Neural Networks to Consumer Networks: EEG in Research and Marketing

Introduction to ERP Analysis using EEGLAB

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PART III

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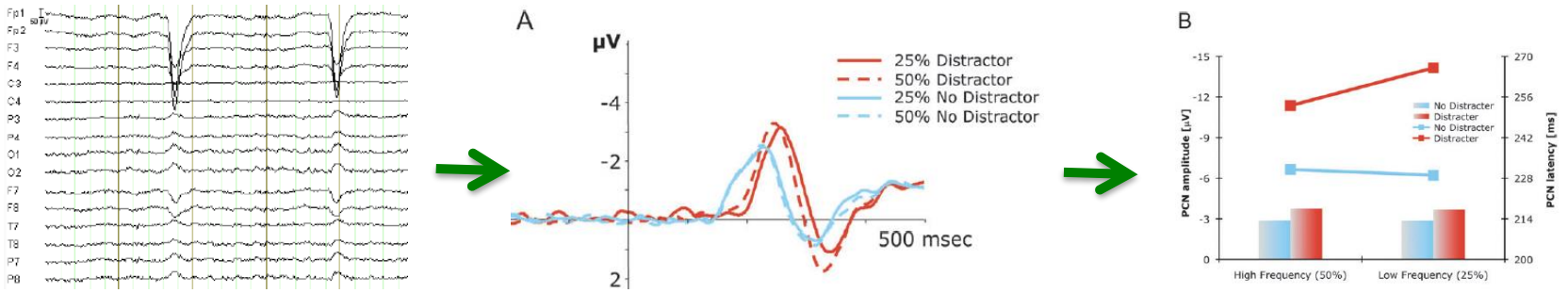
ERPLAB

- For the next seminar, we will mostly be working with the ERPLAB plugin for EEGLAB. Please, find instructions here: https://github.com/lucklab/erplab/wiki/Installation

Final steps ...



How to average condition?

How to plot the data?

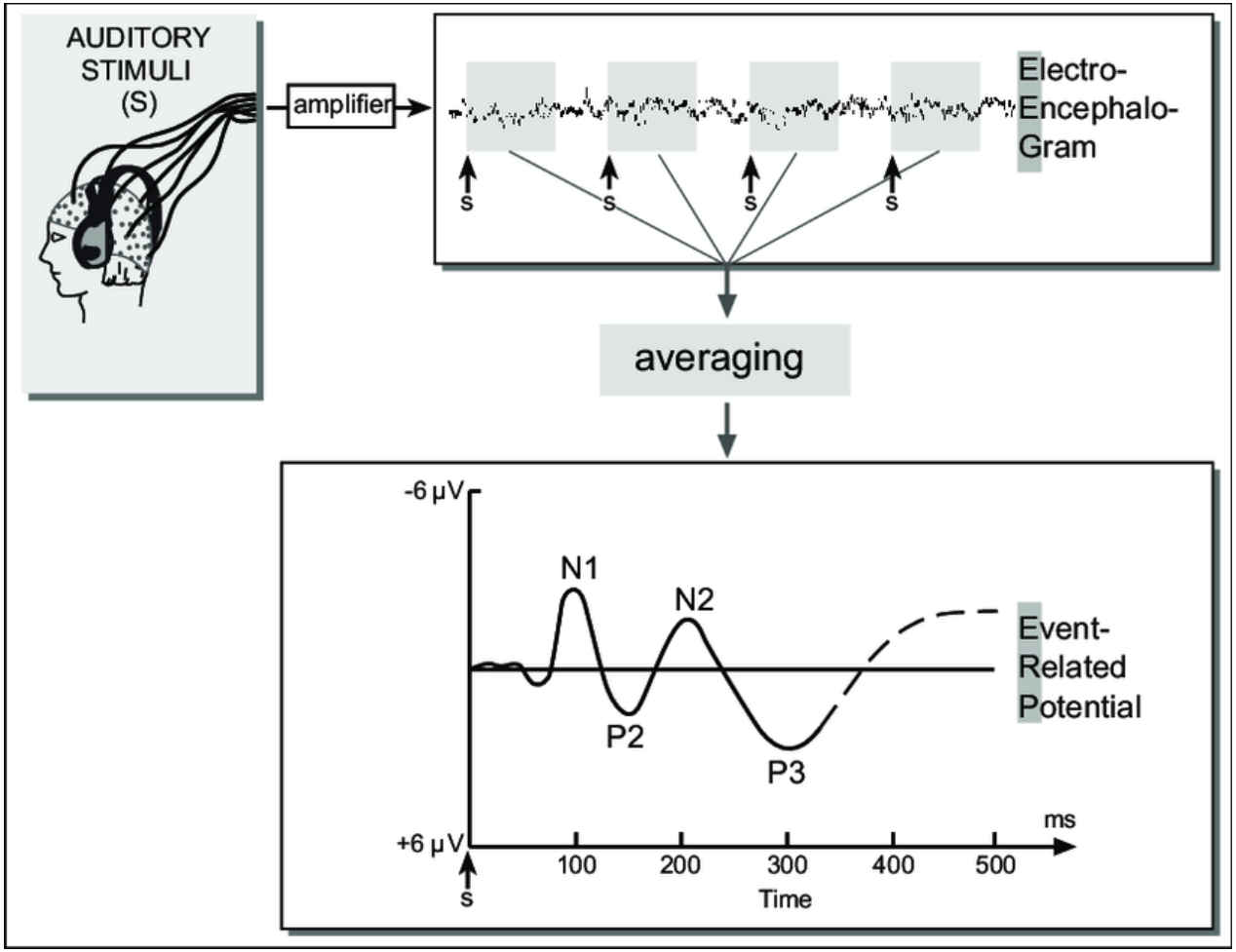
How to measure the components?

How to conduct statistical analyses?

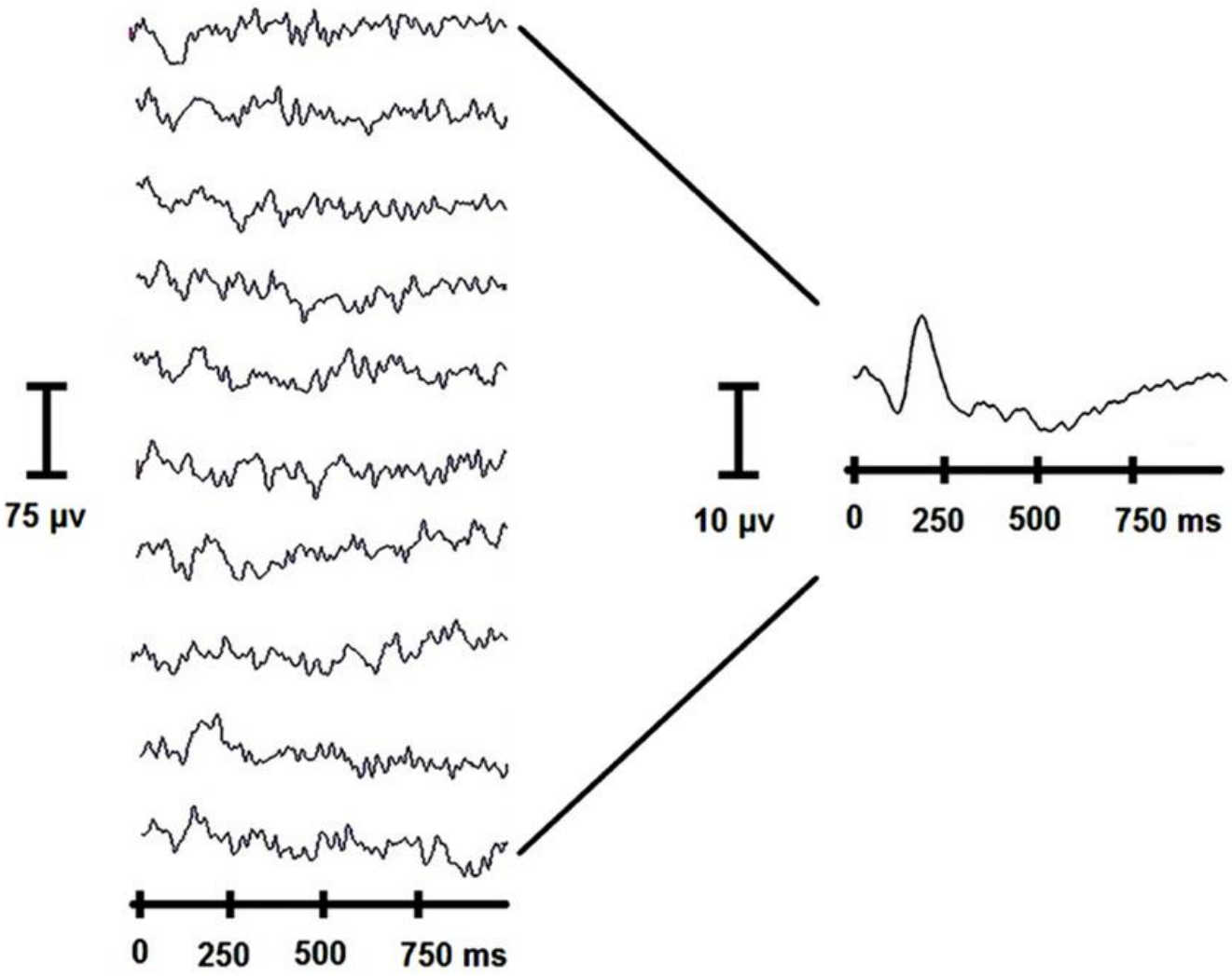
Overview

1. Averaging single trials into specific conditions
2. Plotting ERP data
3. Measuring ERP amplitudes
4. Measuring ERP latencies
5. Computing lateralized components
6. Statistical analysis (SPSS/R/Python)

Averaging


AUDITORY
STIMULI
(S)
amplifier
Electro-
Encephalo-
Gram
s
s
s
s
averaging
-6 µV
+6 µV
N1
N2
P2
P3
Event-
Related
Potential
100
200
300
400
500
ms
Time
s

