An introduction to EEG

Neuroimaging workshop

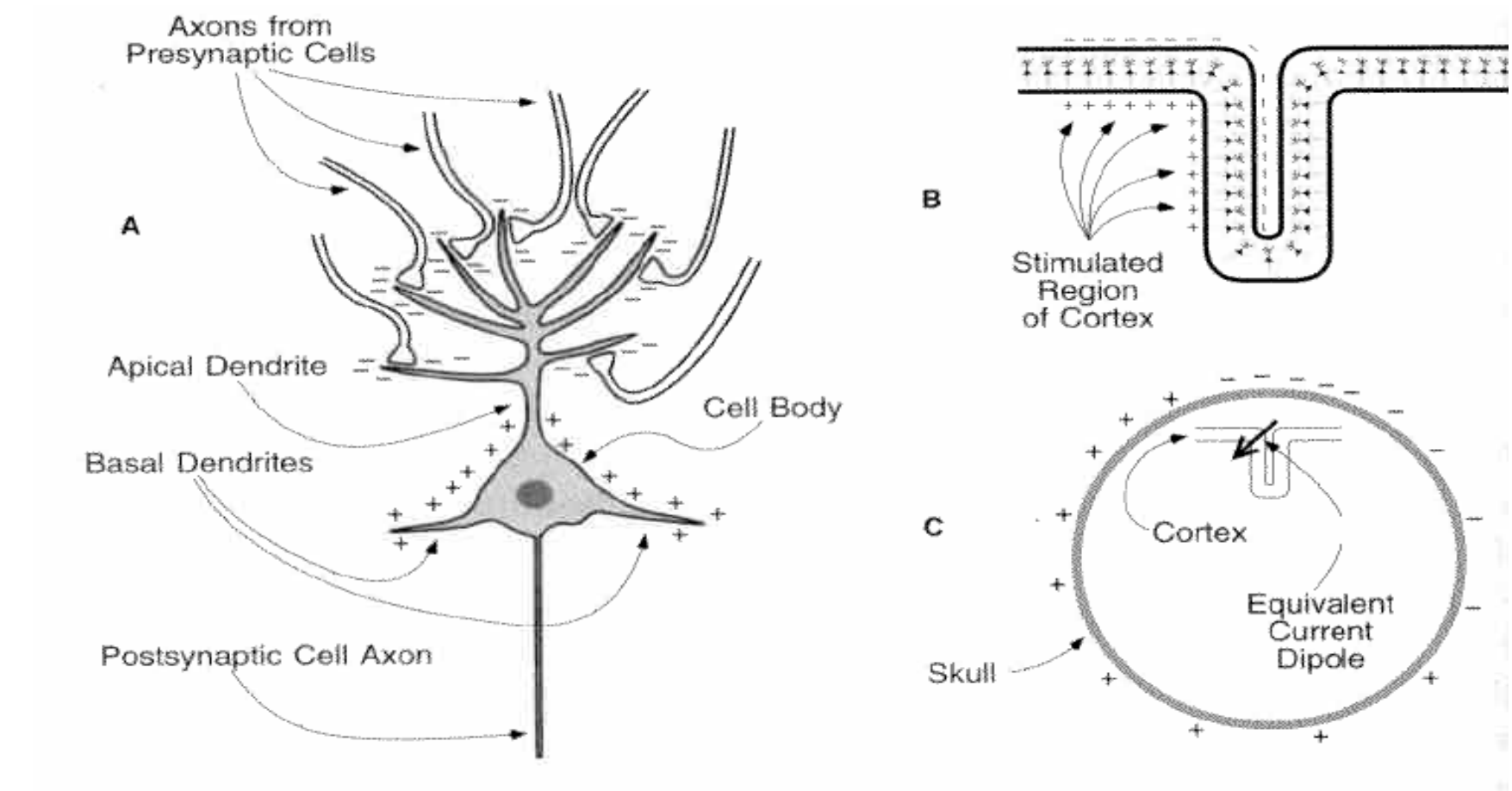
July 15, 2011

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

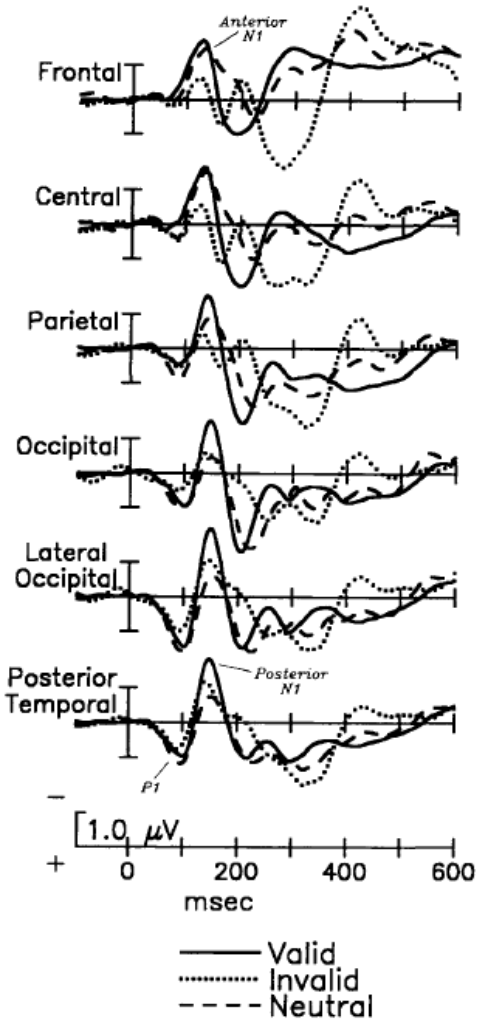


From Luck, S.J., (2005). *An Introduction to the Event-Related Potential Technique.* Cambridge, MA: MIT Press

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)

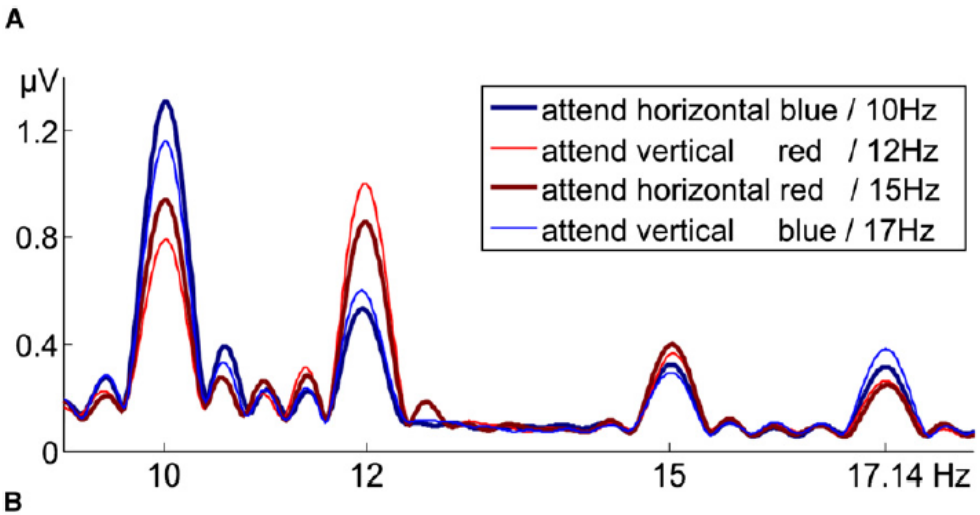
Event-related potential



- 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

Luck, S. J., Hillyard, S. A., Mouloua, M., Woldorff, M. G., Clark, V. P., & Hawkins, H. L. (1994). Effects of spatial cuing on luminance detectability: psychophysical and electrophysiological evidence for early selection. *Journal of Experimental Psychology: Human Perception and Performance, 20(4), 887-904.*

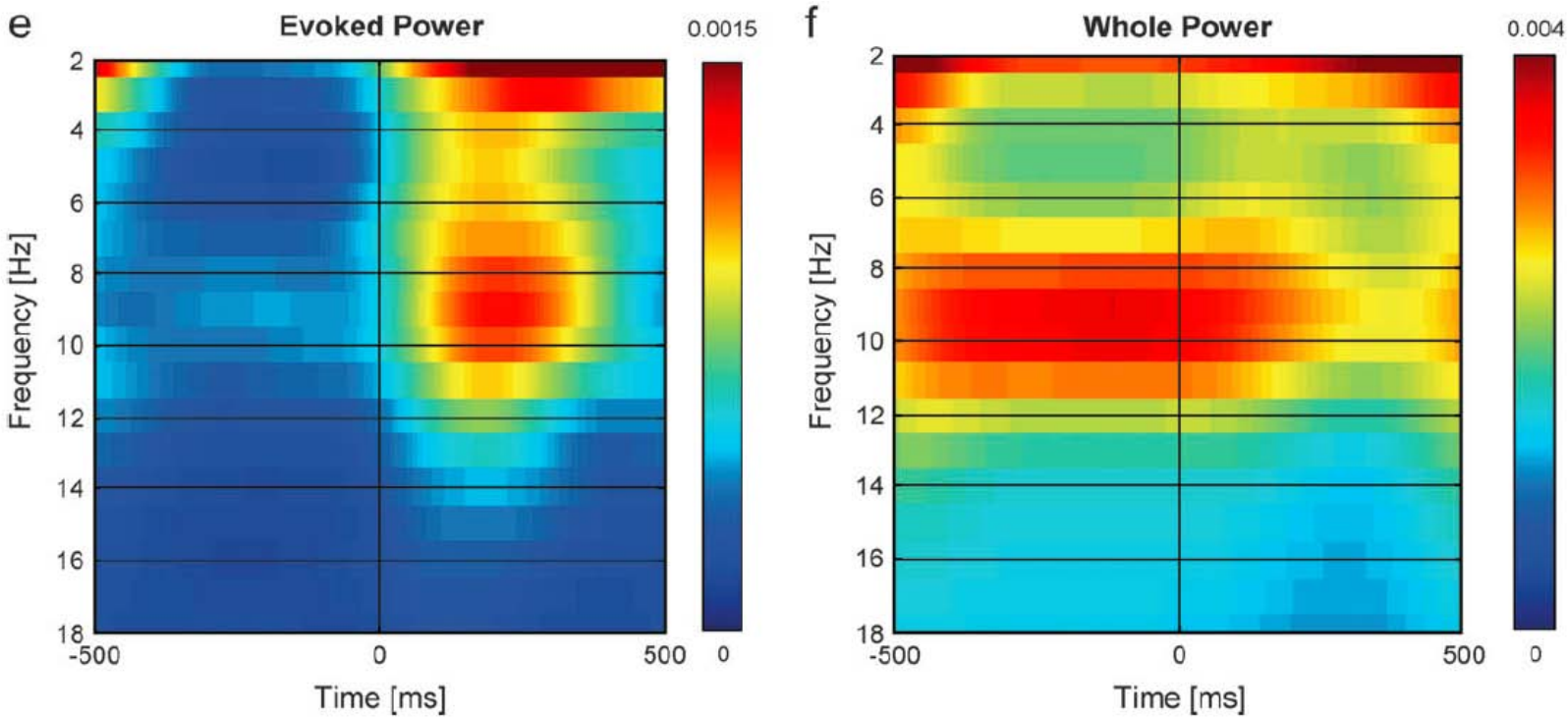
Frequency Spectrum



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)

