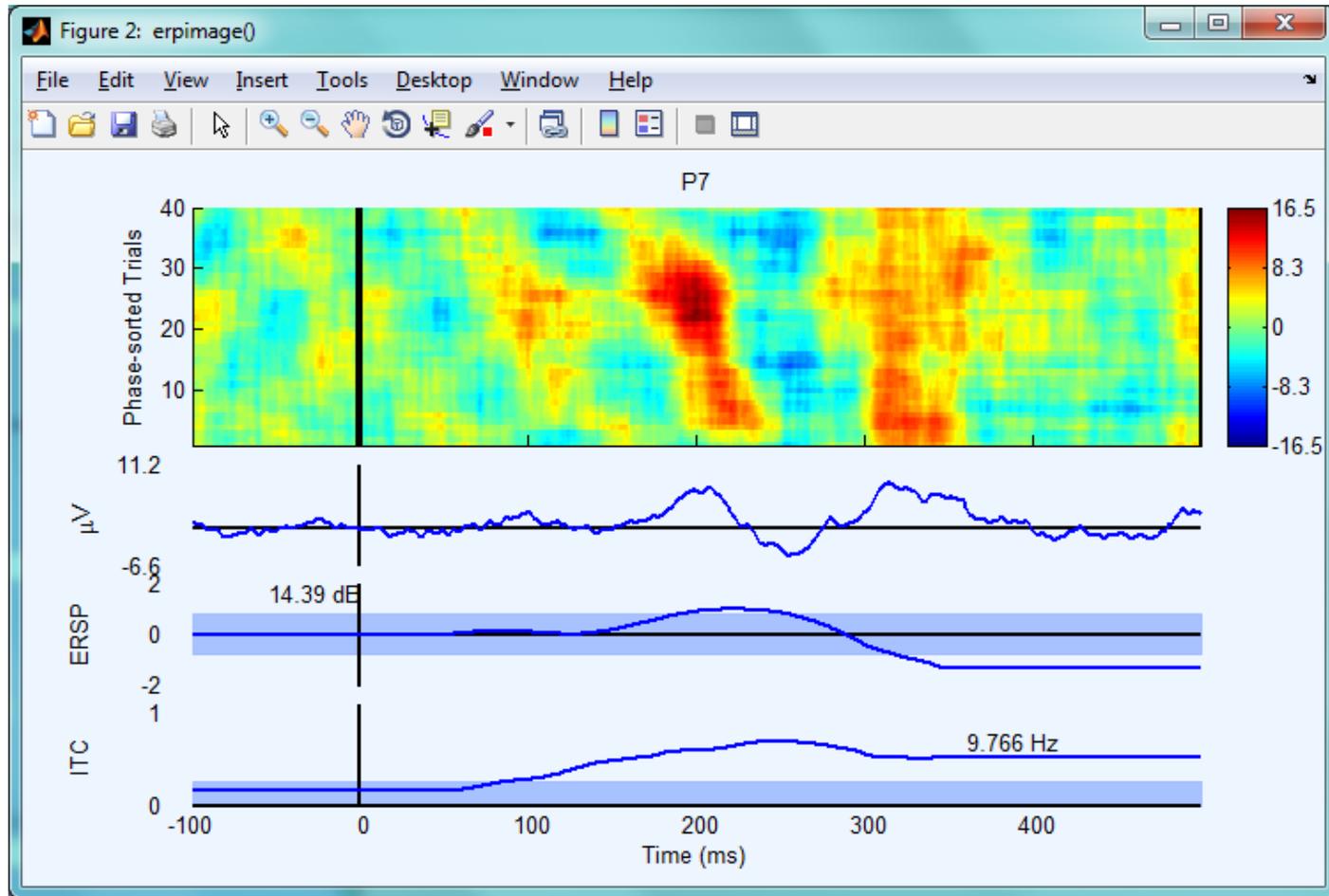
Frequency (Hz | minHz maxHz): 8 12
Signif. level (<0.20): 0.05
Amplitude limits (dB):
Coher limits (<=1):
 Image amps (Requires signif.)