Averaging

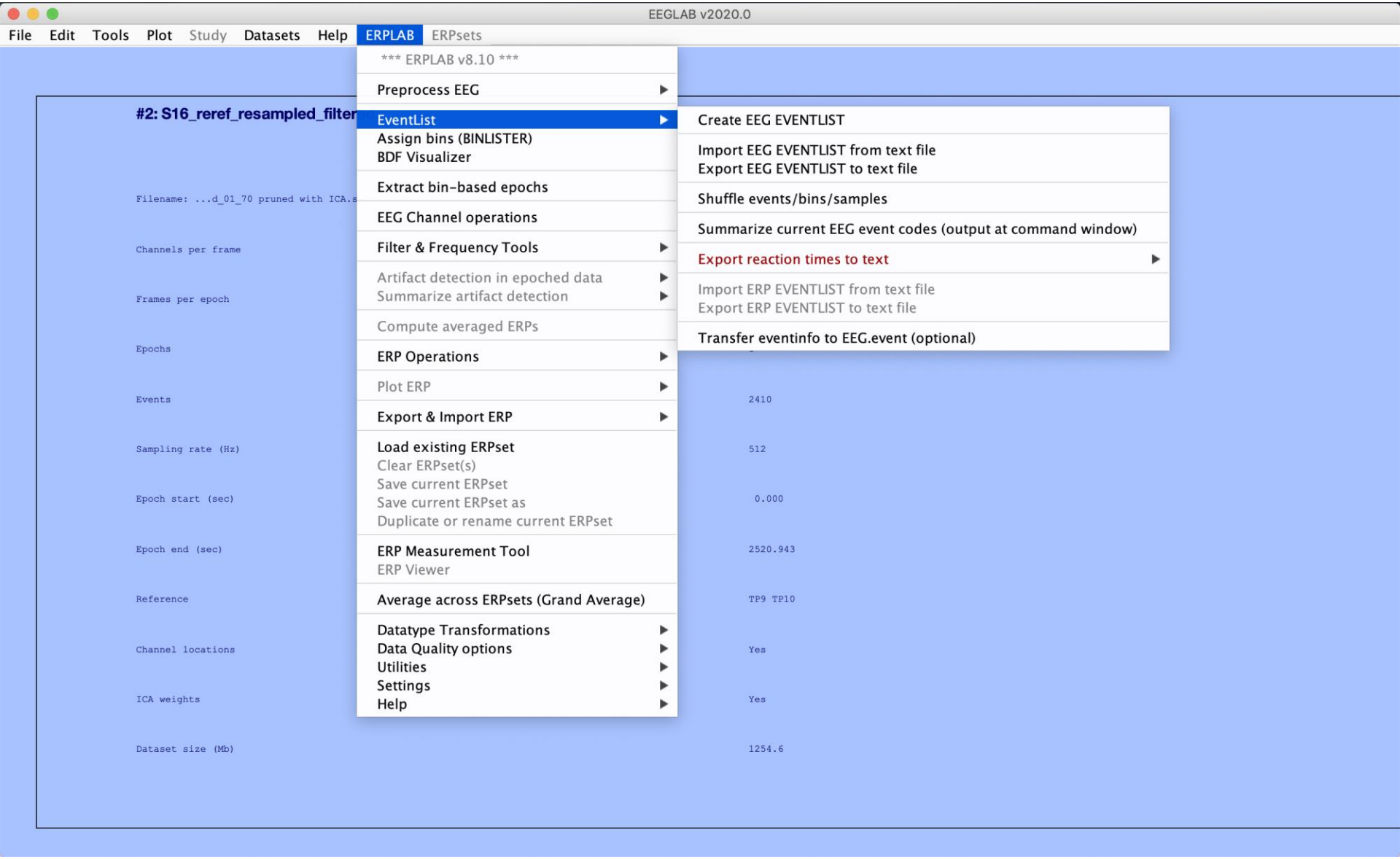


Event list

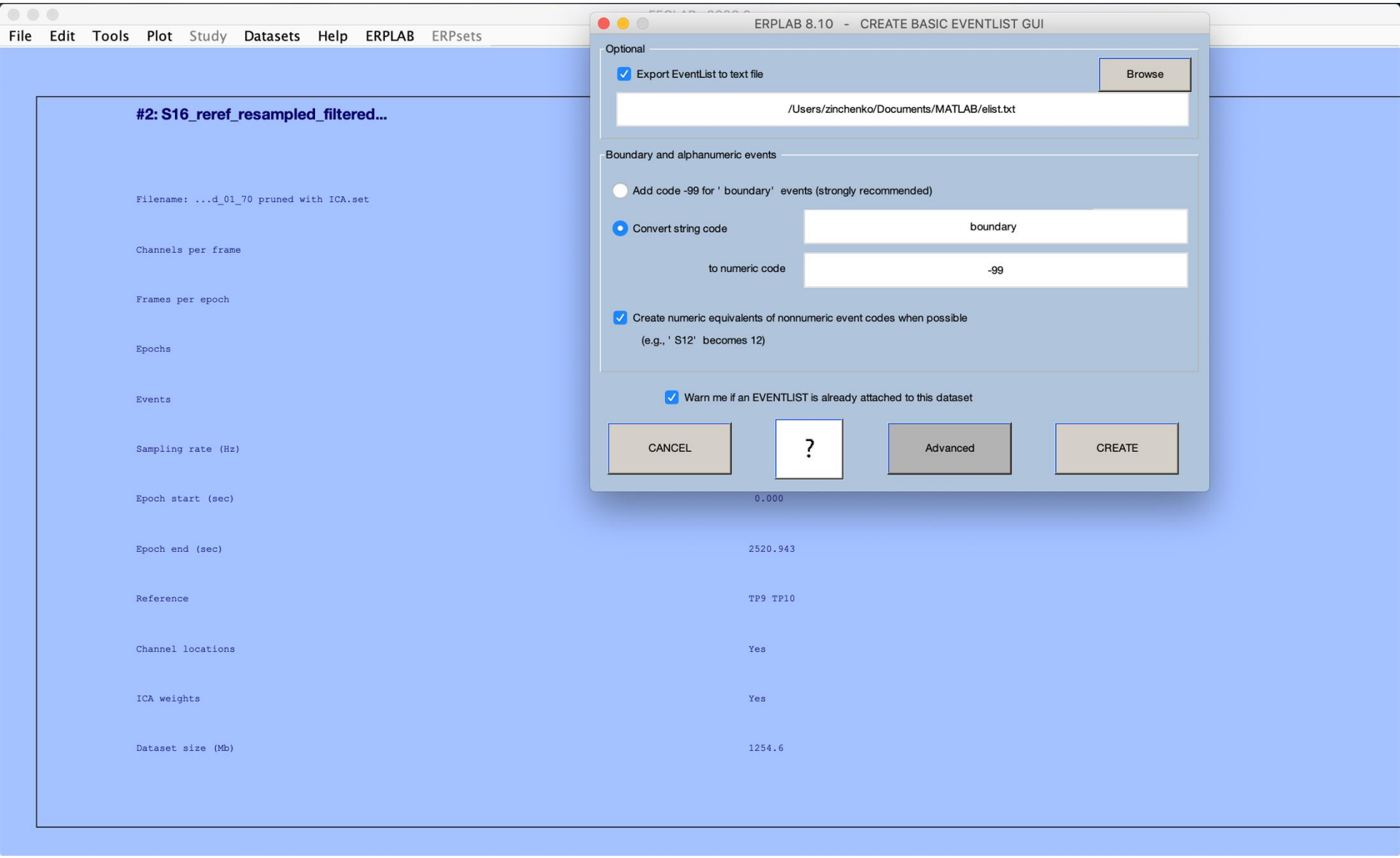
The event codes are embedded in a dataset within EEGLAB's **EEG** structure, which is pretty complicated.

To make it easier to see and manipulate the event codes, ERPLAB creates an EventList, which is a list of all of the event codes and associated information.

Create an event list



Create an event list



elist.txt

```
#  Non-editable header begin ------------------------------------------------------------------------------
#
#  data format...............: continuous
#  setname...................: S16_reref_resampled_filtered_01_70_elist
#  filename..................: S16_reref_resampled_filtered_01_70_ICA.set
#  filepath..................: /Users/zinchenko/Dropbox/EEG_course/EEG_RAW/EEG_preprocessed_s16/
#  nchan.....................: 62
#  pnts......................: 1290724
#  srate.....................: 512
#  nevents...................: 2410
#  generated by (bdf)........:
#  generated by (set)........: S16_reref_resampled_filtered_01_70_elist
#  reported in ..............:
#  prog Version..............: 8.10
#  creation date.............: 20-Jan-2021 12:38:06
#  user Account..............:
#
#  Non-editable header end --------------------------------------------------------------------------------



# item   bepoch   ecode             label            onset              diff       dura       b_flags    a_flags         enable             bin
#                                                    (sec)           (msec)     (msec)    (binary)   (binary)


1       0           -99         boundary             0.0000          0.00          NaN     00000000     00000000          1    [       ]
2       0           -88 noUSBConnectiontoactiCAP              0.0000          0.00          1.0     00000000     00000000          1    [       ]
3       0           -99         boundary             1.1602       1160.16          NaN     00000000     00000000          1    [       ]
4       0           -88 noUSBConnectiontoactiCAP              1.1602          0.00          1.0     00000000     00000000          1    [       ]
5       0             1               S1             3.0432       1883.00          1.0     00000000     00000000          1    [       ]
6       0           102             S102             3.8212        778.00          1.0     00000000     00000000          1    [       ]
7       0            92              S92             4.3392        518.00          1.0     00000000     00000000          1    [       ]
8       0             1               S1             5.3882       1049.00          1.0     00000000     00000000          1    [       ]
9       0           101             S101             6.1192        731.00          1.0     00000000     00000000          1    [       ]
10      0            81              S81             7.0022        883.00          1.0     00000000     00000000          1    [       ]
11      0             1               S1             8.5522       1550.00          1.0     00000000     00000000          1    [       ]
12      0           103             S103             9.2862        734.00          1.0     00000000     00000000          1    [       ]
13      0            92              S92             9.8352        549.00          1.0     00000000     00000000          1    [       ]
14      0             1               S1            10.8852       1050.00          1.0     00000000     00000000          1    [       ]
15      0           100             S100            11.6192        734.00          1.0     00000000     00000000          1    [       ]
16      0            92              S92            12.3682        749.00          1.0     00000000     00000000          1    [       ]
17      0             1               S1            13.4182       1050.00          1.0     00000000     00000000          1    [       ]
18      0           103             S103            14.1532        735.00          1.0     00000000     00000000          1    [       ]
19      0            91              S91            14.7072        554.00          1.0     00000000     00000000          1    [       ]
20      0             1               S1            15.7522       1045.00          1.0     00000000     00000000          1    [       ]
21      0           100             S100            16.4862        734.00          1.0     00000000     00000000          1    [       ]
22      0            92              S92            17.0422        556.00          1.0     00000000     00000000          1    [       ]
23      0             1               S1            18.0842       1042.00          1.0     00000000     00000000          1    [       ]
24      0           100             S100            18.8192        735.00          1.0     00000000     00000000          1    [       ]
25      0            92              S92            19.2742        455.00          1.0     00000000     00000000          1    [       ]
26      0             1               S1            20.3172       1043.00          1.0     00000000     00000000          1    [       ]
27      0           100             S100            21.0522        735.00          1.0     00000000     00000000          1    [       ]
28      0            92              S92            21.8512        799.00          1.0     00000000     00000000          1    [       ]
29      0             1               S1            22.9002       1049.00          1.0     00000000     00000000          1    [       ]
30      0           103             S103            23.6352        735.00          1.0     00000000     00000000          1    [       ]
31      0            91              S91            24.4012        766.00          1.0     00000000     00000000          1    [       ]
32      0             1               S1            25.4492       1048.00          1.0     00000000     00000000          1    [       ]
33      0           102             S102            26.1852        736.00          1.0     00000000     00000000          1    [       ]
34      0            92              S92            26.8582        673.00          1.0     00000000     00000000          1    [       ]
35      0             1               S1            27.9002       1042.00          1.0     00000000     00000000          1    [       ]
36      0           102             S102            28.6352        735.00          1.0     00000000     00000000          1    [       ]
37      0            82              S82            29.2902        655.00          1.0     00000000     00000000          1    [       ]
38      0             1               S1            30.8342       1544.00          1.0     00000000     00000000          1    [       ]
39      0           101             S101            31.5692        735.00          1.0     00000000     00000000          1    [       ]
40      0            81              S81            32.2172        648.00          1.0     00000000     00000000          1    [       ]
```

Bins

A *bin* is a set of averaged ERP waveforms, one for each electrode site, which were created by averaging together a specific set of EEG epochs.

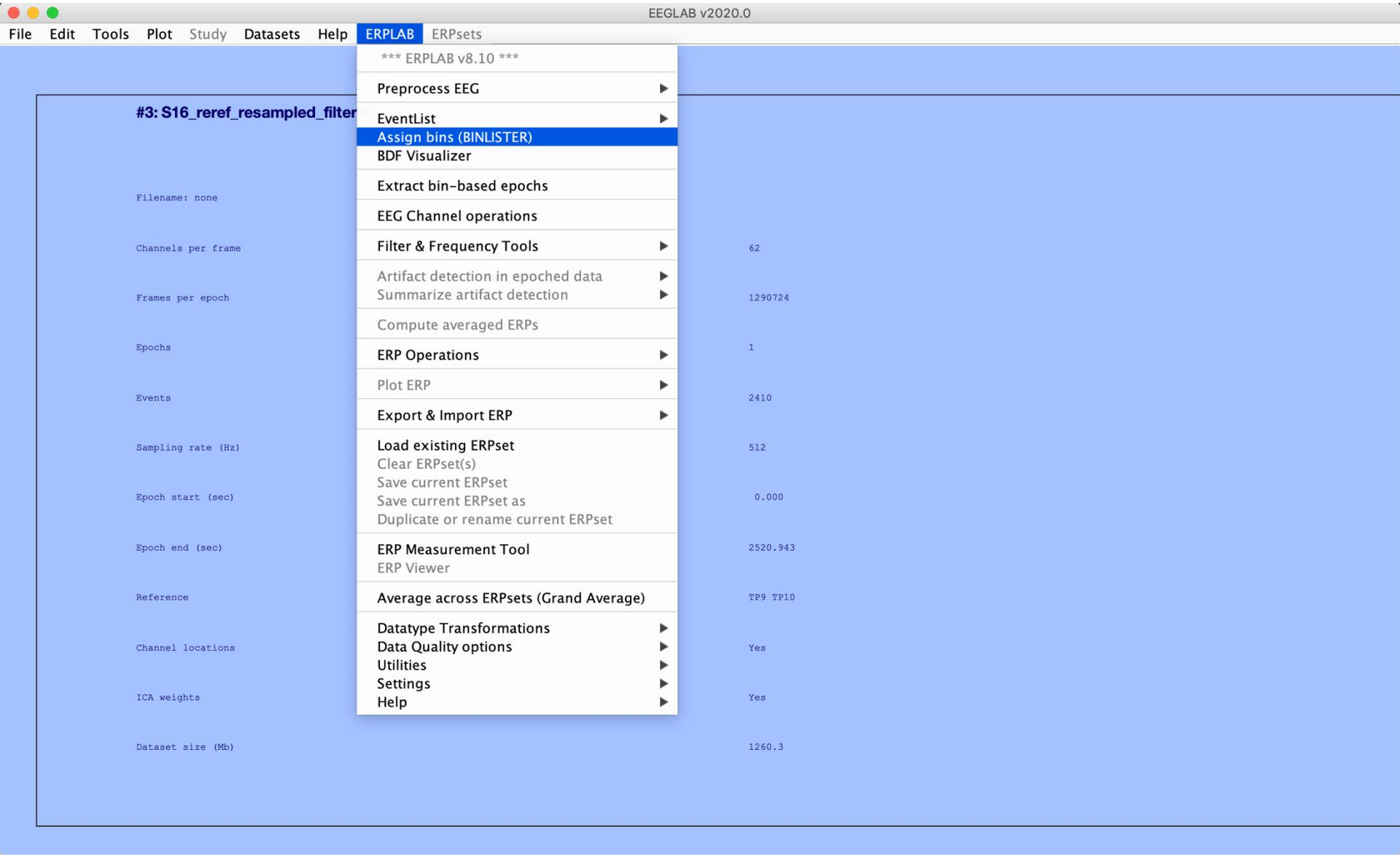
A simple oddball experiment, for example, might have one bin for the infrequent targets and another bin for the frequent standards.