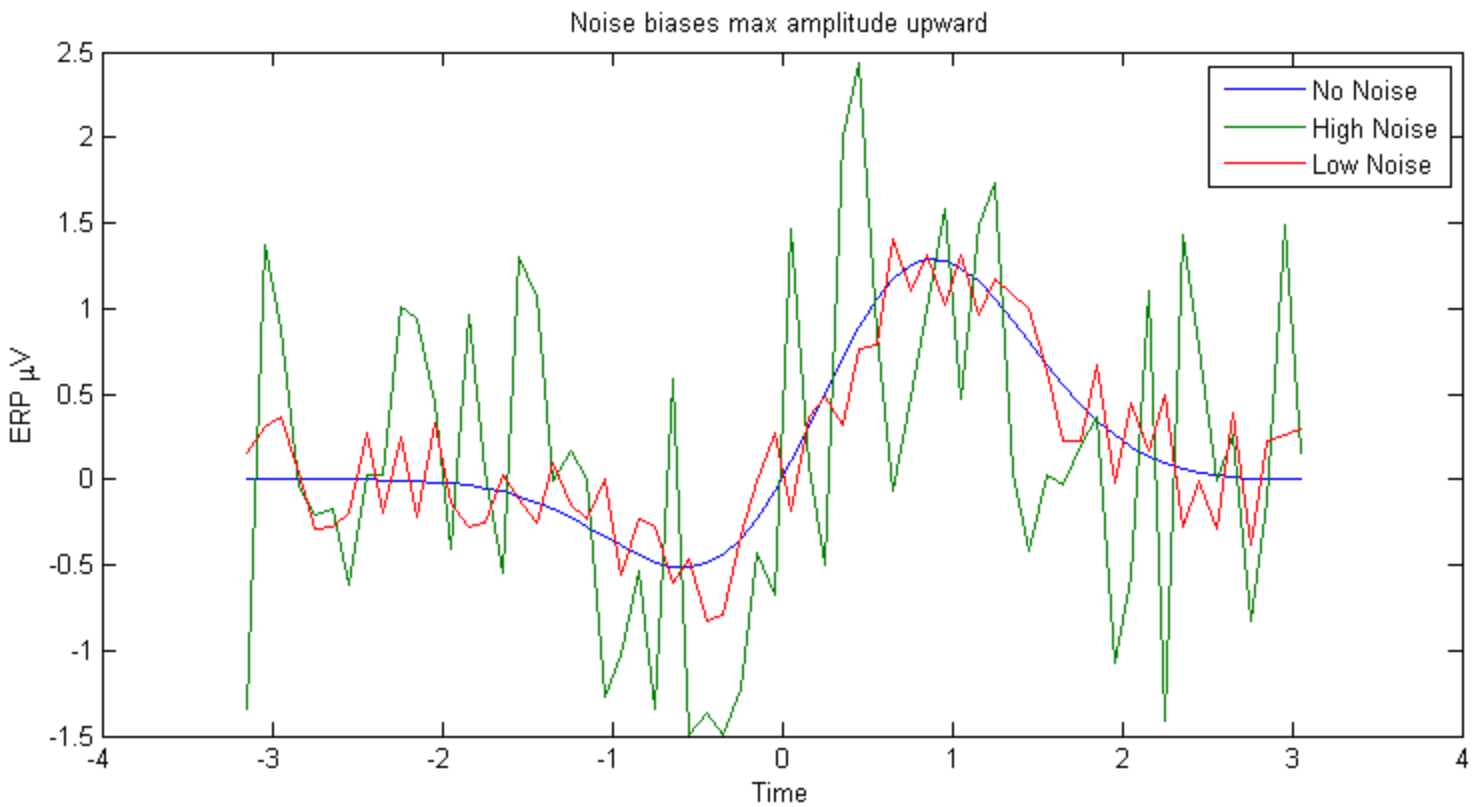
Time/Frequency



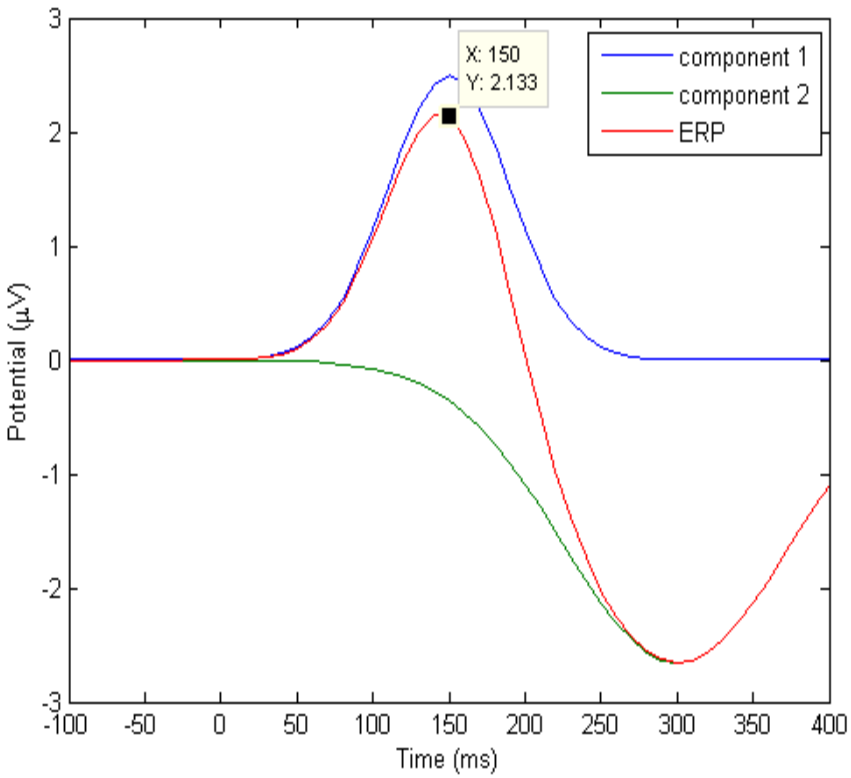
The strength of EEG is timing

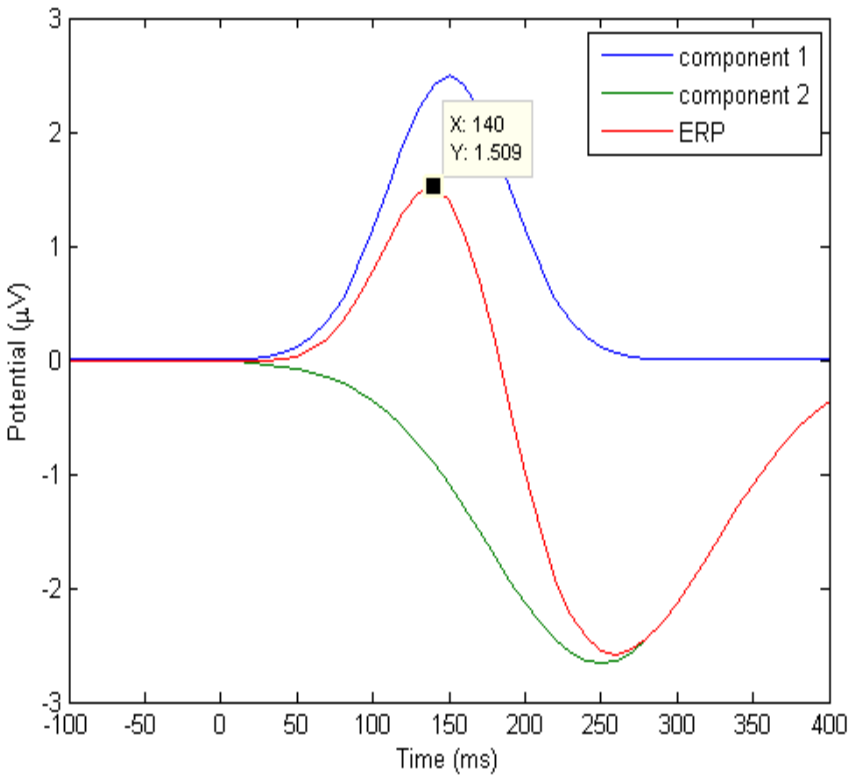
- EEG has very high temporal resolution (typically 2 ms)
- EEG is best suited to hypotheses about time and frequency.
  - Speed of processing
  - Relative order of processes
  - Temporal relationships (correlation, functional connectivity)