Other options

Plot spectrum (minHz maxHz):
Baseline ampl. (dB):
Mark times (ms):
More options (see >> help erpimage):

Help Cancel Ok

See help messages for what all these mean



All this & more in CLI (EEG struct holds everything)

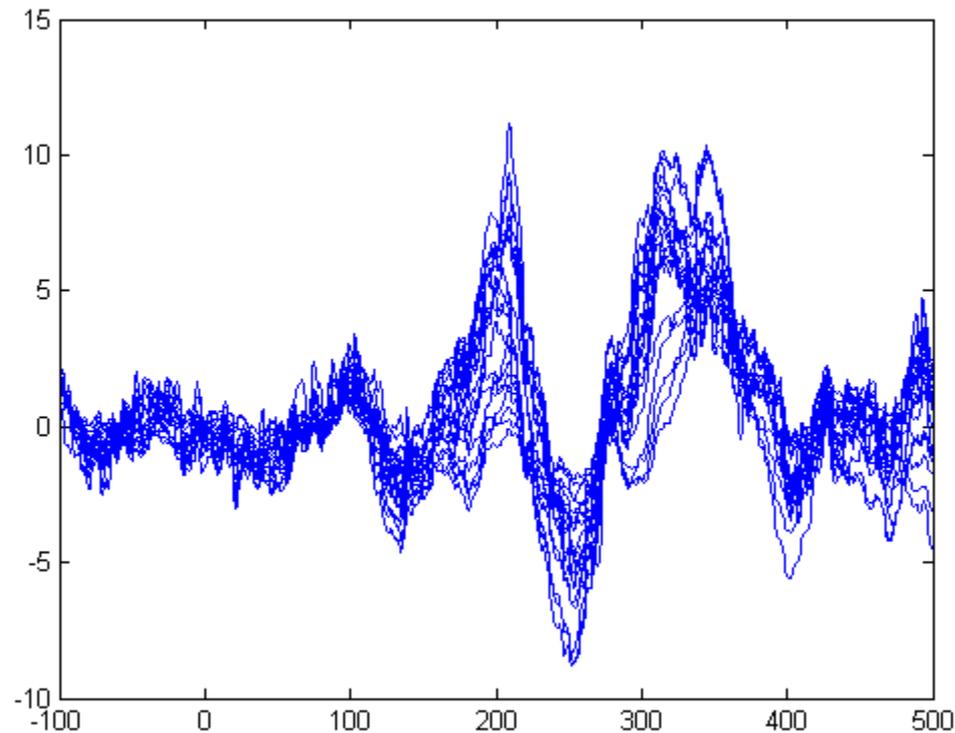
```
>> i1 = find(EEG.times>=175,1); i2 = find(EEG.times>=225,1);  
>> ERP = mean(EEG.data,3);  
>> mean_volts = mean(ERP(:,i1:i2),2)
```

```
mean_volts =
```

```
4.6884  
3.1726  
0.7312  
-0.2285  
-1.1829  
-0.8637  
0.0870  
1.3938  
2.6218  
4.6386  
4.4706  
1.4810  
-0.6342  
0.0185  
1.9373  
3.2168  
5.9935  
5.0837  
3.3981  
4.2518  
4.9725
```

```
>>
```

Use CLI to get a butterfly plot



```
>> figure; plot(EEG.times,mean(EEG.data,3),'b')
```

Advanced topics

- Permutation Testing
- Using all your electrodes
- Independent Components Analysis
- Source analysis

Permutation testing

- Null hypothesis:
 - There is NO DIFFERENCE between datasets A and B
- Logic:
 - If there is no difference, re-assigning data points from set A to B (and vice-versa) should not affect the outcome of any test
- Procedure:
 - Relabel datapoints to create pseudo-sets of A & B
 - Compare a statistic (e.g. t) for the actual dataset to that same statistic for your pseudo-sets
 - If the proportion of pseudo-sets generating a test statistic more extreme than your actual statistic is low (less than p), reject the null hypothesis

Example:

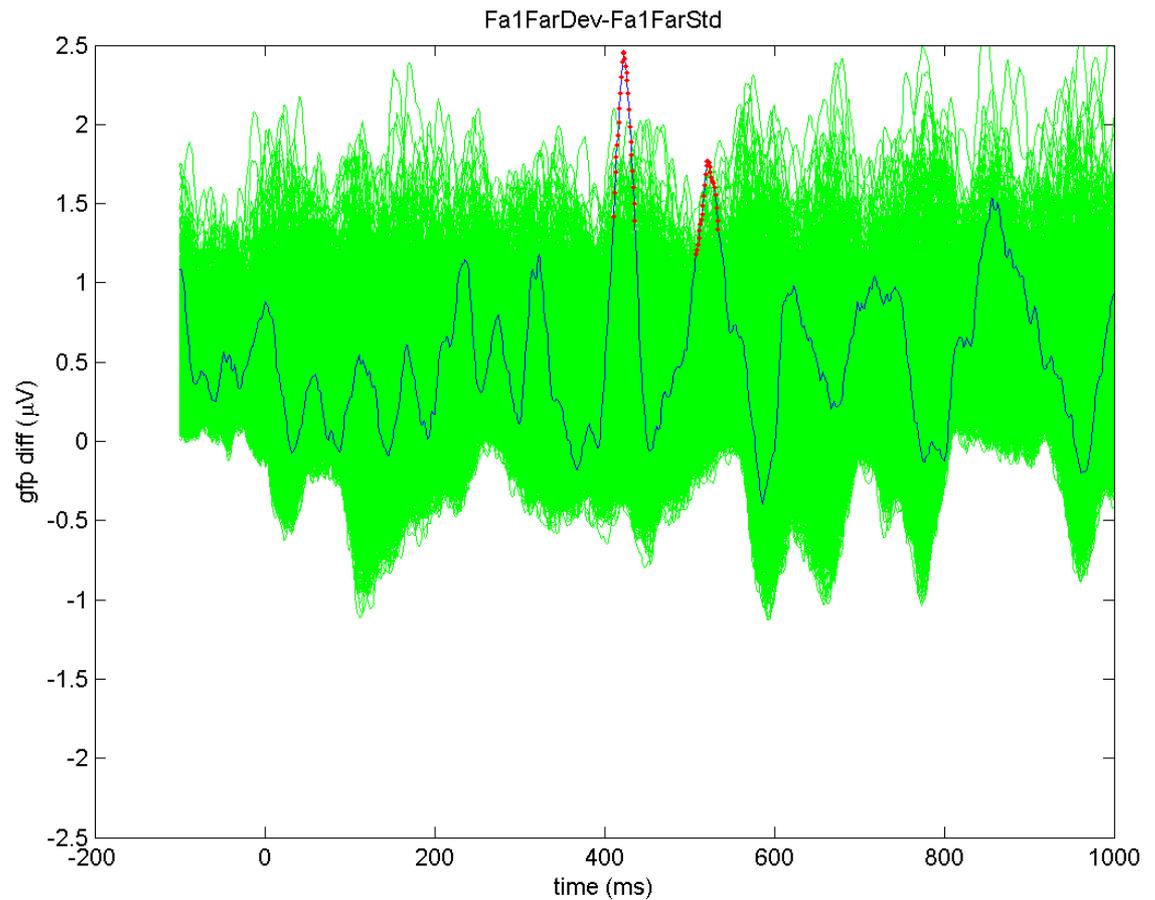
100 'deviant' trials

1000 'standard' trials

Create pseudo-sets by taking all 1100 trials and randomly assigning 100 to be called 'deviant'.

Compute my measure (here, GFP difference) on ~2000 re-labelings

Compare the null distribution to my actual result



Nichols, T. E., & Holmes, A. P. (2002). Nonparametric permutation tests for functional neuroimaging: a primer with examples. *Human Brain Mapping, 15(1), 1-25.*

Using all your electrodes

- Global Field Potential
 - Measures overall amount of activity at a time-point
 - Spatial RMS
- Topographic Dissimilarity
 - Summary of how different a pair of topographic maps are
 - Controls for differences in GFP

Murray, M. M., Brunet, D., & Michel, C. M. (2008). Topographic ERP analyses: a step-by-step tutorial review. *Brain Topography*, 20(4), 249-264.
- BSS/ICA
 - Finds spatial filters with recurring activity patterns

Independent Components Analysis

- Various methods exist:
 - Infomax, jader, sobi
- All seek spatial patterns in the EEG data that occur together
- Assumes observations result from a linear mixture of (unknown) sources

Source Localization

- Two problems
 - Inverse problem: Given these observations, what were the sources?
 - Forward problem: Given a source, what will the observations be?
- The solutions? Make assumptions. (Choose a model)
 - Spherical shell, 1-dipole
 - Finite element model, source current density
- Using standard methods, spatial resolution is low (on the order of 2-3 cm)
 - Fancy methods can achieve much higher spatial resolution (on the order of a few mm)

Check out Brainstorm

- <http://neuroimage.usc.edu/brainstorm/>
- Very user-friendly