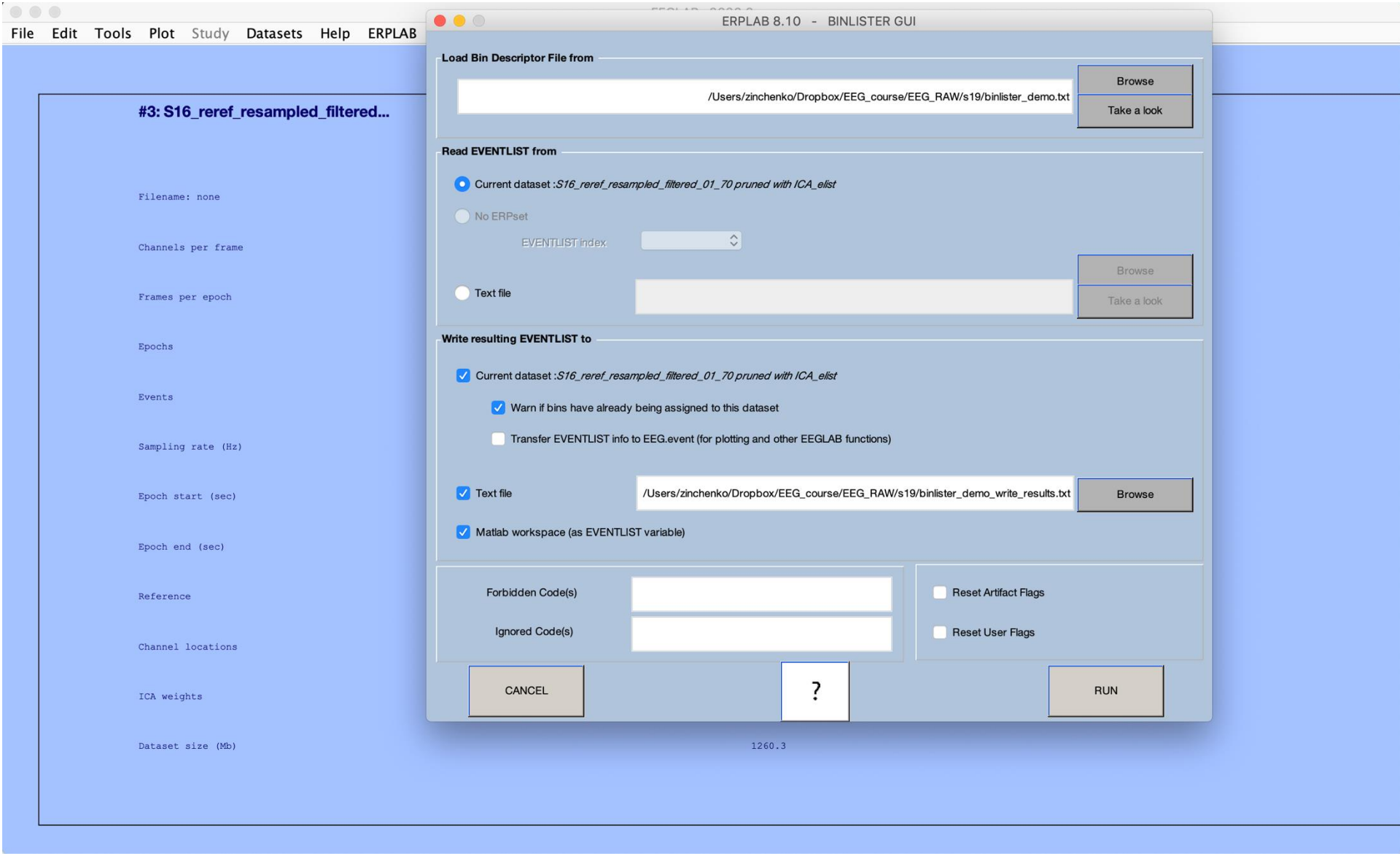
In ERPLAB, an ERPset can contain an unlimited number of bins, and each data processing operation is typically applied to all of the bins in the currently active ERPset.

Assigning Events to Bins with BINLISTER

binlister_demo

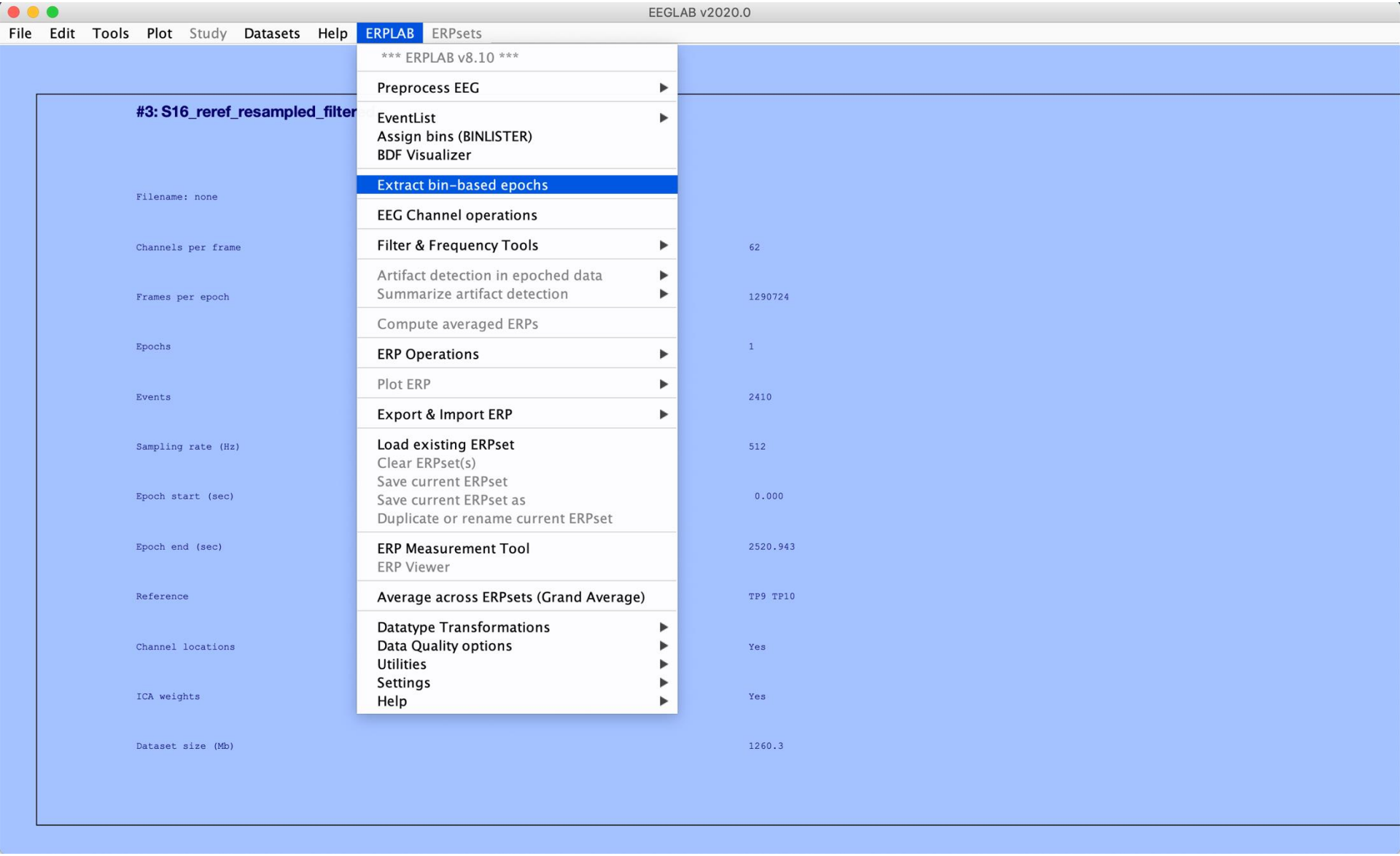
```
Bin 1
.{100}{t<200-3000>91;92}

Bin 2
.{101}{t<200-3000>91;92}

Bin 3
.{102}{t<200-3000>91;92}

Bin 4
.{103}{t<200-3000>91;92}
```


EEGLAB v2020.0
File Edit Tools Plot Study Datasets Help ERPLAB ERPsets
*** ERPLAB v8.10 ***
Preprocess EEG
EventList
Assign bins (BINLISTER)
BDF Visualizer
Extract bin-based epochs
EEG Channel operations
Filter & Frequency Tools
Artifact detection in epoched data
Summarize artifact detection
Compute averaged ERPs
ERP Operations
Plot ERP
Export & Import ERP
Load existing ERPset
Clear ERPset(s)
Save current ERPset
Save current ERPset as
Duplicate or rename current ERPset
ERP Measurement Tool
ERP Viewer
Average across ERPsets (Grand Average)
Datatype Transformations
Data Quality options
Utilities
Settings
Help
#3: S16_reref_resampled_filter
Filename: none
Channels per frame 62
Frames per epoch 1290724
Epochs 1
Events 2410
Sampling rate (Hz) 512
Epoch start (sec) 0.000
Epoch end (sec) 2520.943
Reference TP9 TP10
Channel locations Yes
ICA weights Yes
Dataset size (Mb) 1260.3