EEG can measure amplitude



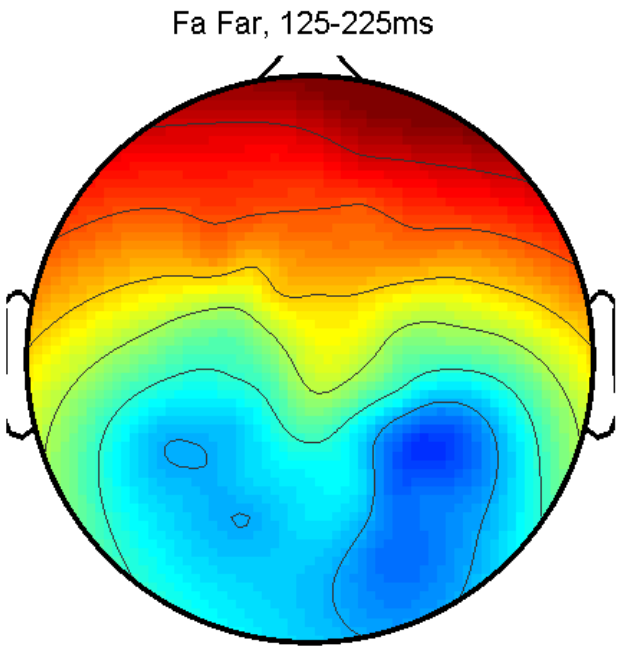
Amplitude can be tricky to interpret



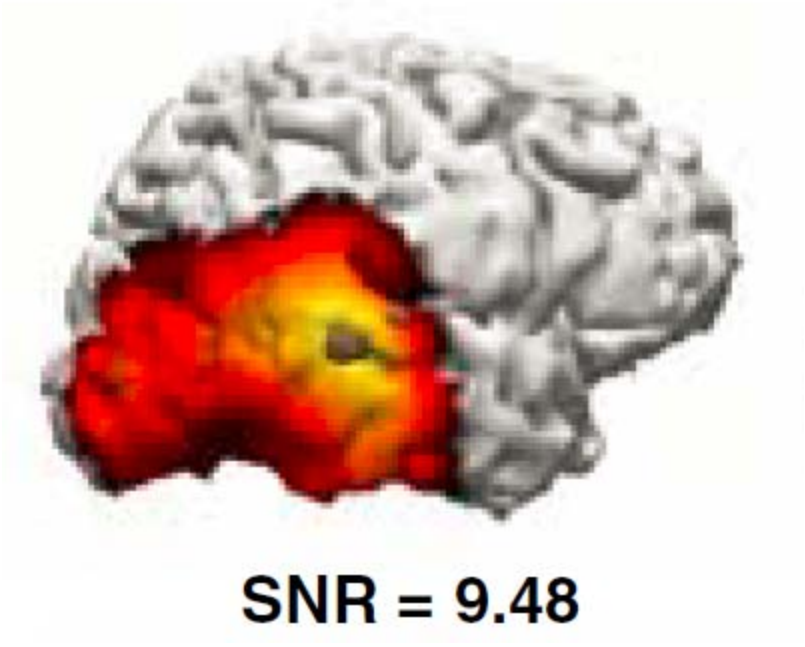


EEG can provide spatial information

Scalp Topography



Source localization



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

Photo 1: http://www.neuroscan.com/EpilepsyPlatforms.cfm

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

Images from neuroscan.com

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

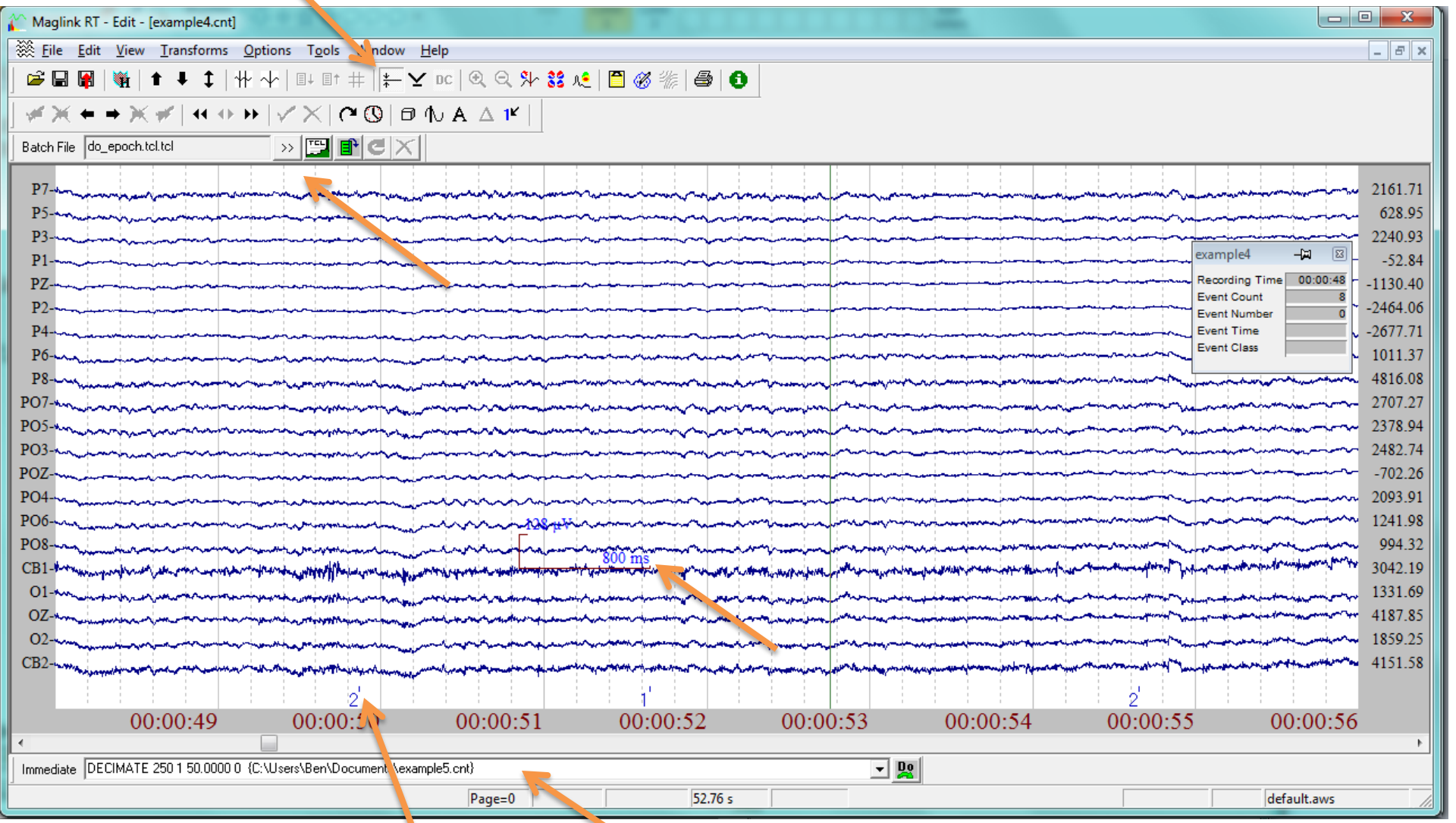