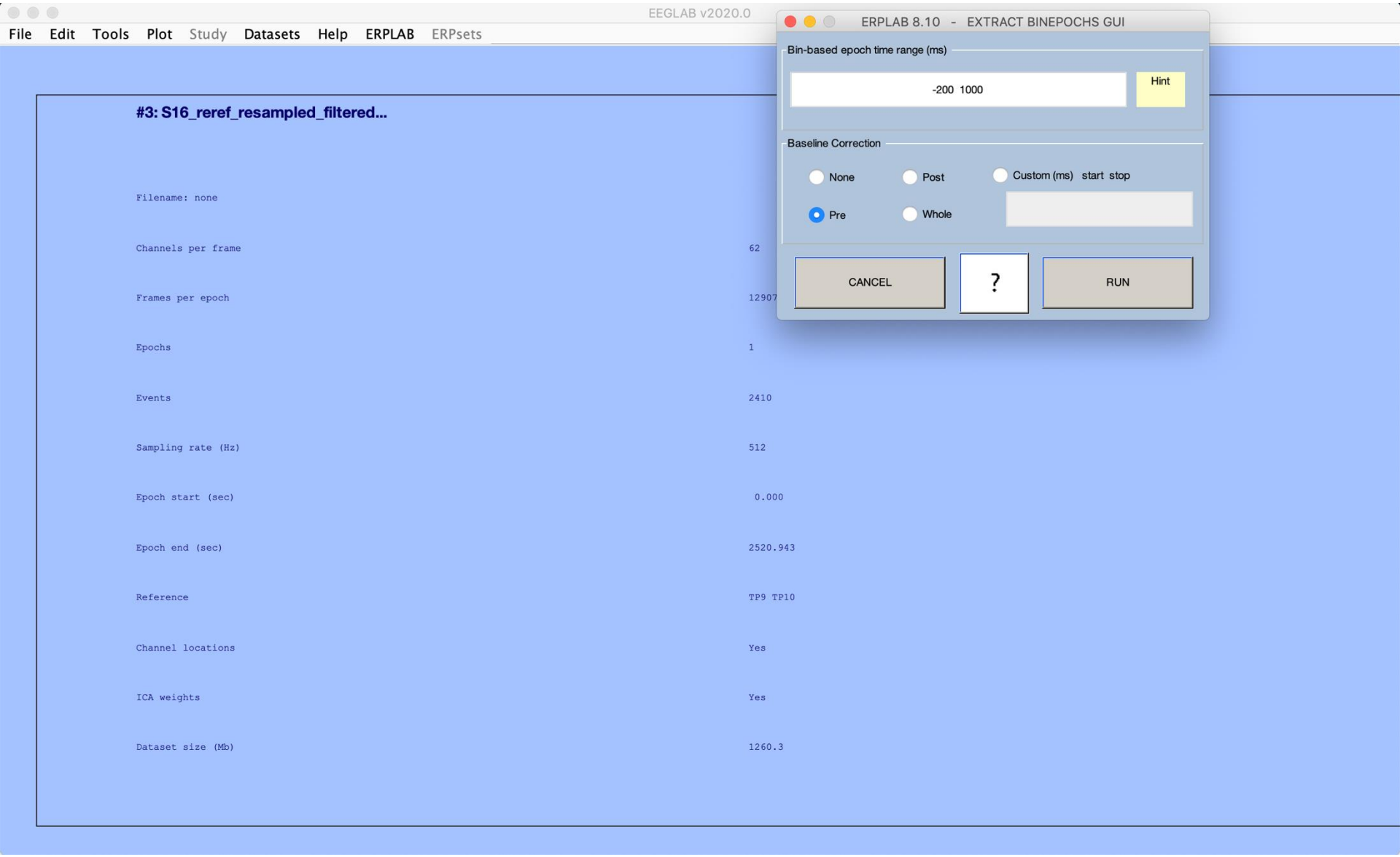


https://github.com/lucklab/erplab/wiki/Assigning-Events-to-Bins-with-BINLISTER:-Tutorial

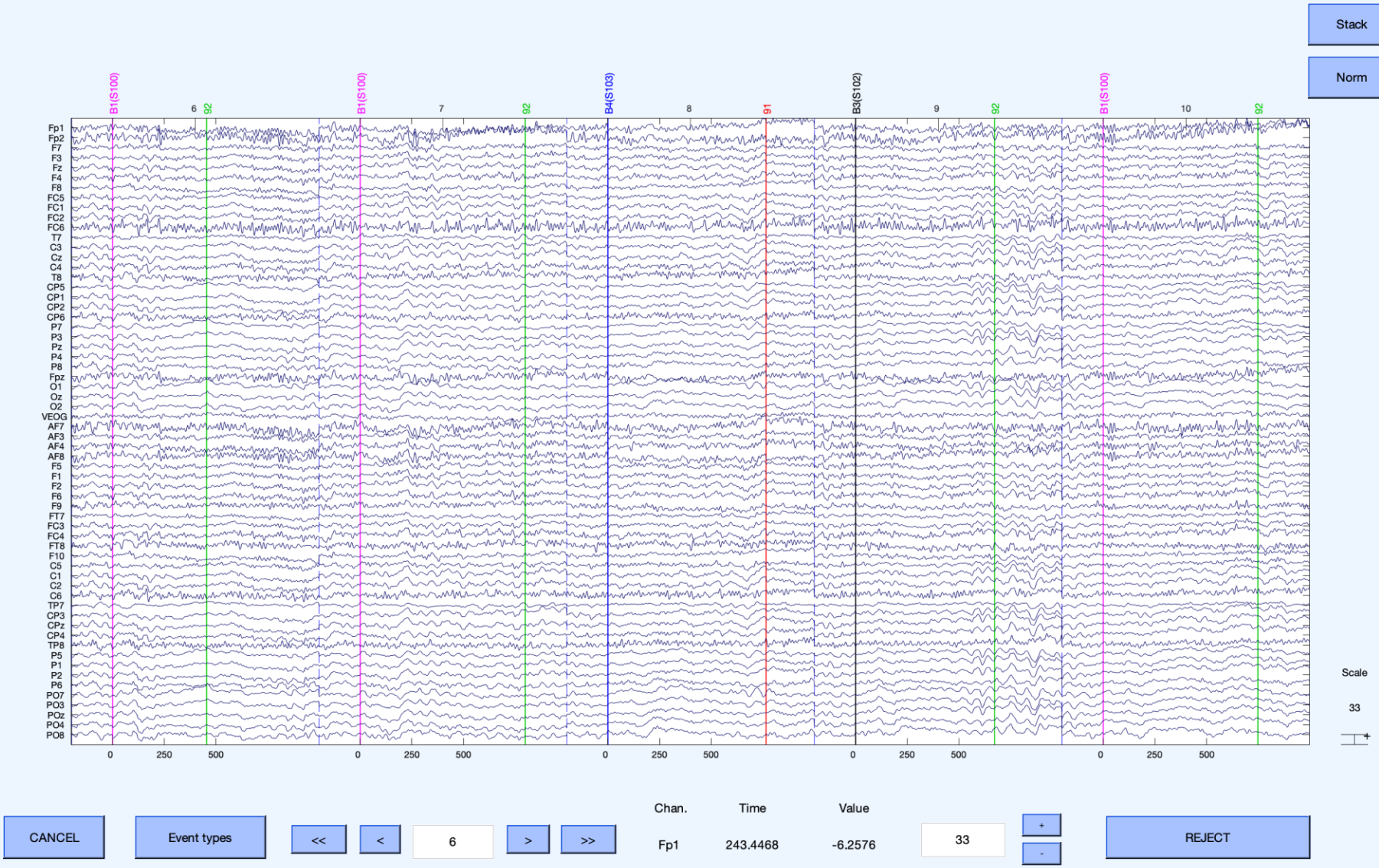
Creating Bin Based EEG Epochs



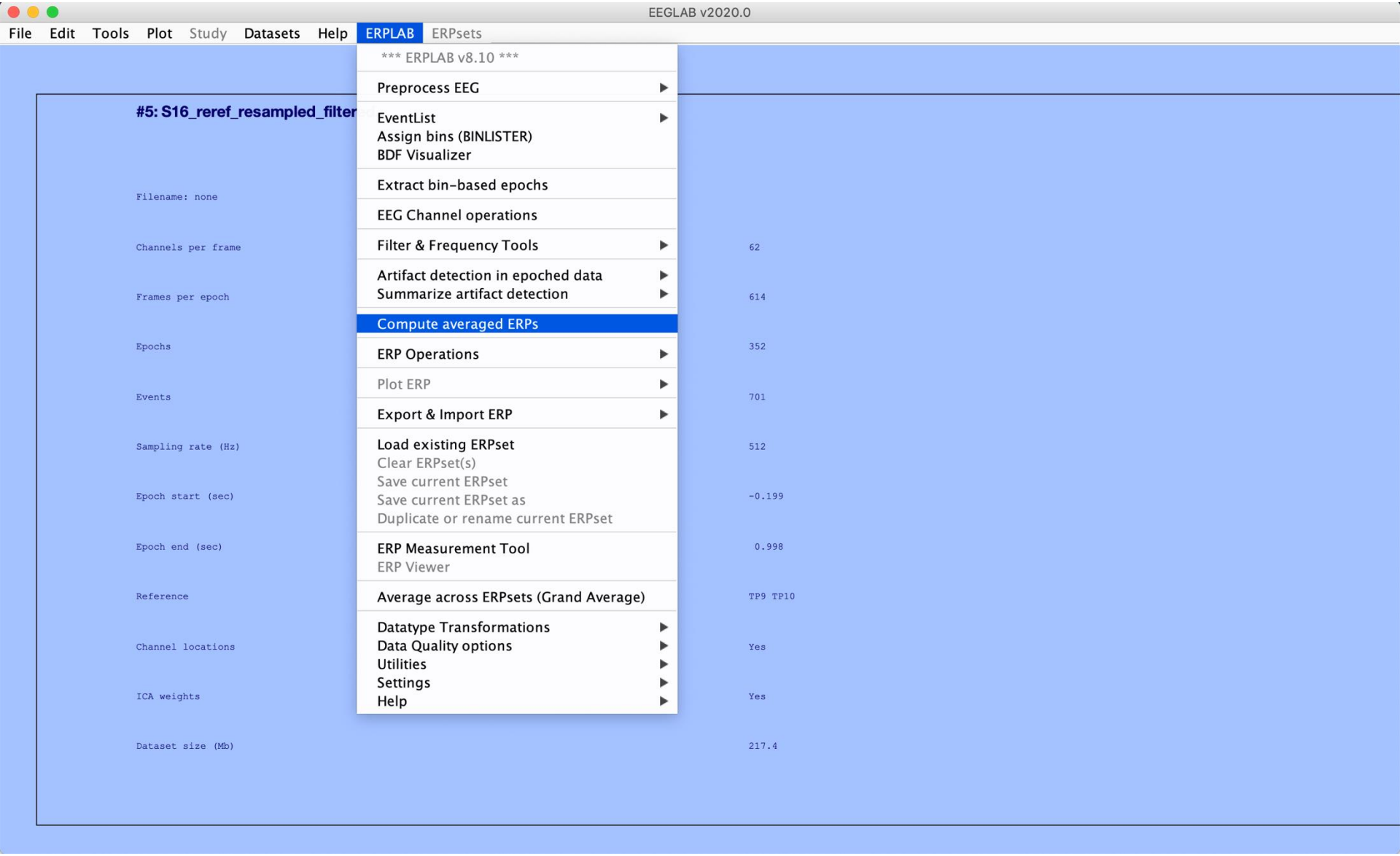
Creating Bin Based EEG Epochs



Creating Bin Based EEG Epochs



Averaging


EEGLAB v2020.0
File Edit Tools Plot Study Datasets Help ERPLAB ERPsets
*** ERPLAB v8.10 ***
Preprocess EEG
EventList
Assign bins (BINLISTER)
BDF Visualizer
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Artifact detection in epoched data
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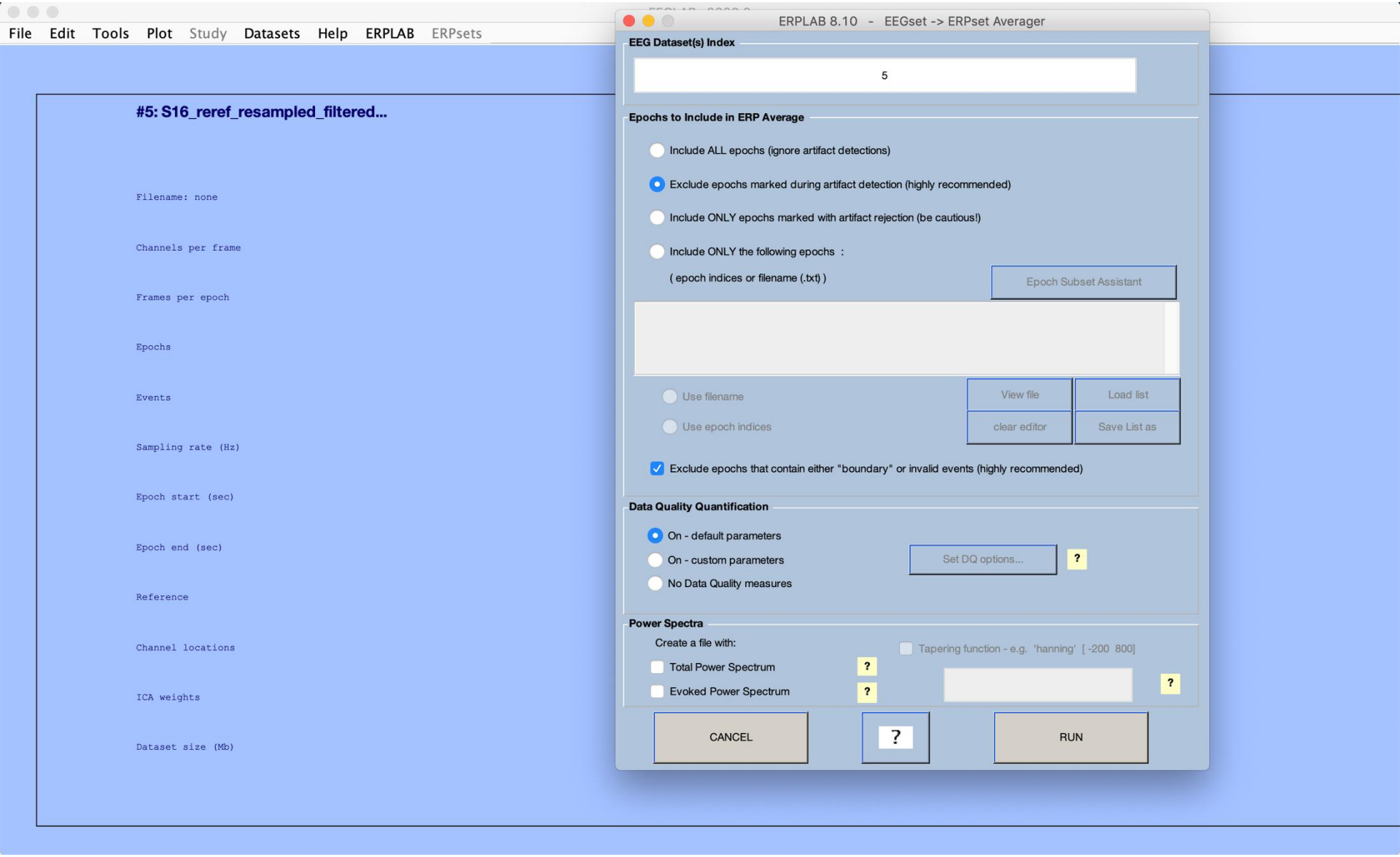
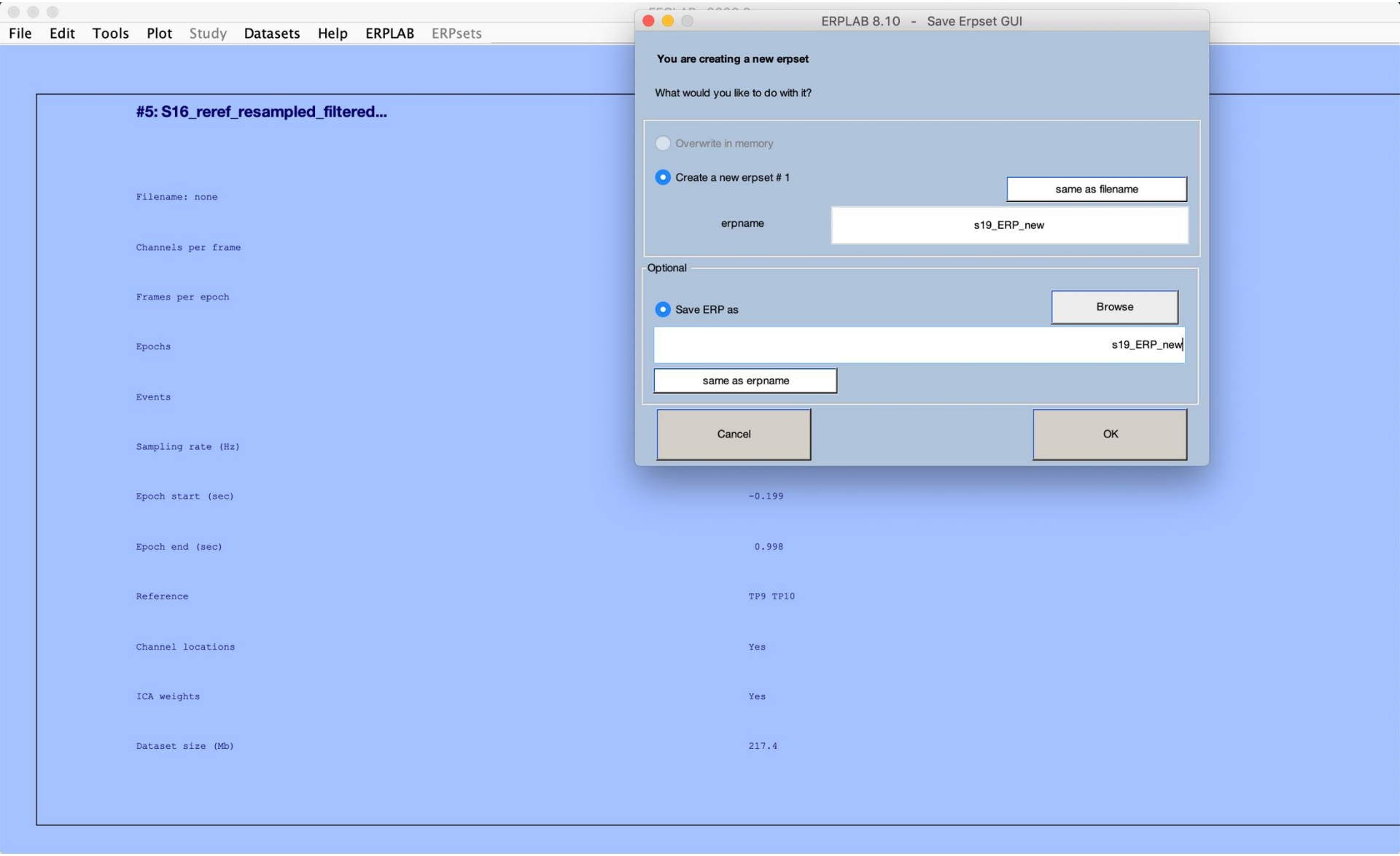
Save current ERPset as
Duplicate or rename current ERPset
ERP Measurement Tool
ERP Viewer
Average across ERPsets (Grand Average)
Datatype Transformations
Data Quality options
Utilities
Settings
Help
#5: S16_reref_resampled_filter
Filename: none
Channels per frame 62
Frames per epoch 614
Epochs 352
Events 701
Sampling rate (Hz) 512
Epoch start (sec) -0.199
Epoch end (sec) 0.998
Reference TP9 TP10
Channel locations Yes
ICA weights Yes
Dataset size (Mb) 217.4

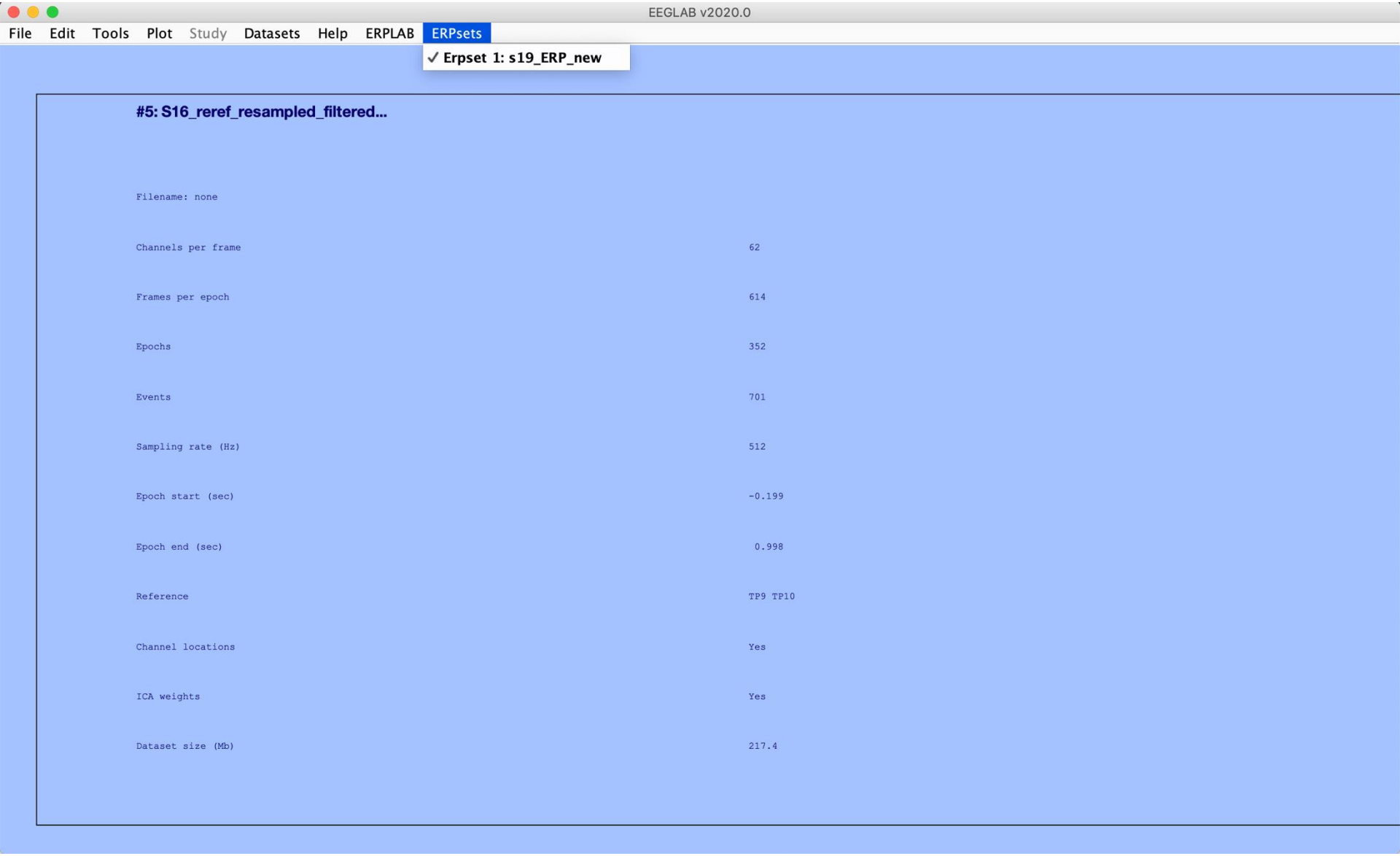
Averaging


File Edit Tools Plot Study Datasets Help ERPLAB ERPsets
#5: S16_reref_resampled_filtered...
Filename: none
Channels per frame
Frames per epoch
Epochs
Events
Sampling rate (Hz)
Epoch start (sec)
Epoch end (sec)
Reference
Channel locations
ICA weights
Dataset size (Mb)
ERPLAB 8.10 - EEGset -> ERPset Averager
EEG Dataset(s) Index
5
Epochs to Include in ERP Average
Include ALL epochs (ignore artifact detections)
Exclude epochs marked during artifact detection (highly recommended)
Include ONLY epochs marked with artifact rejection (be cautious!)
Include ONLY the following epochs :
(epoch indices or filename (.txt))
Epoch Subset Assistant
Use filename
Use epoch indices
View file
Load list
clear editor
Save List as
Exclude epochs that contain either "boundary" or invalid events (highly recommended)
Data Quality Quantification
On - default parameters
On - custom parameters
No Data Quality measures
Set DQ options...
Power Spectra
Create a file with:
Total Power Spectrum
Evoked Power Spectrum
Tapering function - e.g. 'hanning' [-200 800]
CANCEL
RUN

Averaging


File Edit Tools Plot Study Datasets Help ERPLAB ERPsets
#5: S16_reref_resampled_filtered...
Filename: none
Channels per frame
Frames per epoch
Epochs
Events
Sampling rate (Hz)
Epoch start (sec) -0.199
Epoch end (sec) 0.998
Reference TP9 TP10
Channel locations Yes
ICA weights Yes
Dataset size (Mb) 217.4
ERPLAB 8.10 - Save Erpset GUI
You are creating a new erpset
What would you like to do with it?
Overwrite in memory
Create a new erpset # 1
same as filename
erpname
s19_ERP_new
Optional
Save ERP as
Browse
s19_ERP_new
same as erpname
Cancel
OK

Averaging


EEGLAB v2020.0
File Edit Tools Plot Study Datasets Help ERPLAB ERPsets
✓ Erpset 1: s19_ERP_new
#5: S16_reref_resampled_filtered...
Filename: none
Channels per frame 62
Frames per epoch 614
Epochs 352
Events 701
Sampling rate (Hz) 512
Epoch start (sec) -0.199
Epoch end (sec) 0.998
Reference TP9 TP10
Channel locations Yes
ICA weights Yes
Dataset size (Mb) 217.4

Overview

1. Averaging single trials into specific conditions
2. Plotting ERP data
3. Measuring ERP amplitudes
4. Measuring ERP latencies
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6. Statistical analysis (SPSS/R/Python)

Society for Psychophysiological Research guidelines

„The presentation of averaged ERP waveforms that illustrate the principal phenomena is mandatory“

Picton et al., 2002, p. 139

You must show plots of the key ERP waveforms!