Demo analysis

- 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

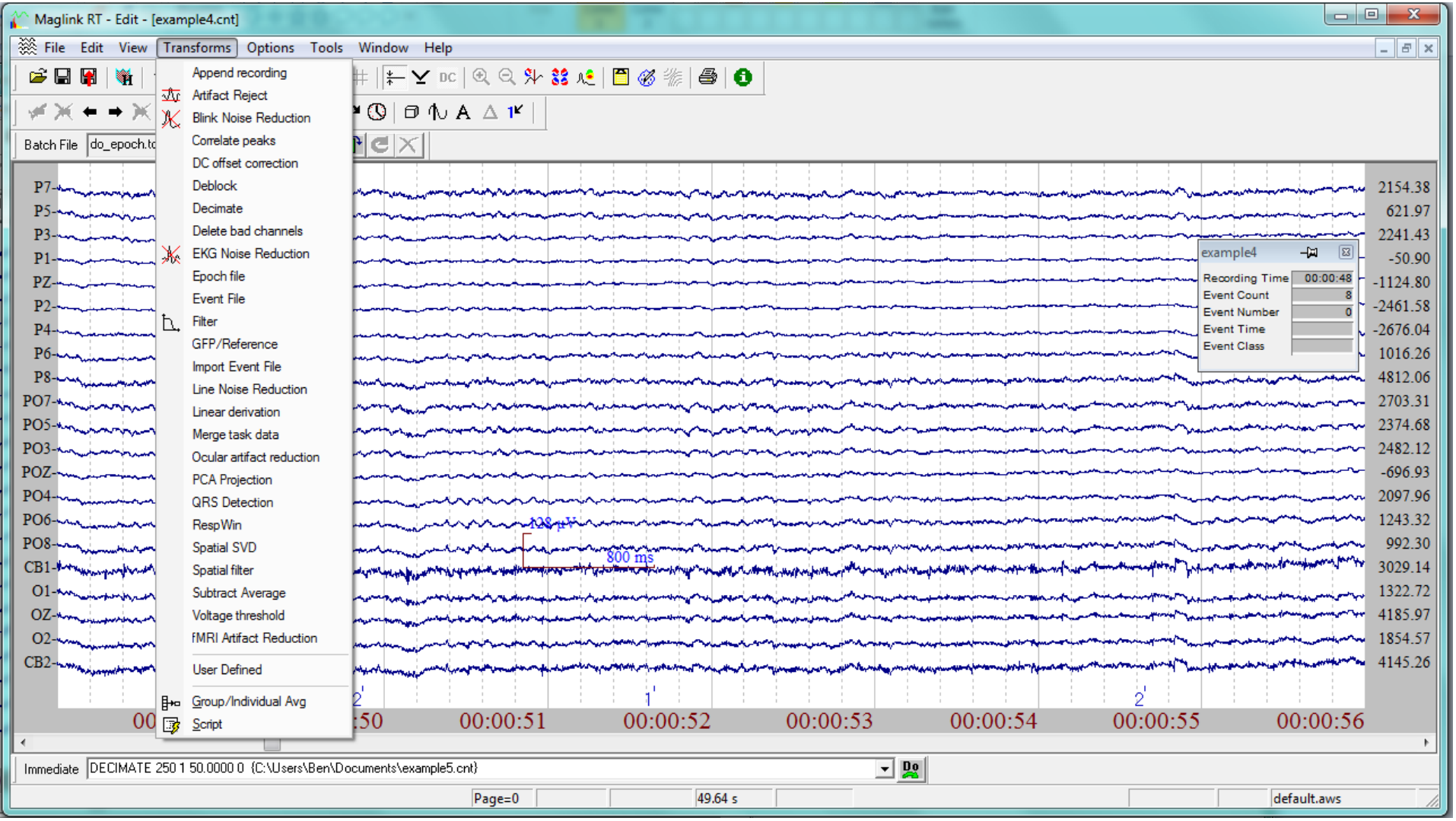
General Workflow

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

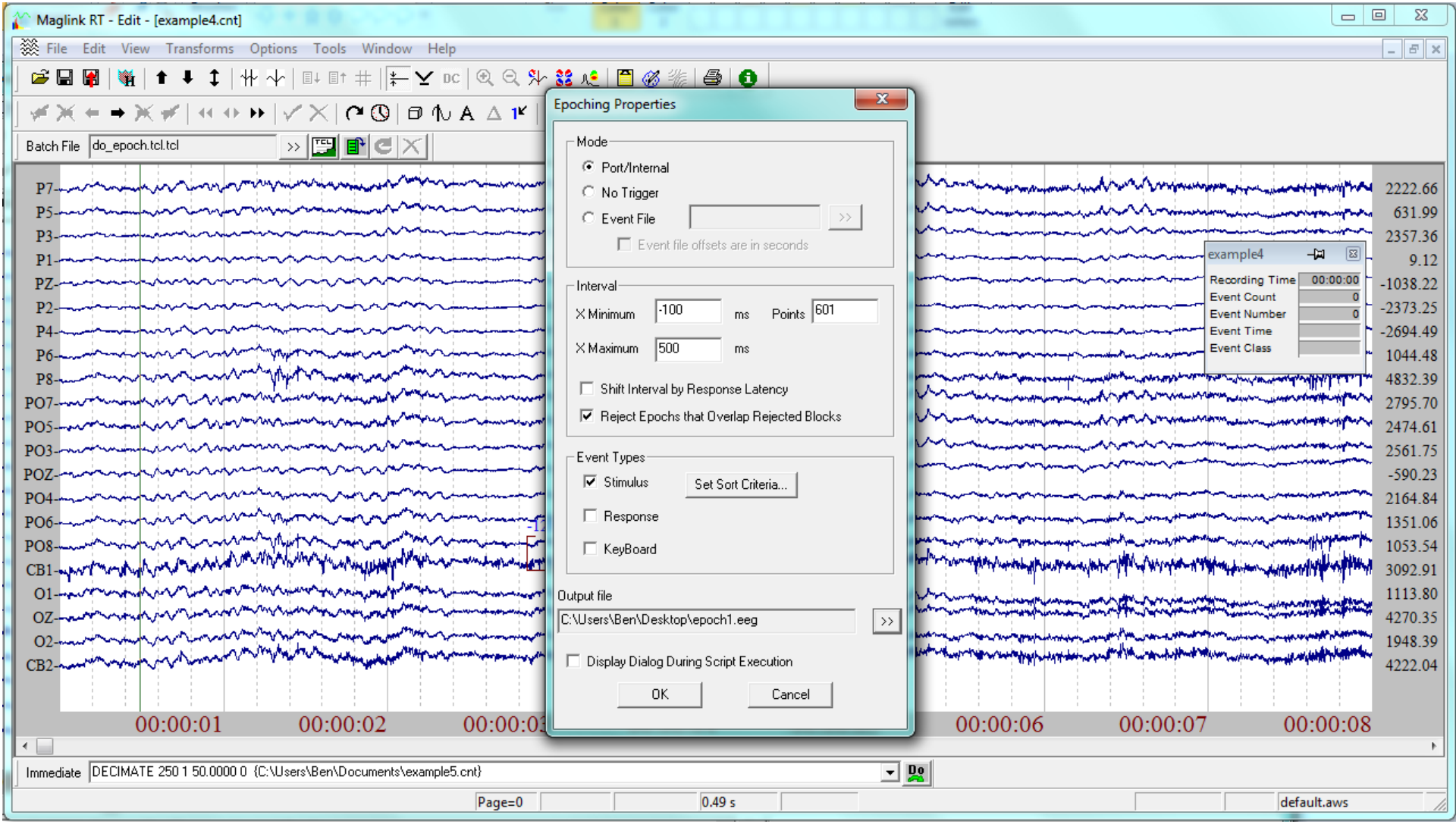
Demo using EDIT: A CNT file



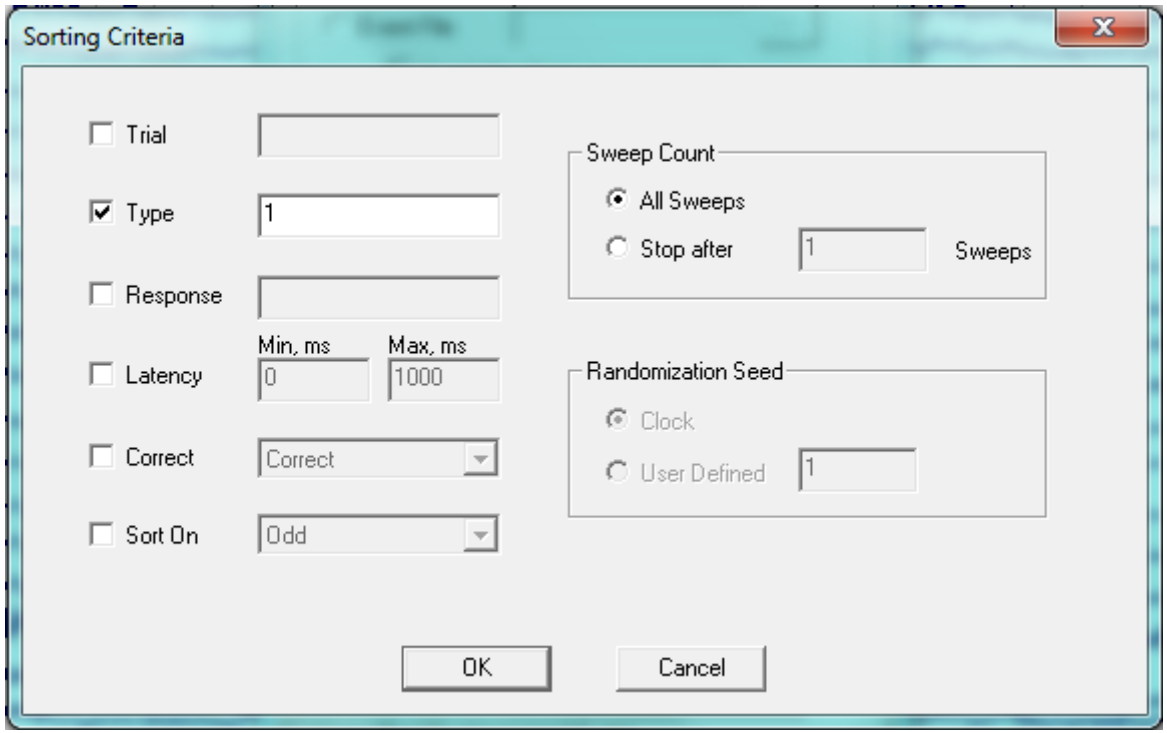
The action is in the transforms menu



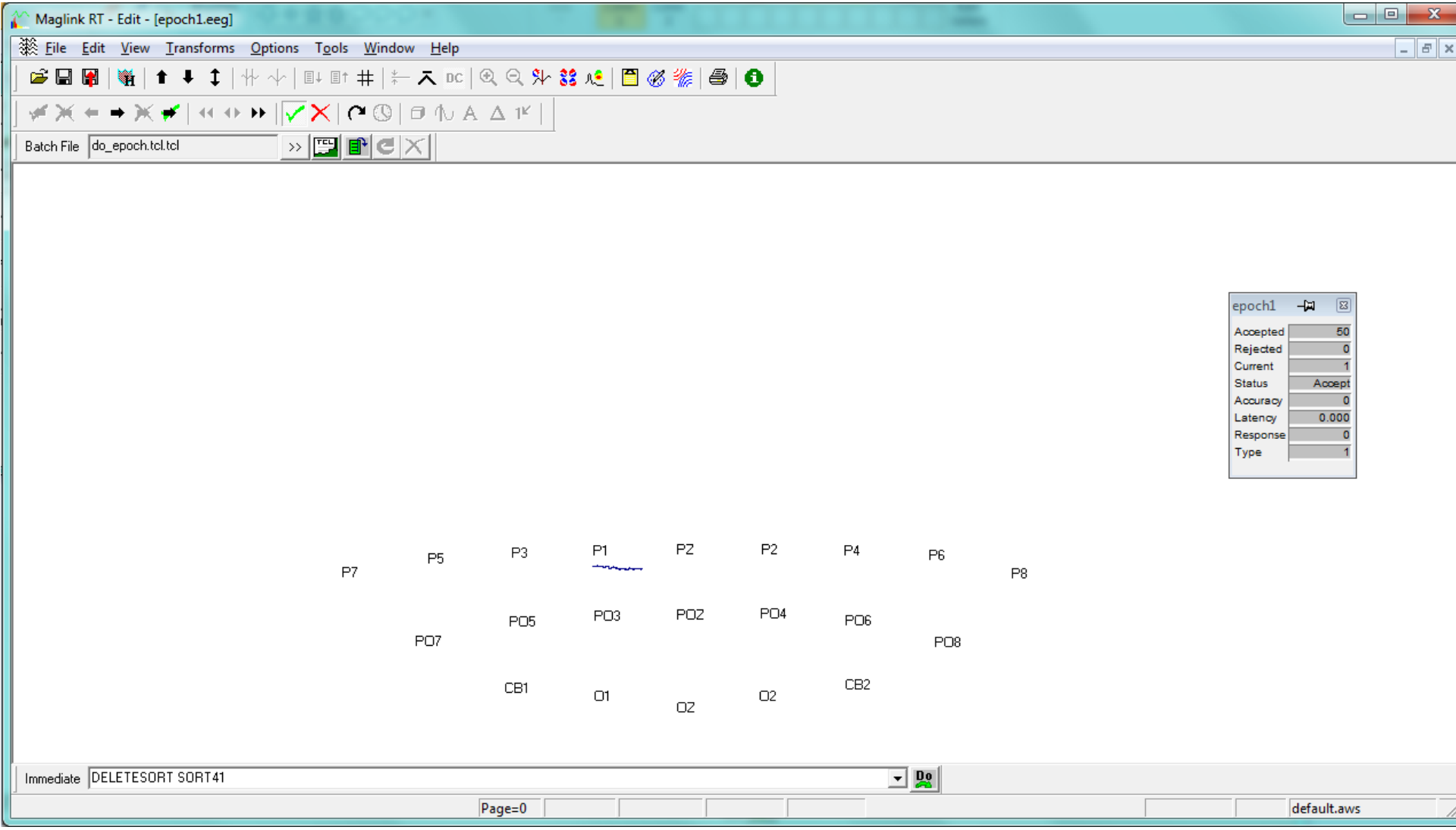
Transforms -> epoch



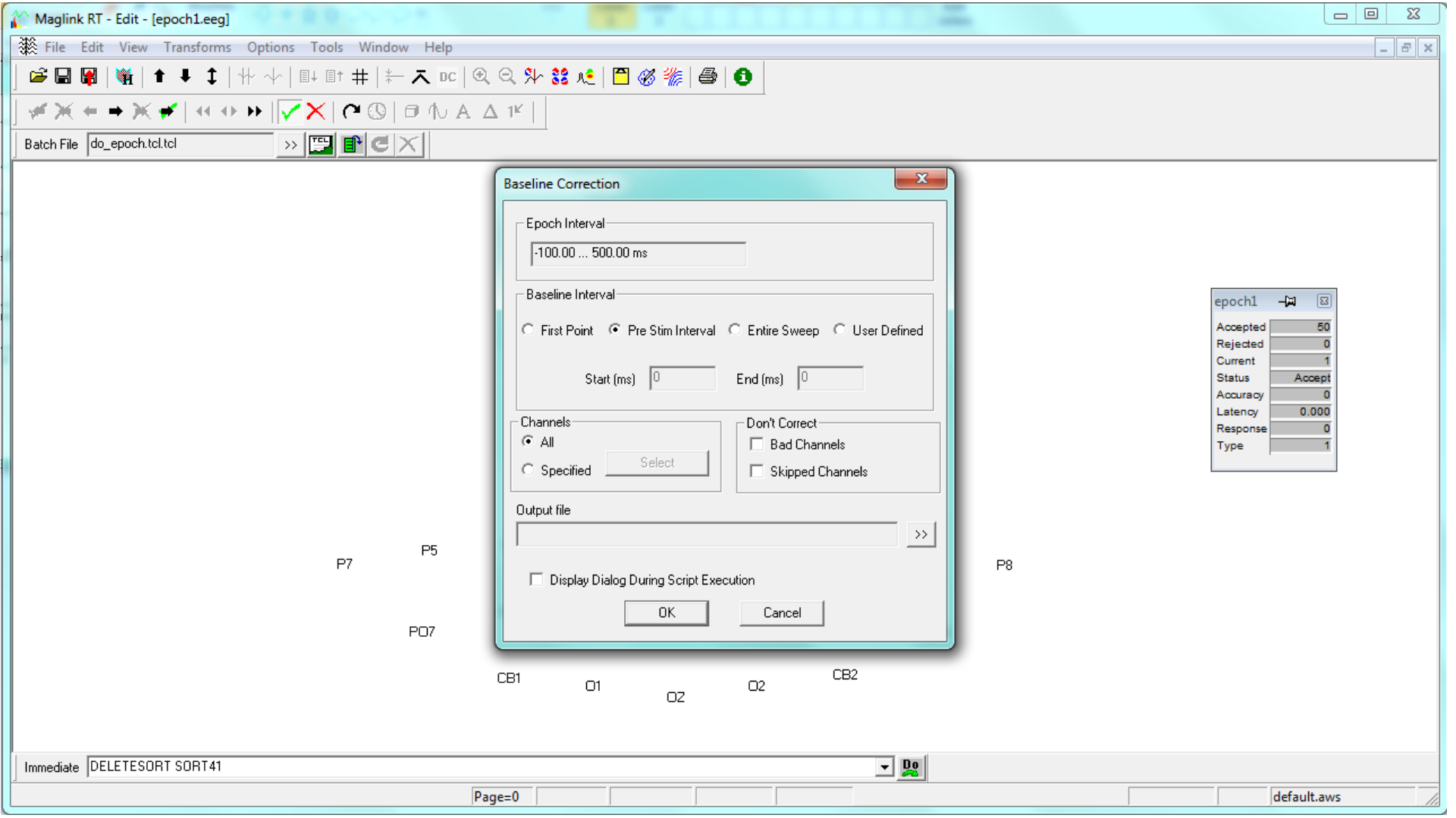
Set sort criteria…



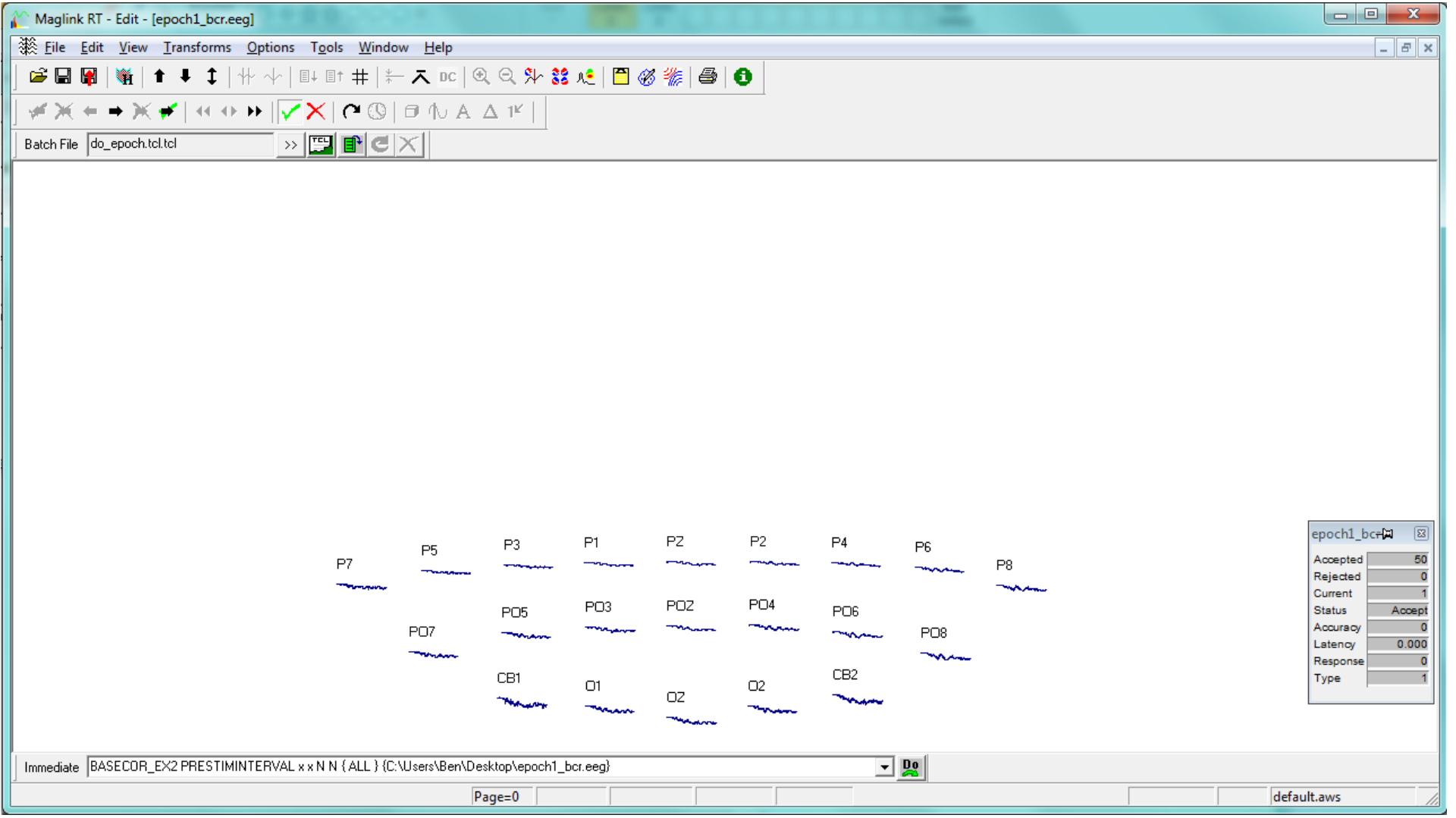
An epoched file (*.eeg)