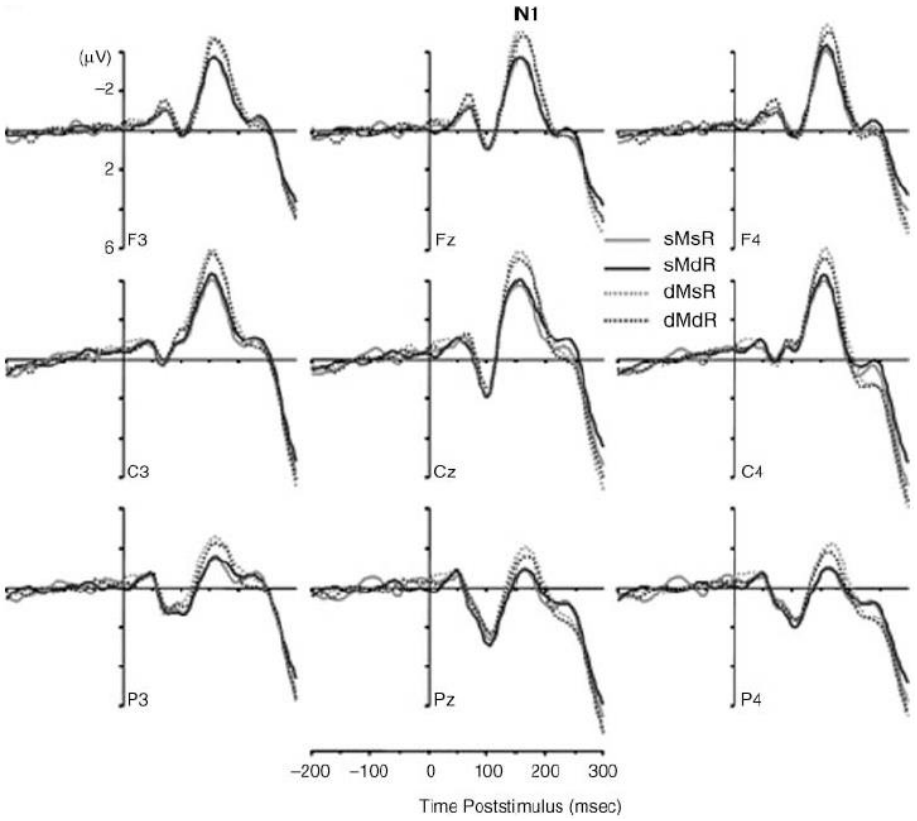
General Recommendations

1. show data from multiple electrode sites

- spanning the region of the scalp (with equal distances) where the effects of interest are present

- helps to determine underlying component structure: lateralized?

- avoid showing more than 8-10 sites per figure



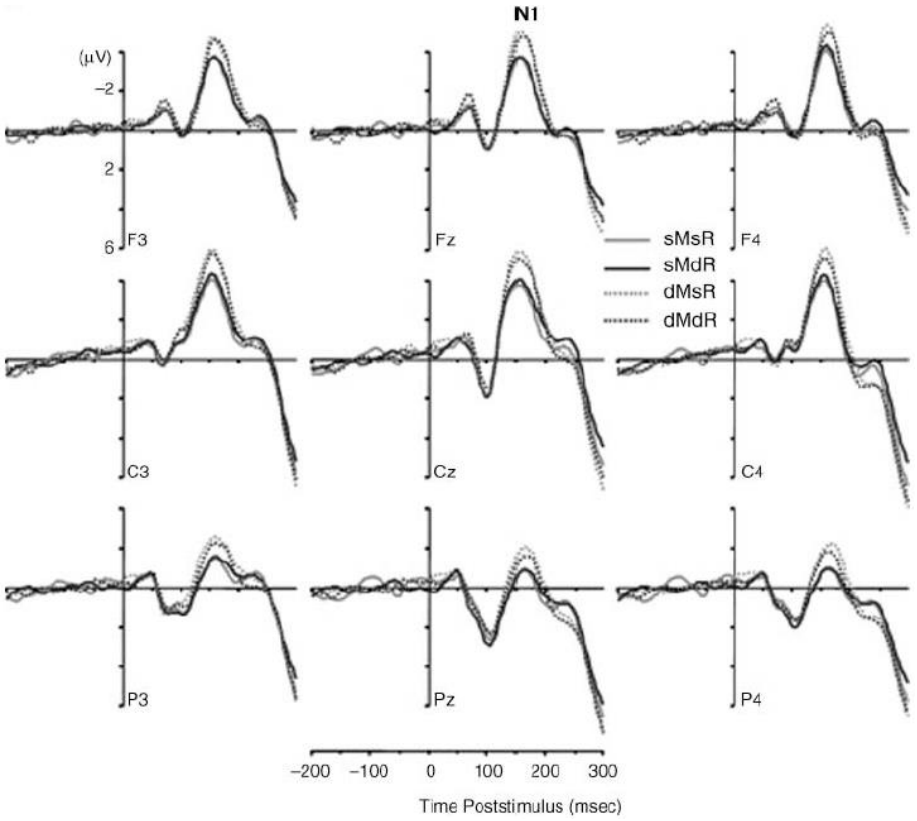
General Recommendations

1. show data from multiple electrode sites

‣ however, exact number of electrode sites depends on expected audience:

‣ broad selection for ERP-oriented journals (e.g., Psychophysiology)

‣ only key sites for journals that are not specifically ERP-oriented

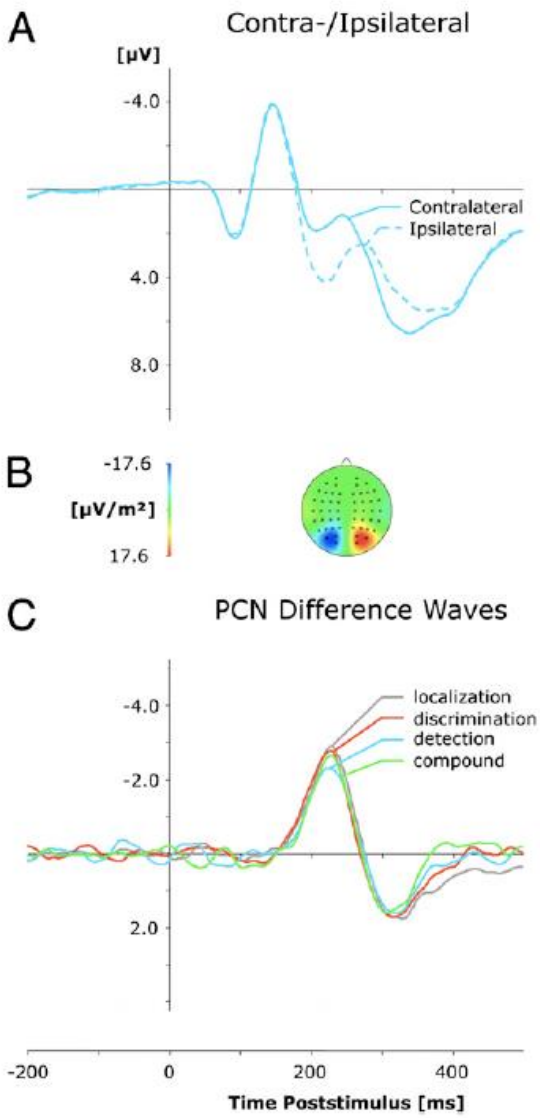


General Recommendations

1. show data from multiple electrode sites

- EXCEPTION: just one site for well-established event-related lateralizations (PCN, CDA, LRP)

- in this case, show both original and difference waves



Töllner et al., 2012, PNAS

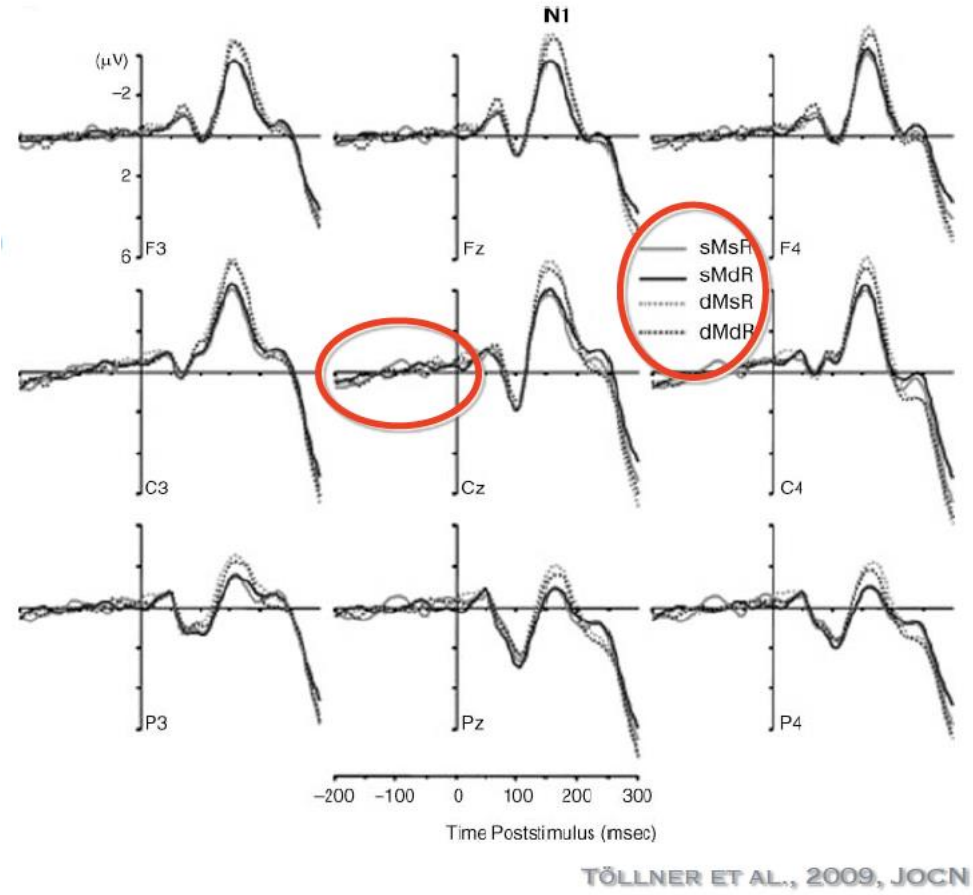
General Recommendations

3. A pre-stimulus baseline must be shown

- typically 200 ms (minimum: 100 ms)

- baseline needs to show 0 µV (in average)