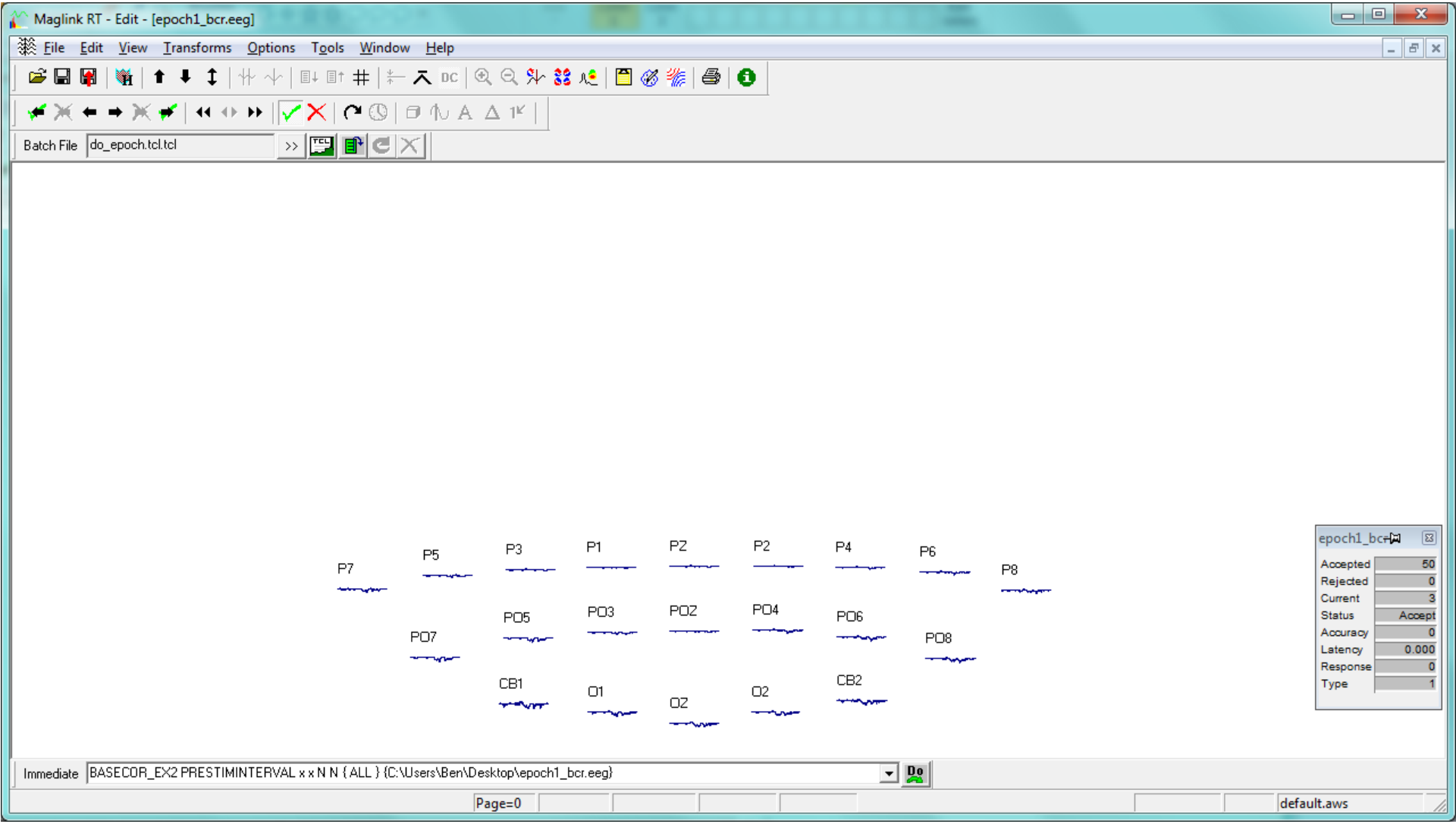
Baseline correction



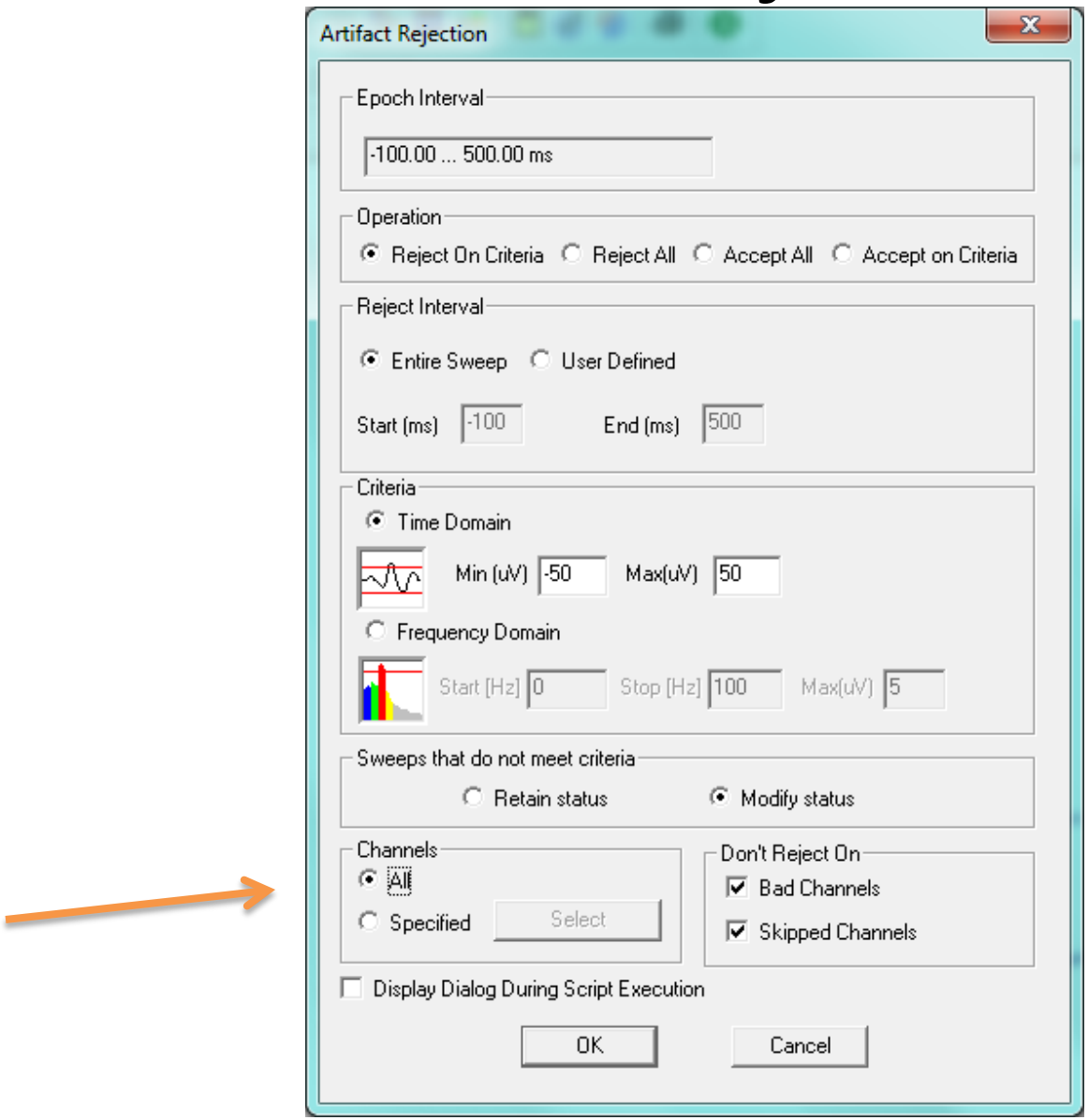
Epoch 1


Maglink RT - Edit - [epoch1_bcr.eeg]
File Edit View Transforms Options Tools Window Help
Batch File
do_epoch.tcl.tcl
P7
P5
P3
P1
PZ
P2
P4
P6
P8
PO7
PO5
PO3
POZ
PO4
PO6
PO8
CB1
O1
OZ
O2
CB2
epoch1_bcr
Accepted 50
Rejected 0
Current 1
Status Accept
Accuracy 0
Latency 0.000
Response 0
Type 1
Immediate
BASECOR_EX2 PRESTIMINTERVAL x x N N { ALL } {C:\Users\Ben\Desktop\epoch1_bcr.eeg}
Do
Page=0
default.aws

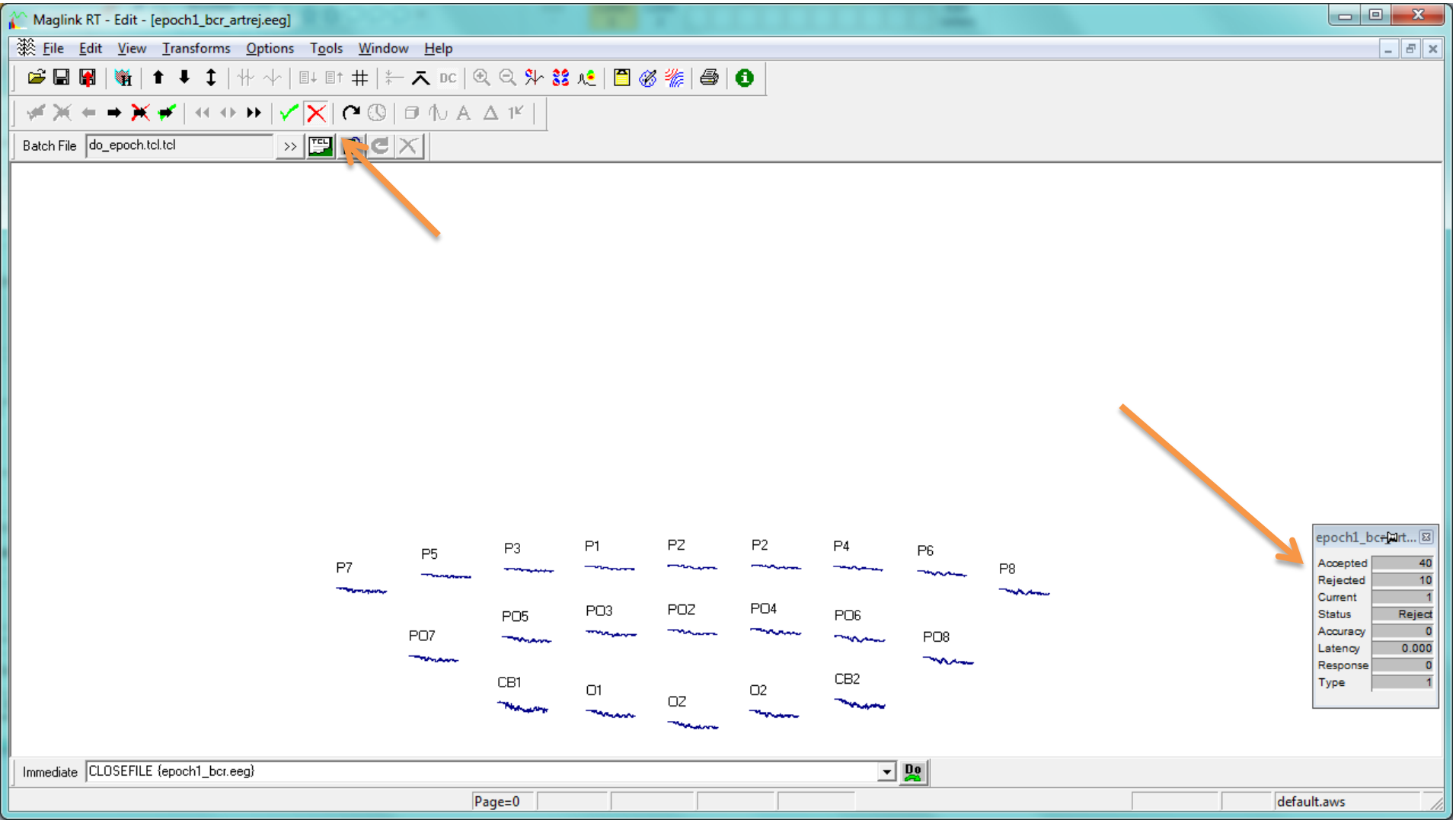
Epoch 3


Maglink RT - Edit - [epoch1_bcr.eeg]
File Edit View Transforms Options Tools Window Help
Batch File
do_epoch.tcl.tcl
P7
P5
P3
P1
PZ
P2
P4
P6
P8
PO7
PO5
PO3
POZ
PO4
PO6
PO8
CB1
O1
OZ
O2
CB2
epoch1_bcr
Accepted 50
Rejected 0
Current 3
Status Accept
Accuracy 0
Latency 0.000
Response 0
Type 1
Immediate
BASECOR_EX2 PRESTIMINTERVAL x x N N { ALL } {C:\Users\Ben\Desktop\epoch1_bcr.eeg}
Do
Page=0
default.aws