4. Provide figure legend to indicate experimental conditions



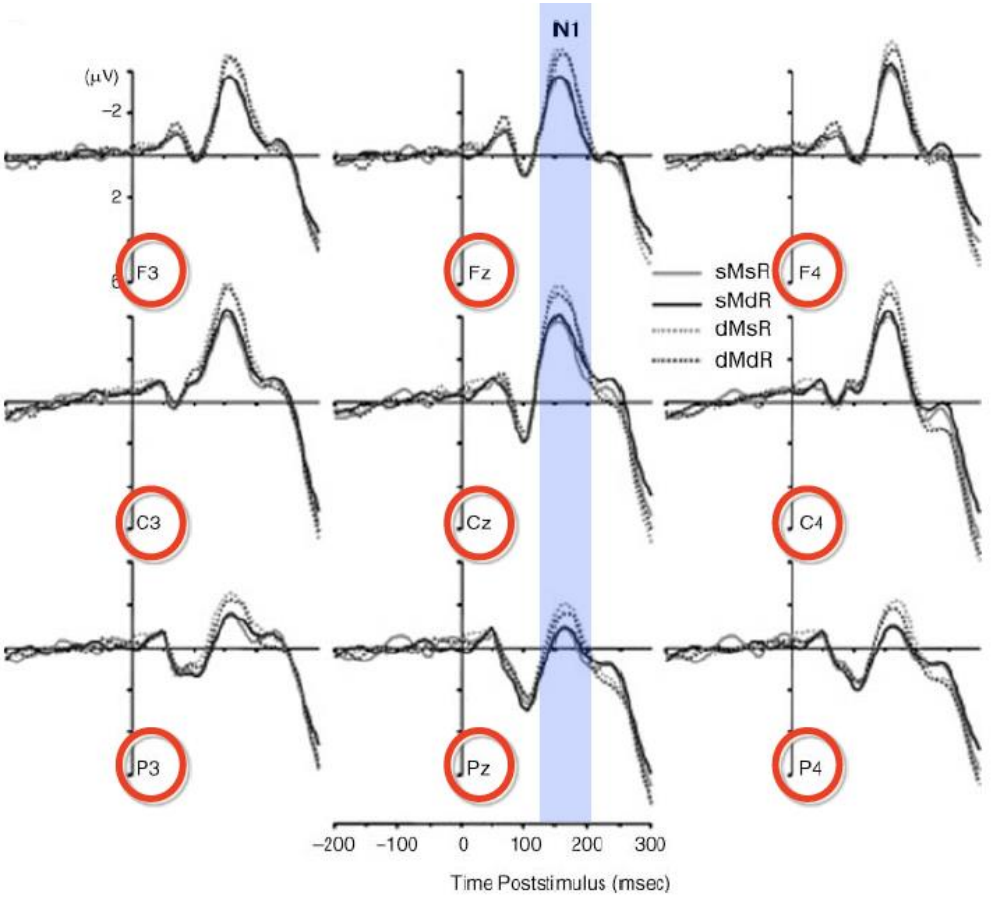
TÖLLNER ET AL., 2009, JOCN

General Recommendations

5. Label electrode sites

6. ERP waveforms should be overlapping (max. 4)

7. Eventually highlight time window (or component) of interest



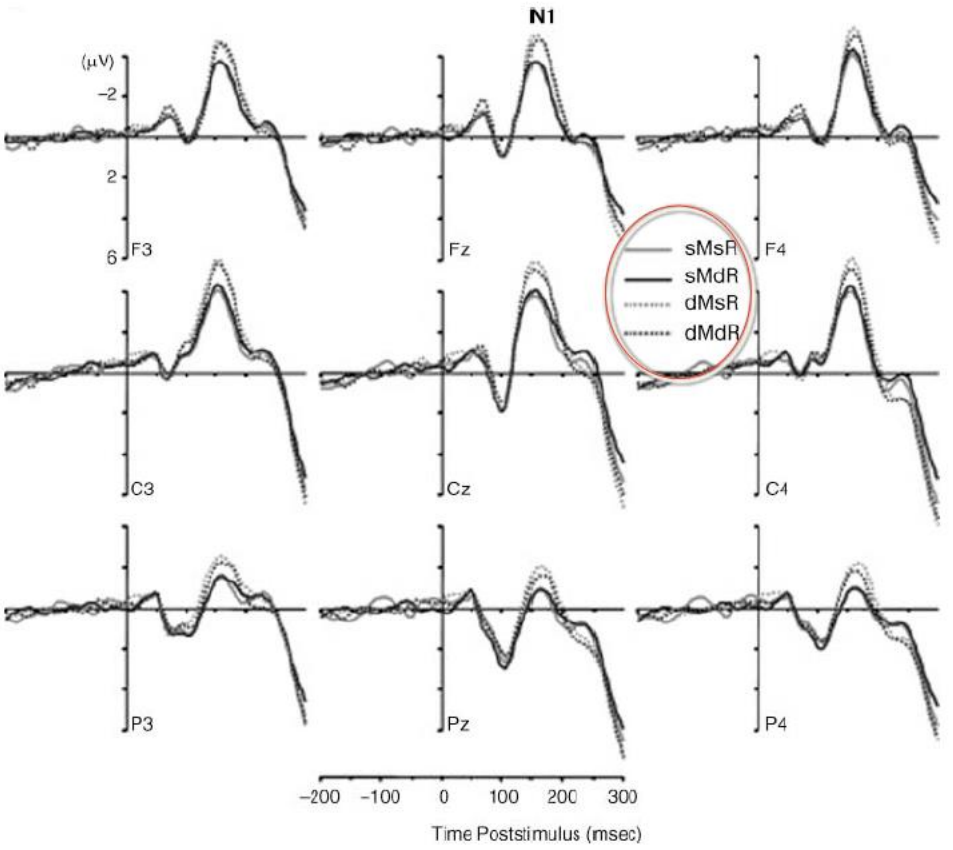
TÖLLNER ET AL., 2009, JOCN

8. use easy-to-distinguish line types for conditions

‣ to differentiate: use solid, dashed, dotted (or differently colored) lines ...

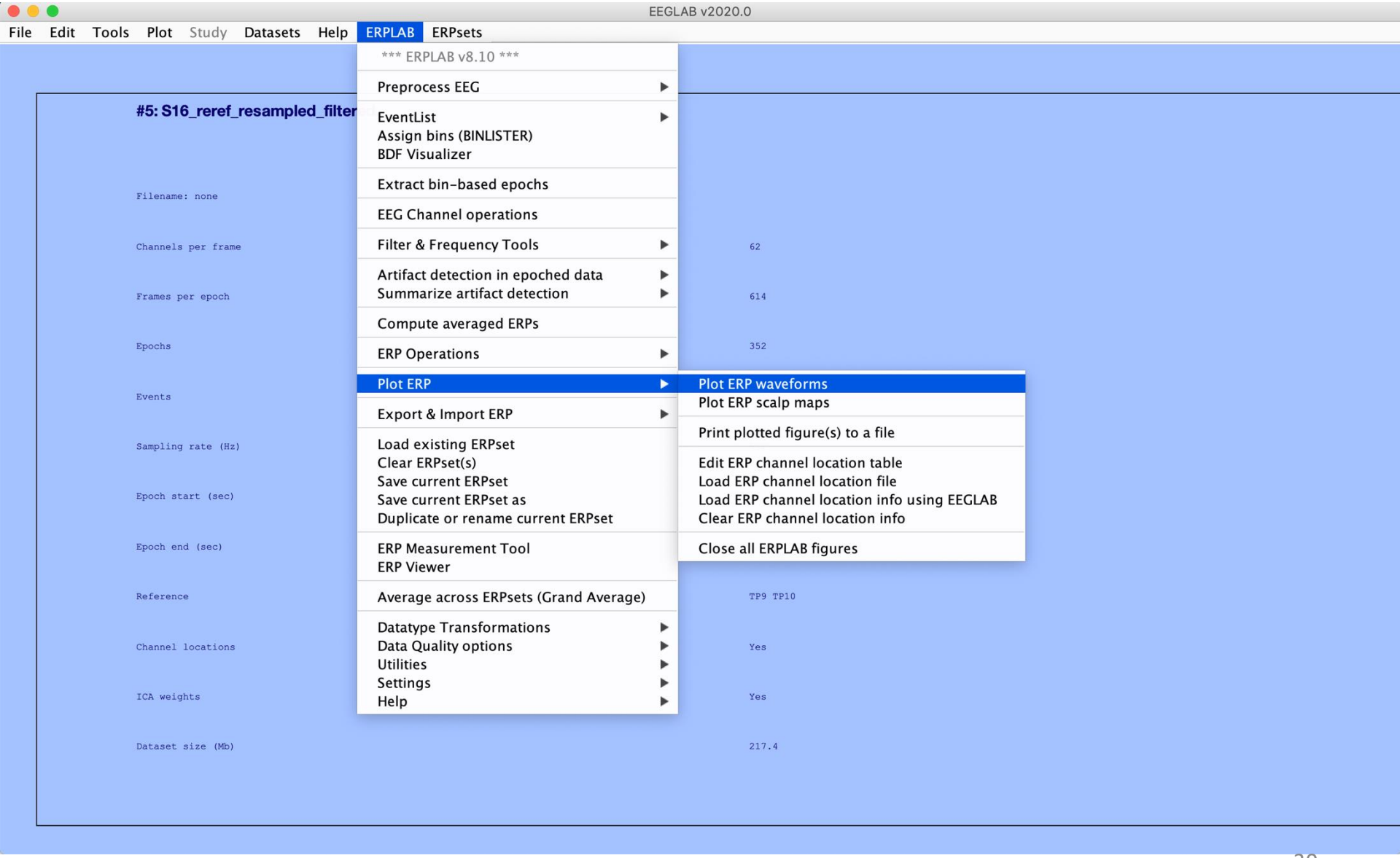
‣ use reasonably thick lines (1-2 points width)