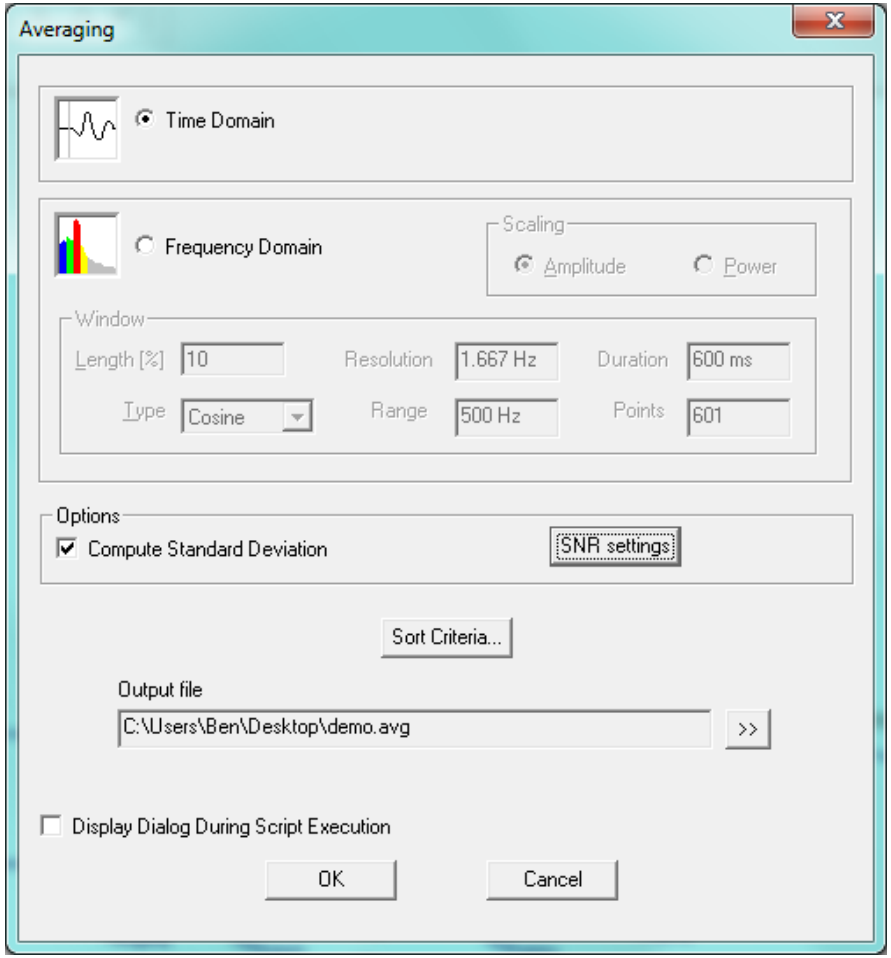
Artifact Rejection



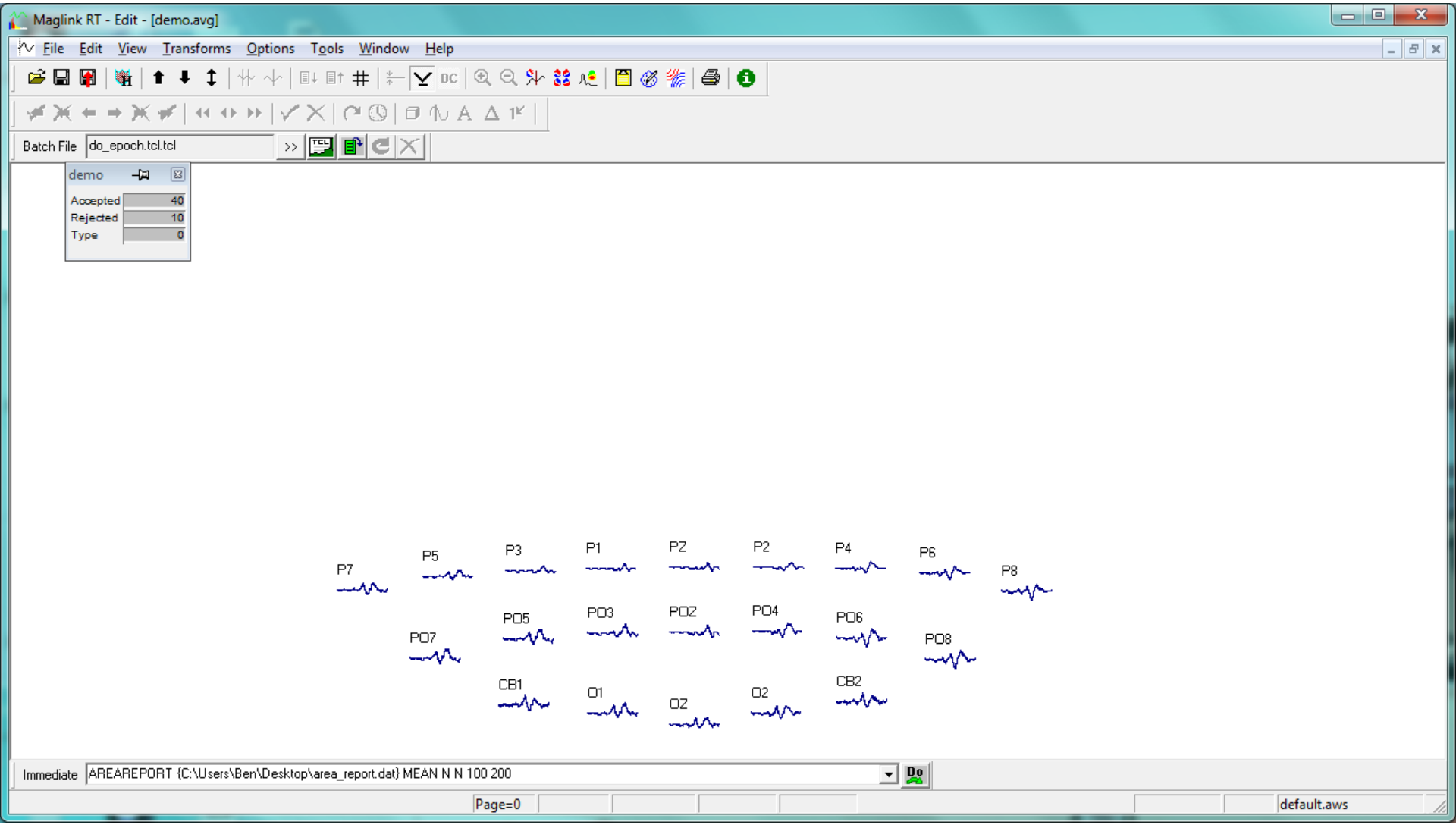
After artifact rejection



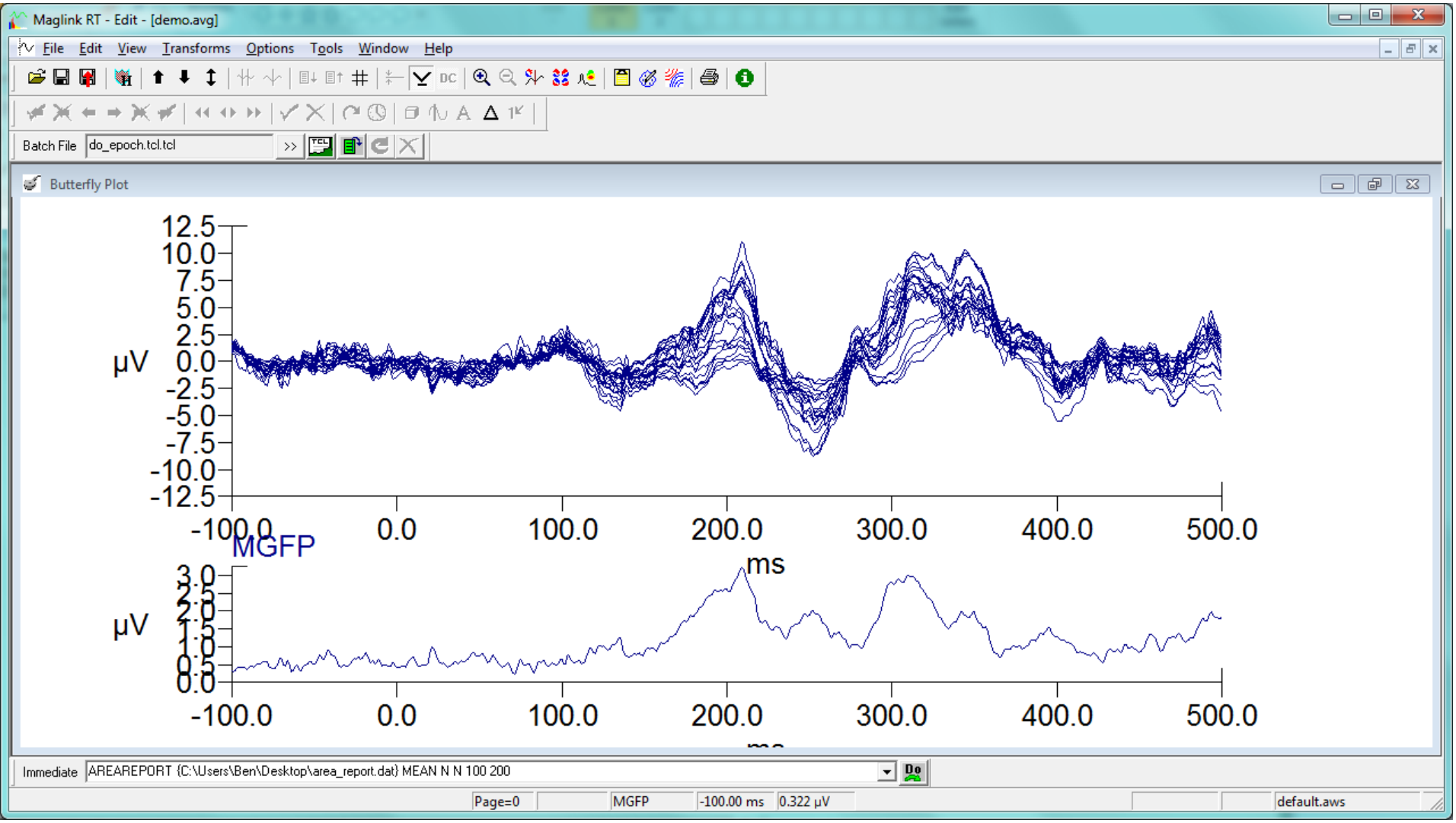
averaging


Averaging
Time Domain
Frequency Domain
Scaling
Amplitude
Power
Window
Length [%]
10
Resolution
1.667 Hz
Duration
600 ms
Type
Cosine
Range
500 Hz
Points
601
Options
Compute Standard Deviation
SNR settings
Sort Criteria...
Output file
C:\Users\Ben\Desktop\demo.avg
>>
Display Dialog During Script Execution
OK
Cancel

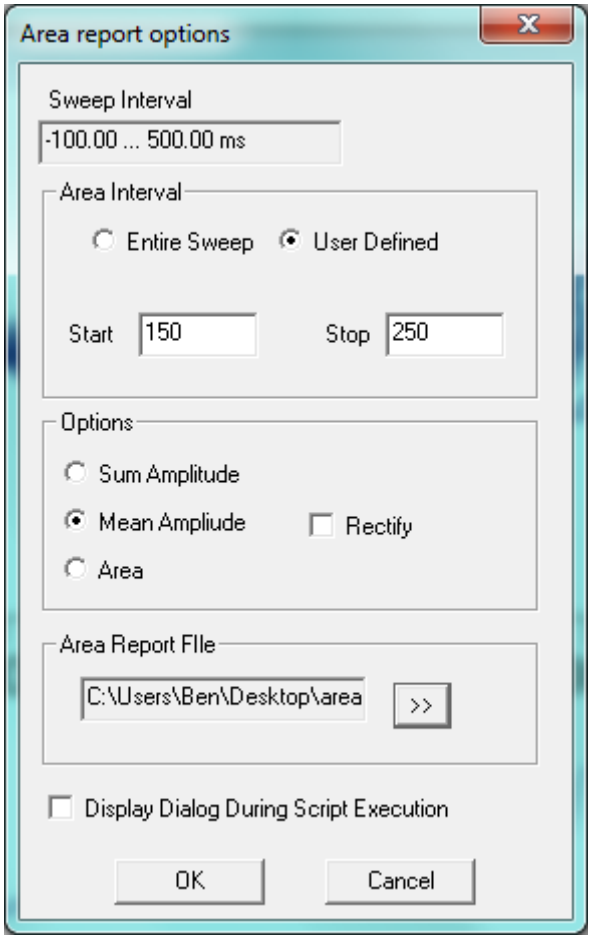
There’s your ERP



Right-click -> butterfly plot



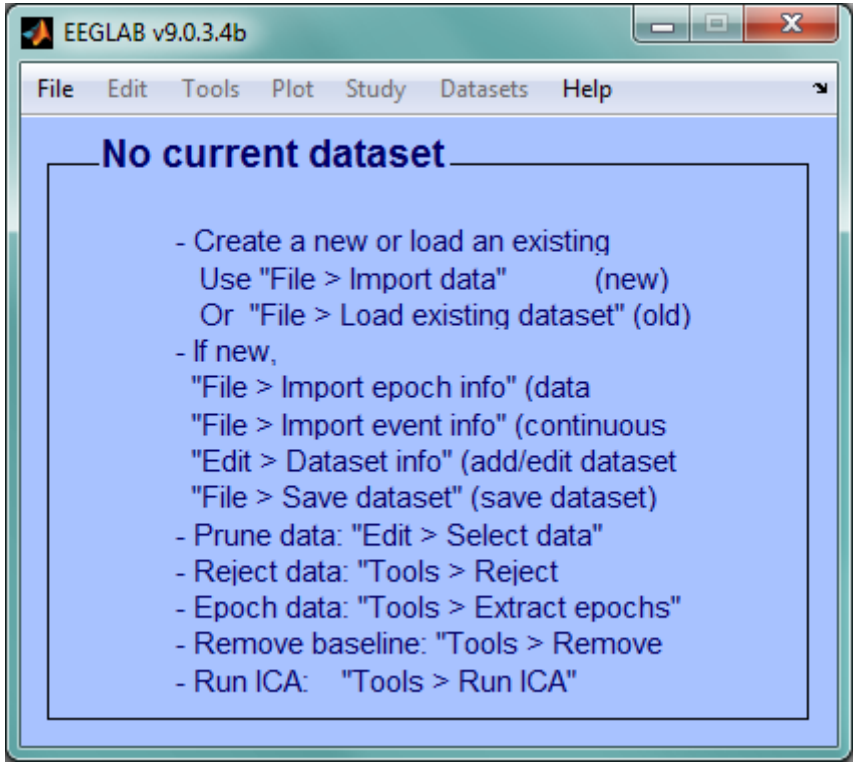
Export for hypothesis testing



Here’s an area report

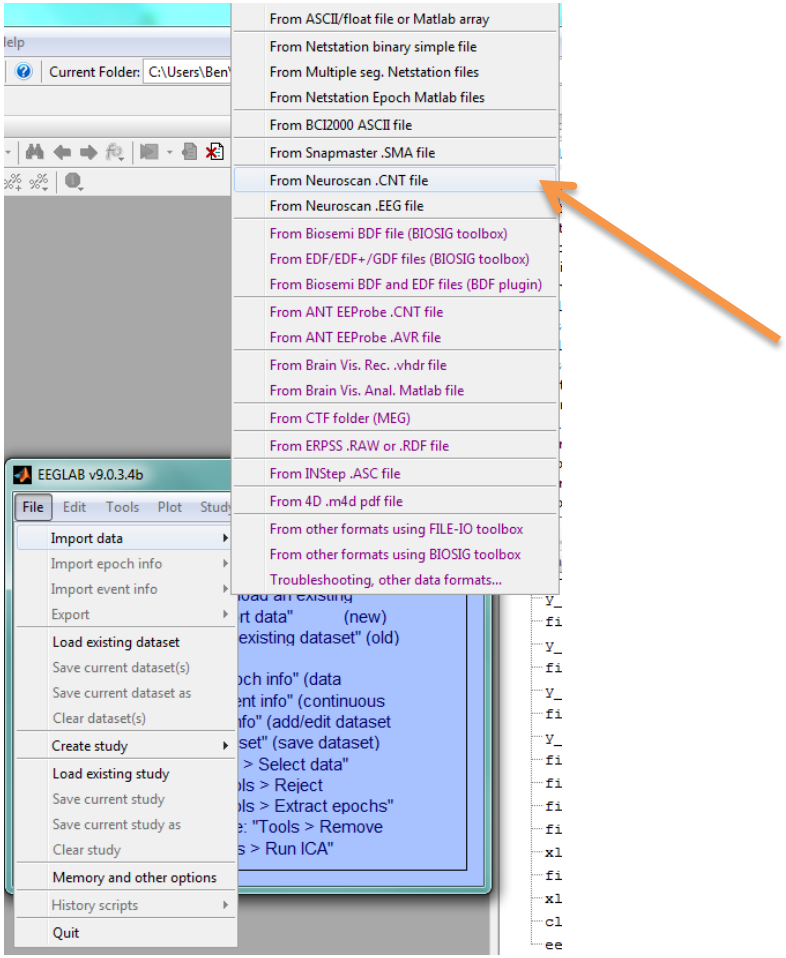
Sweep Number	Channel	Mean(175.00->225.00ms)
1	P7	4.690564
1	P5	3.174123
1	P3	0.730975
1	P1	-0.231918
1	PZ	-1.183108
1	P2	-0.863040
1	P4	0.089758
1	P6	1.402170
1	P8	2.635723
1	PO7	4.648739
1	PO5	4.478690
1	PO3	1.482446
1	POZ	-0.636791
1	PO4	0.022323
1	PO6	1.946077
1	PO8	3.224173
1	CB1	5.995599
1	O1	5.090222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

Demo using EEGLAB

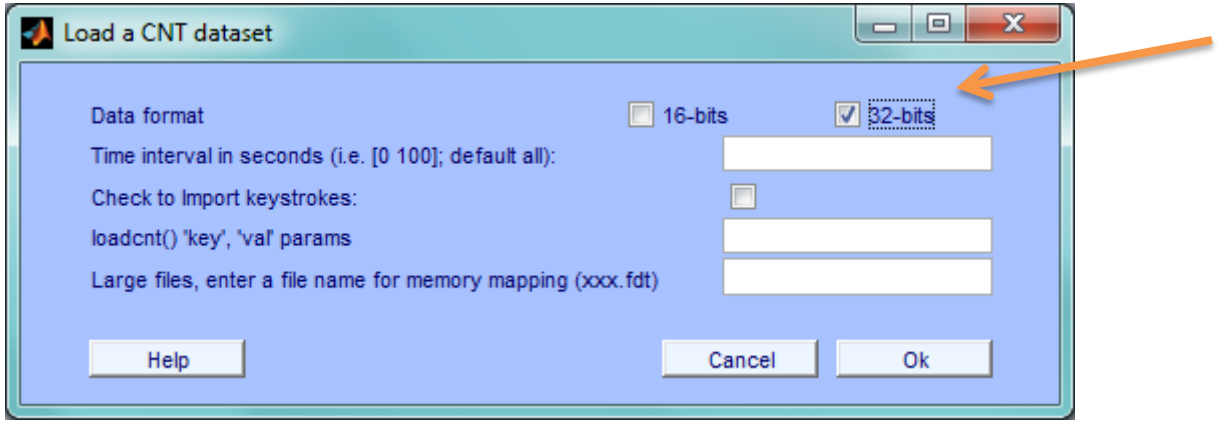


Matlab:
>>eeglab

File>import data>from neuroscan .cnt



32 bits!


Load a CNT dataset
Data format
16-bits
32-bits
Time interval in seconds (i.e. [0 100]; default all):
Check to Import keystrokes:
loadcnt() 'key', 'val' params
Large files, enter a file name for memory mapping (xxx.fdt)
Help
Cancel
Ok

Help tells you how to do it with scripts

MATLAB File Help: pop_loadcnt

File Edit View Go Debug Desktop Window Help

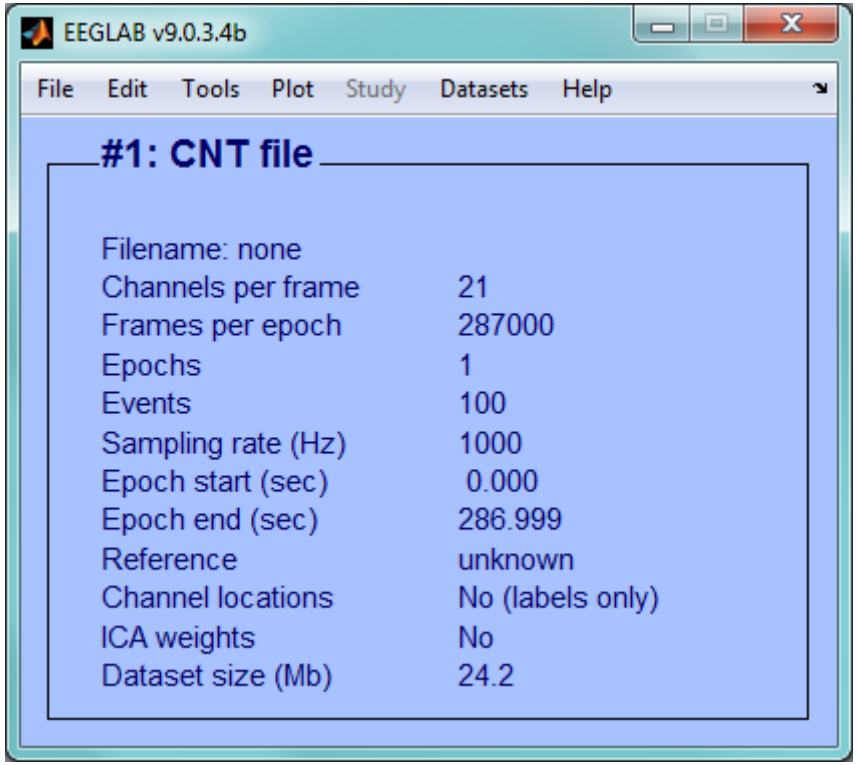
Location: MATLAB File Help: pop_loadcnt

MATLAB File Help: pop_loadcnt View code for pop_loadcnt Default Topics

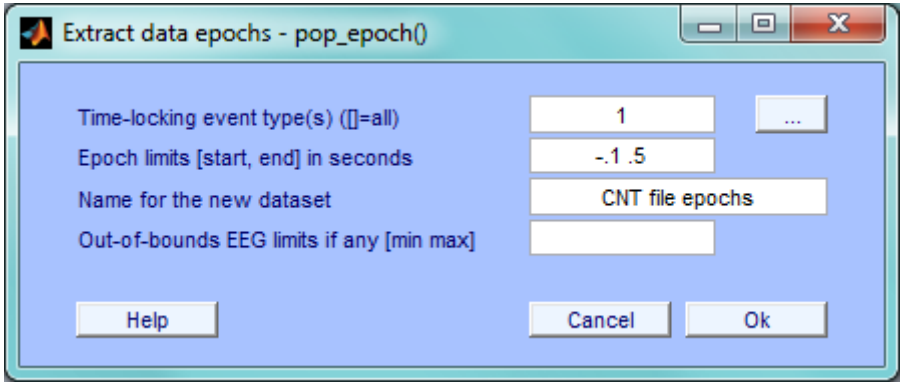
pop_loadcnt

```
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 fomat" - [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 conventially.  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
```

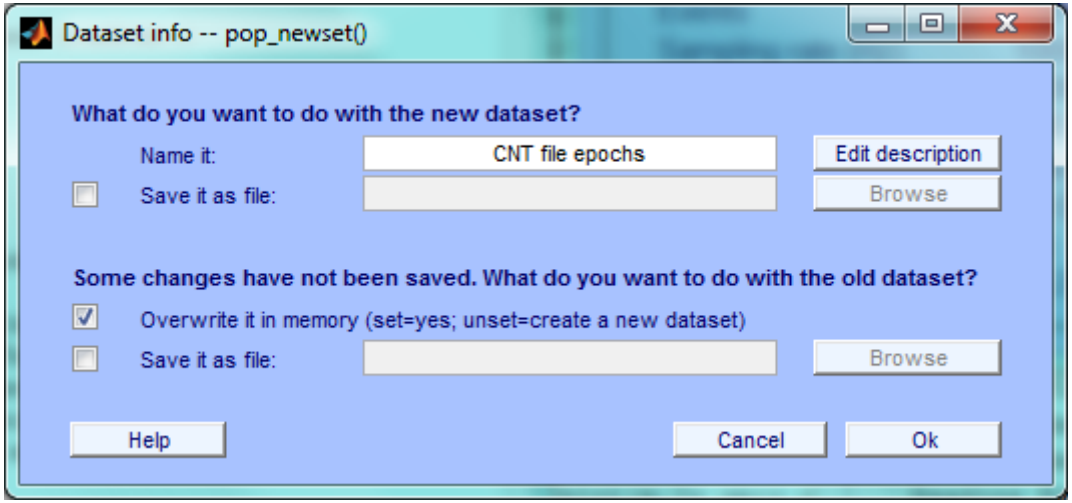
Now the data's in.



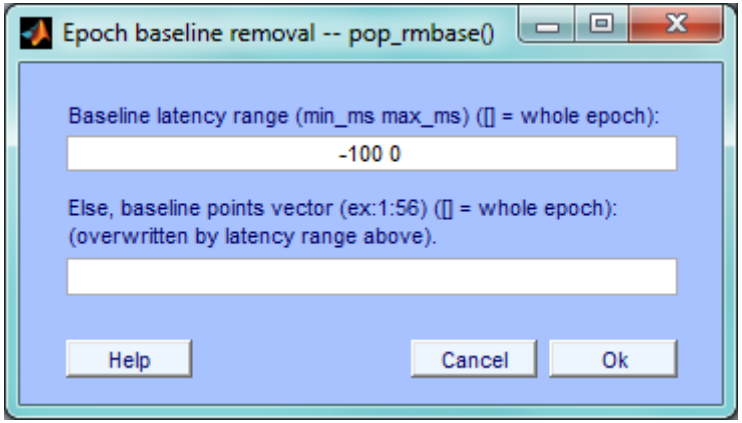
Tools > extract epochs



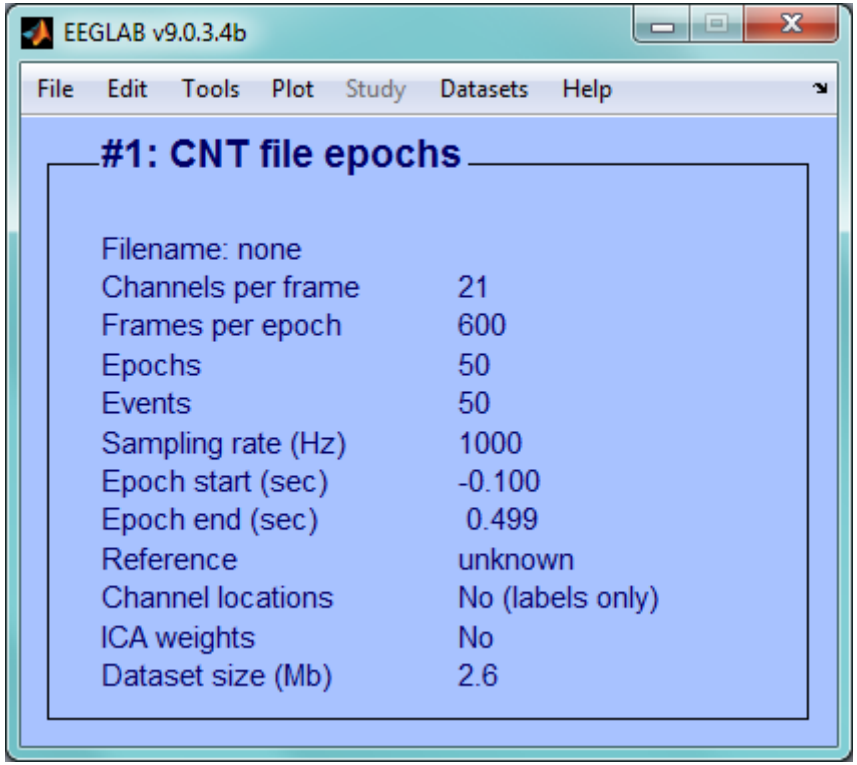
You can choose to overwrite, save, rename etc.



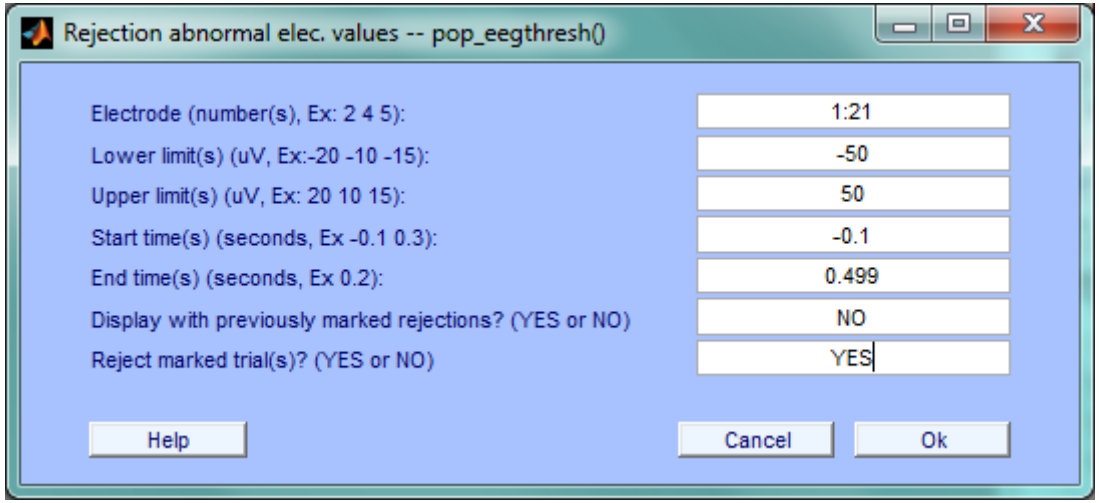
It knows baseline correction is next



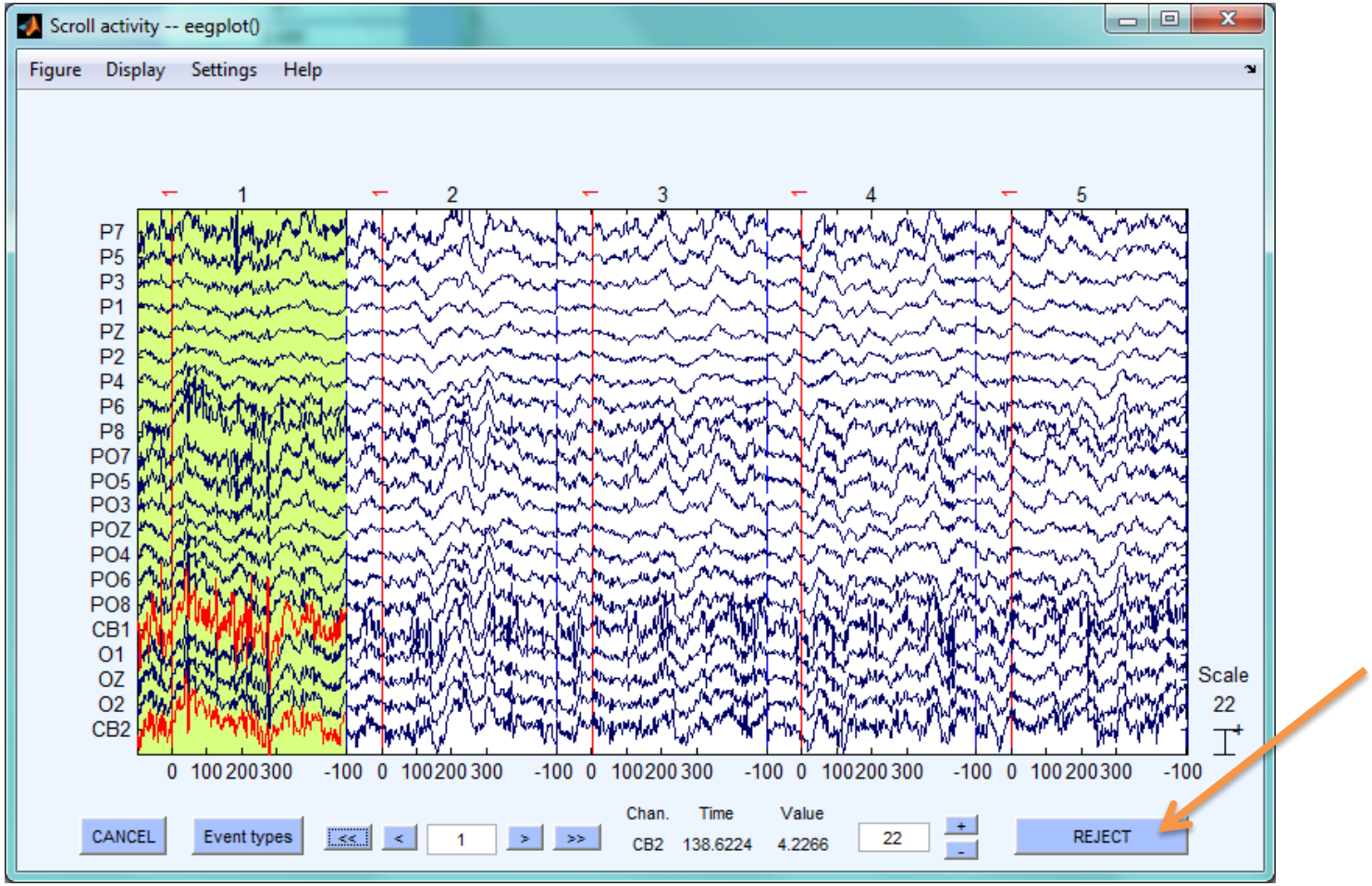
Check number of sweeps etc.



Tools > reject data epochs > reject extreme values

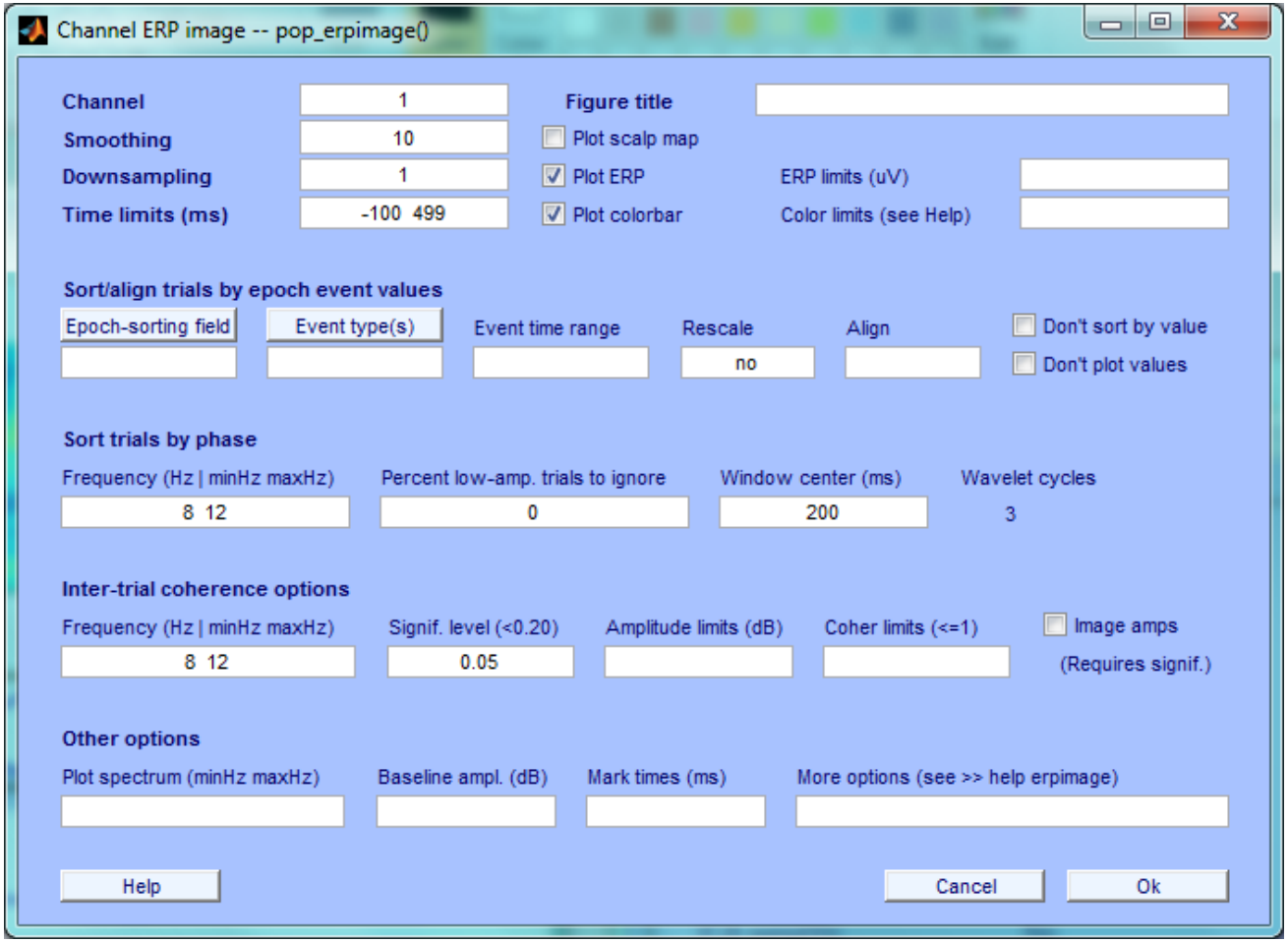


Epochs are marked for rejection, with the offending electrode(s) highlighted

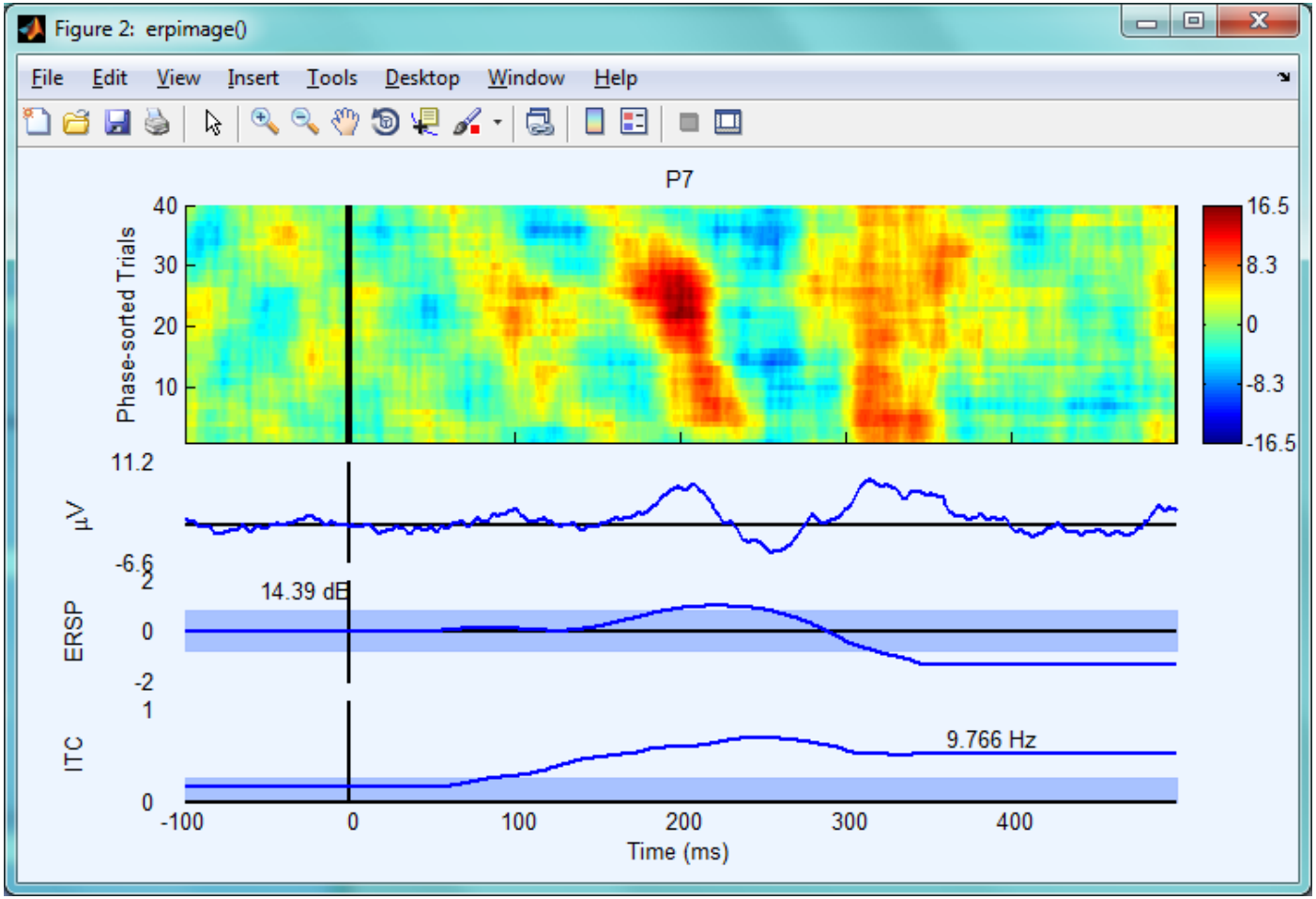


Plot > channel erp image

(many plots are unavailable w/o locations)



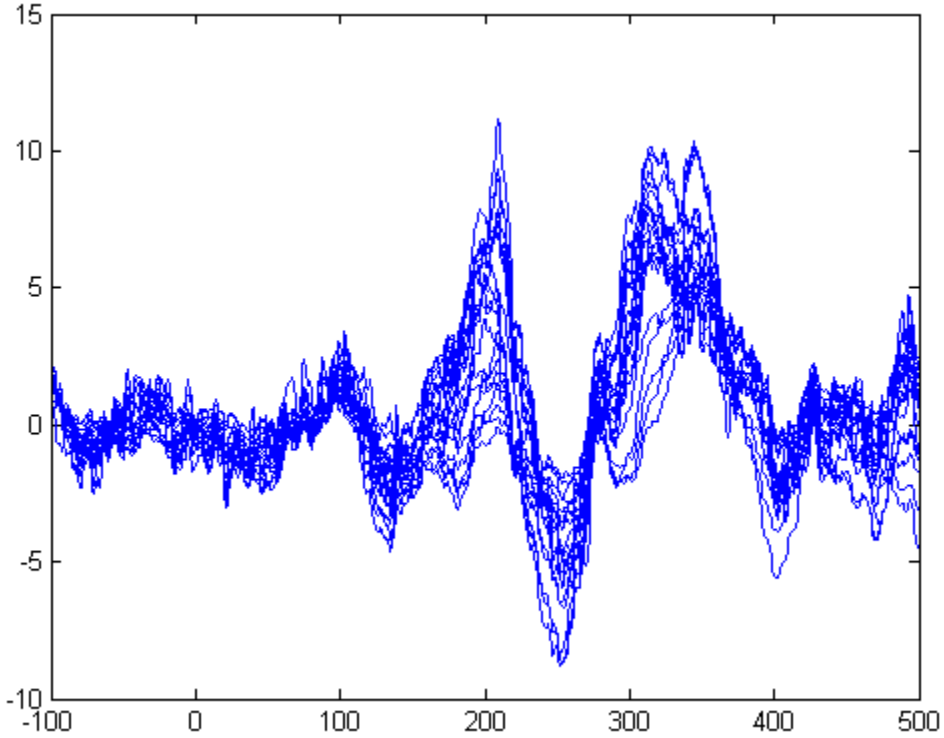
See help messages for what all these mean



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

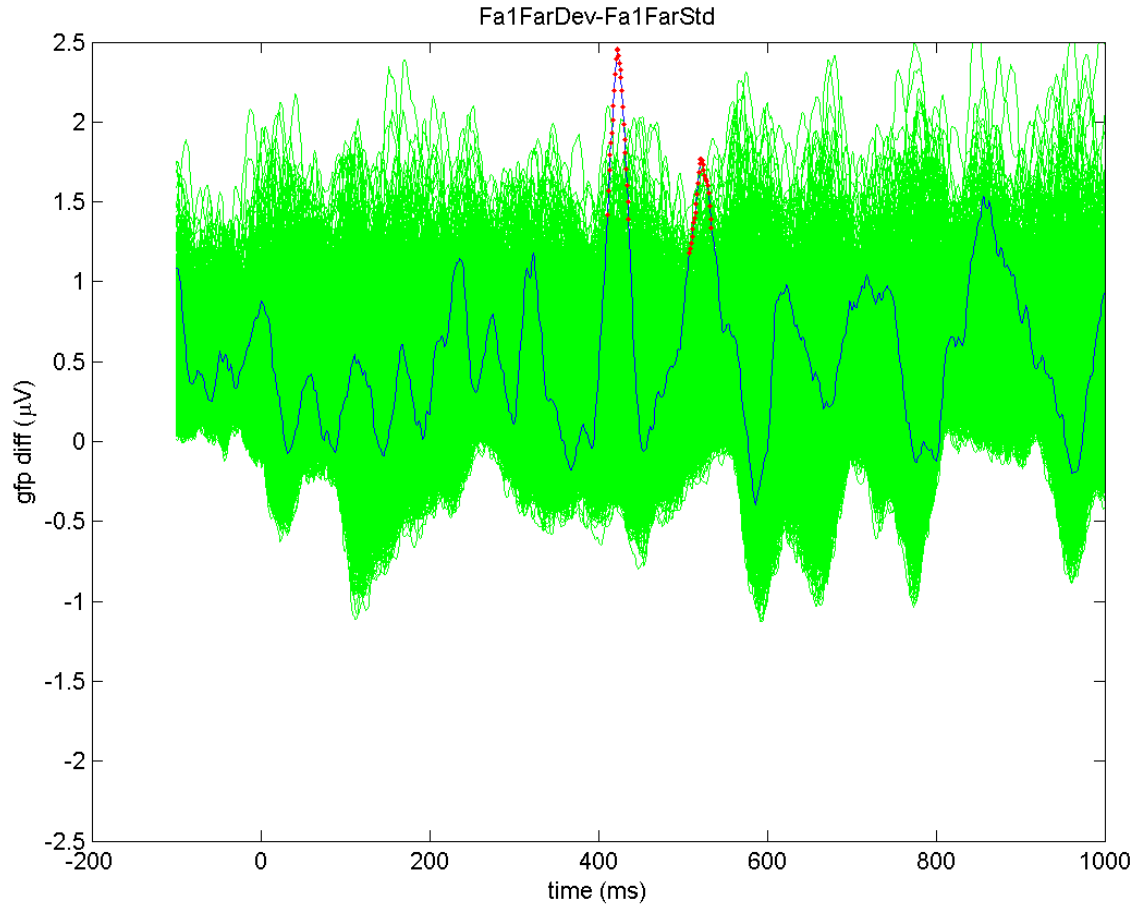
- Null hypothesis:
  - There is NO DIFFERENCE between datasets A and B
- Logic:
  - If there is no difference, re-assigning data points from set A to B (and vice-versa) should not affect the outcome of any test
- Procedure:
  - Relabel datapoints to create pseudo-sets of A & B
  - Compare a statistic (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