‣ but, avoid different line thicknesses

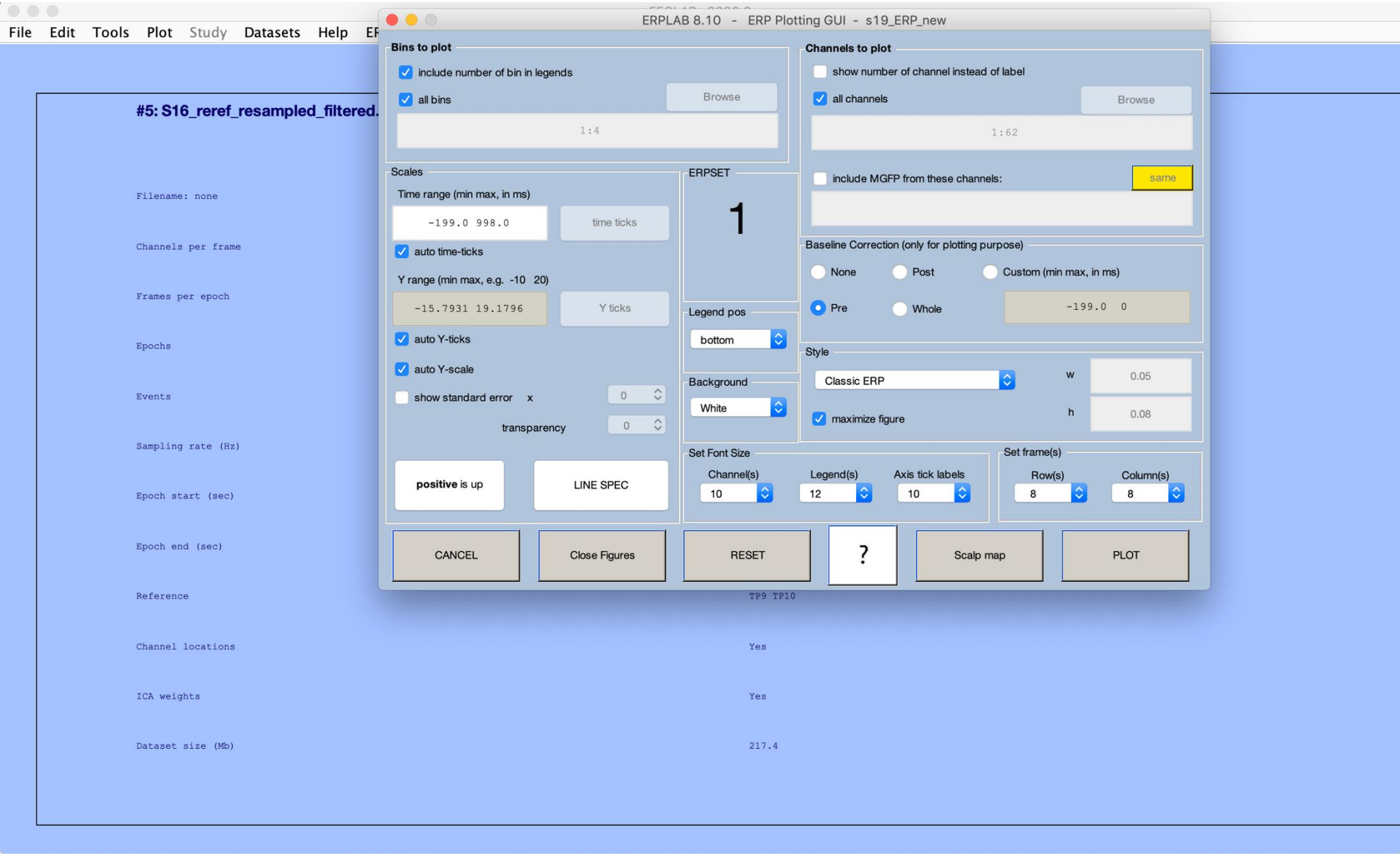


TÖLLNER ET AL., 2009, JOCN

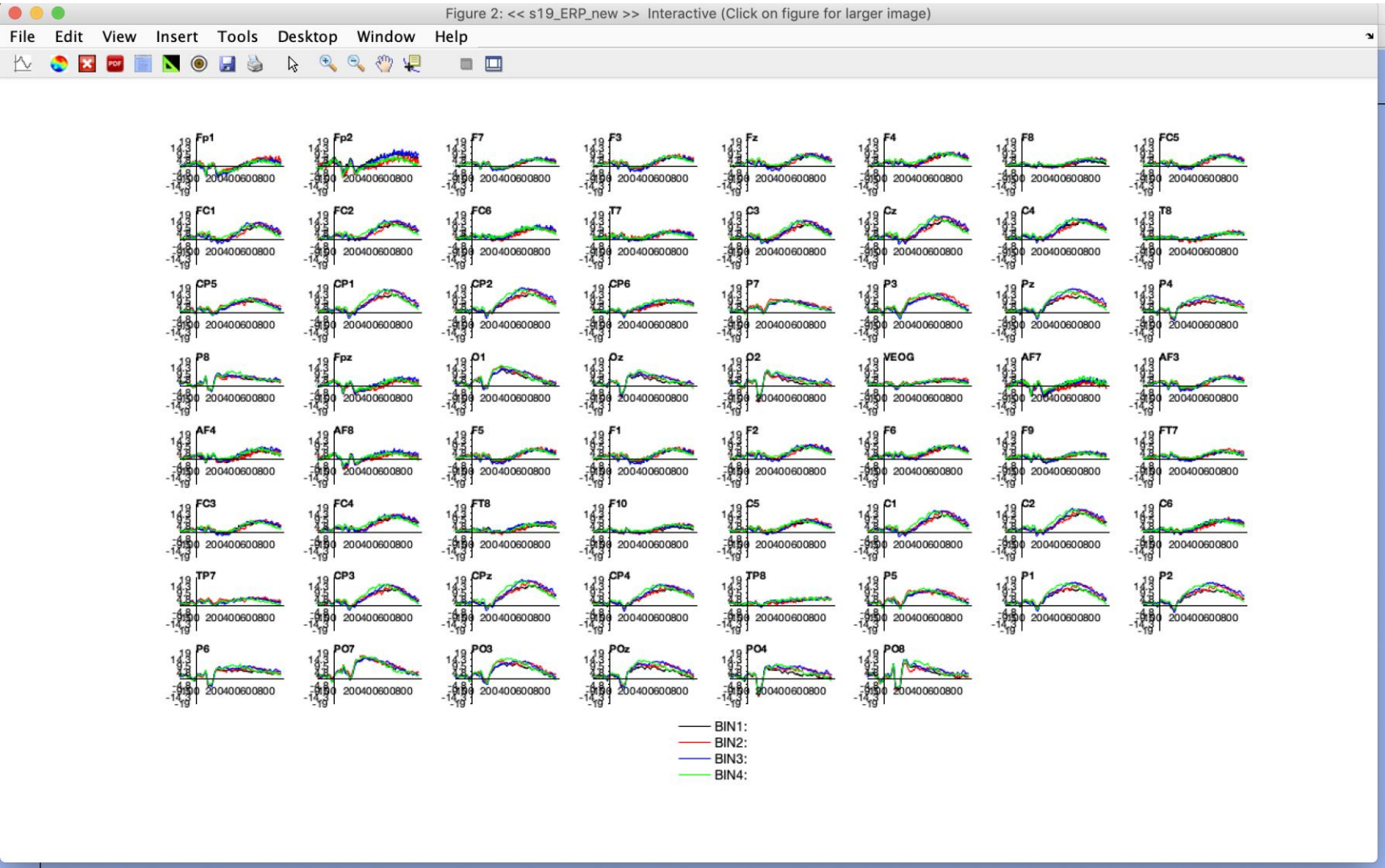
Plotting ERP data



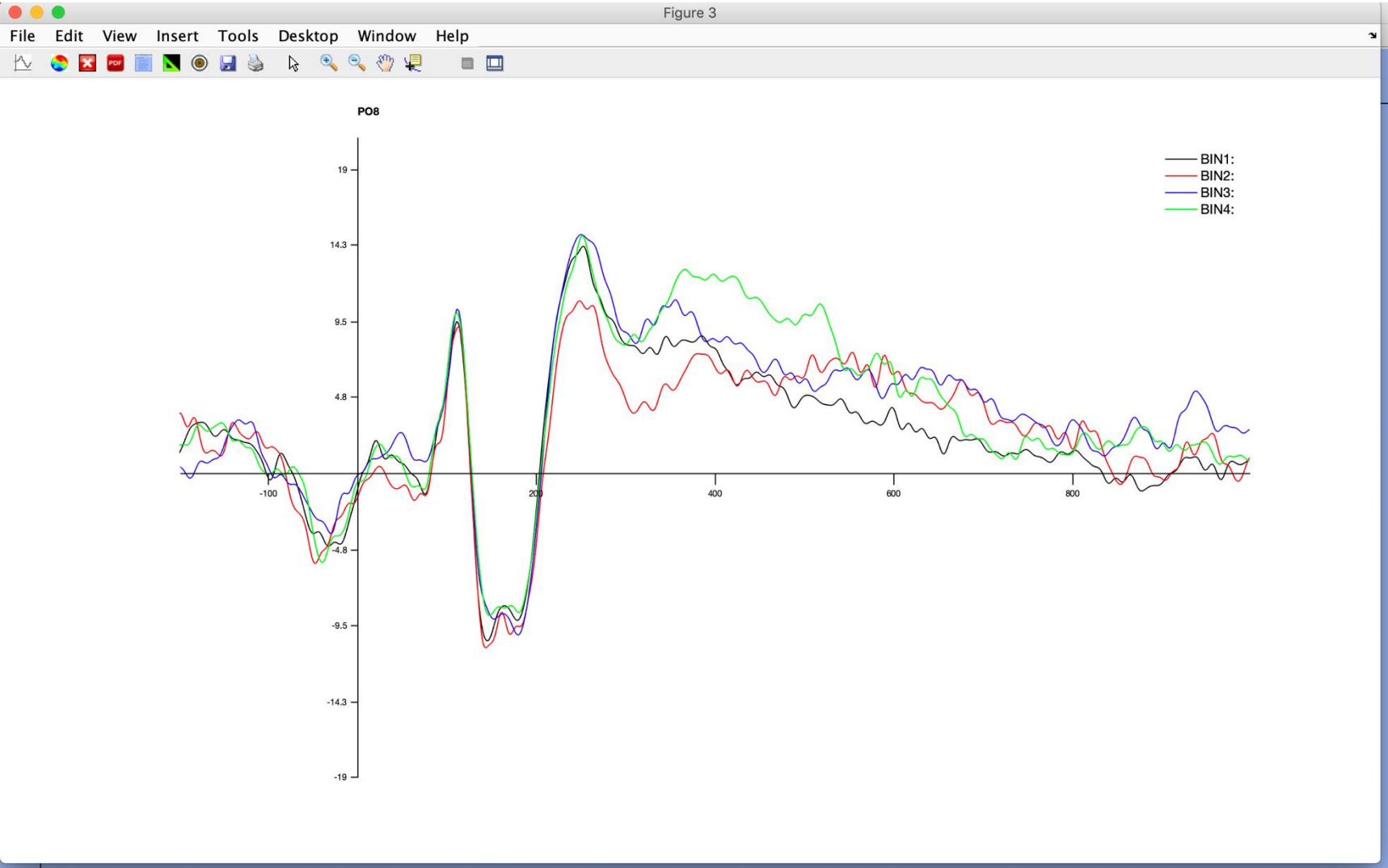
Plotting ERP data



Plotting ERP data



Plotting ERP data



Overview

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6. Statistical analysis (SPSS/R/Python)

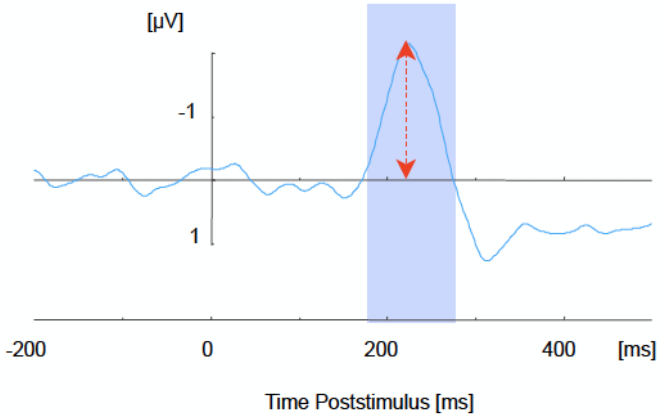
Main Goal (challenge) is ...

„ ... to provide an accurate measurement of the size of the underlying ERP component“ - Luck, 2005

2 common ways:

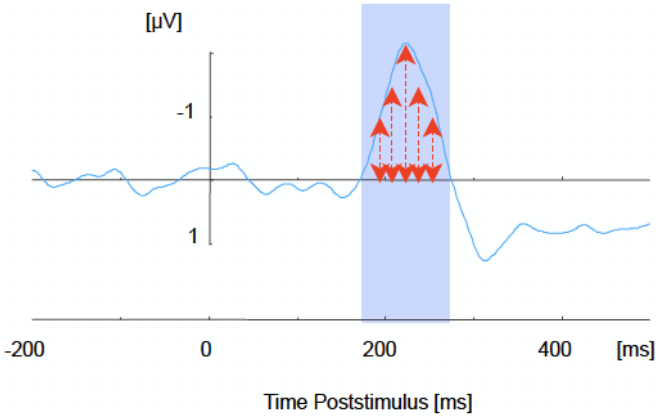
#1 - peak amplitude

- ... find the maximum amplitude in pre-defined time window

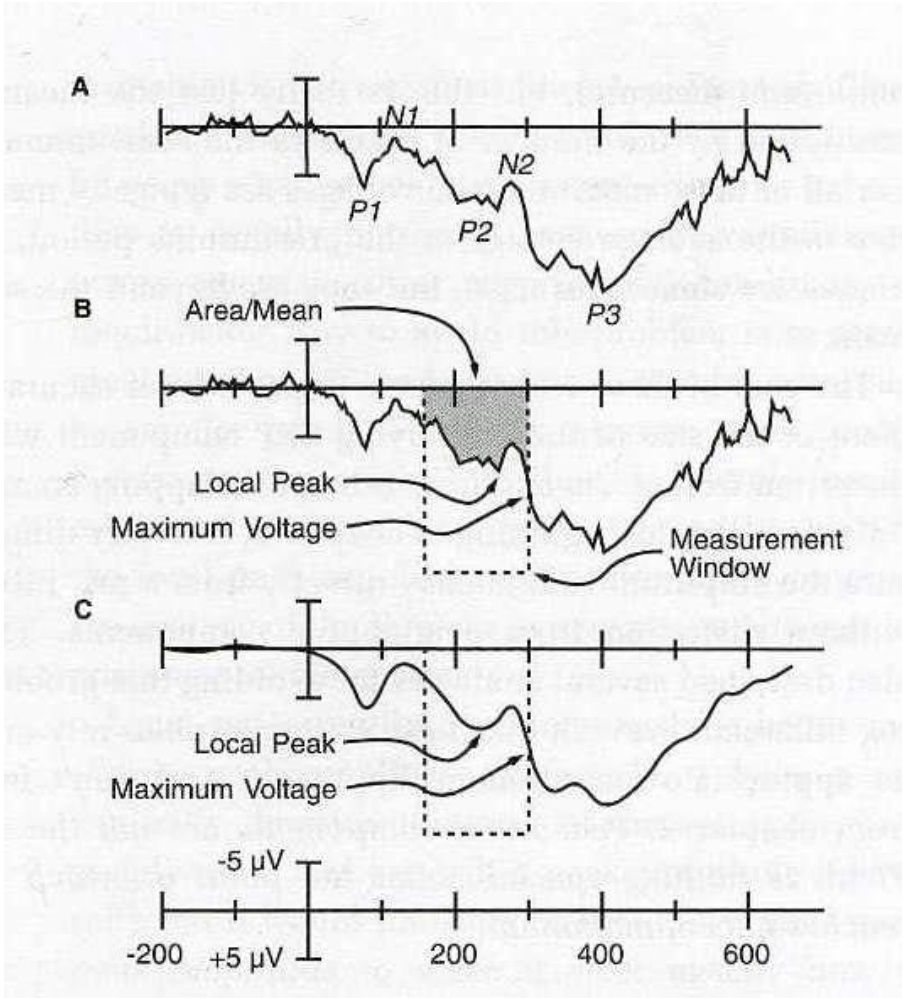


#2 - mean/area amplitude

- calculate the mean voltage in pre-defined time window



Peak Amplitude: Shortcomings



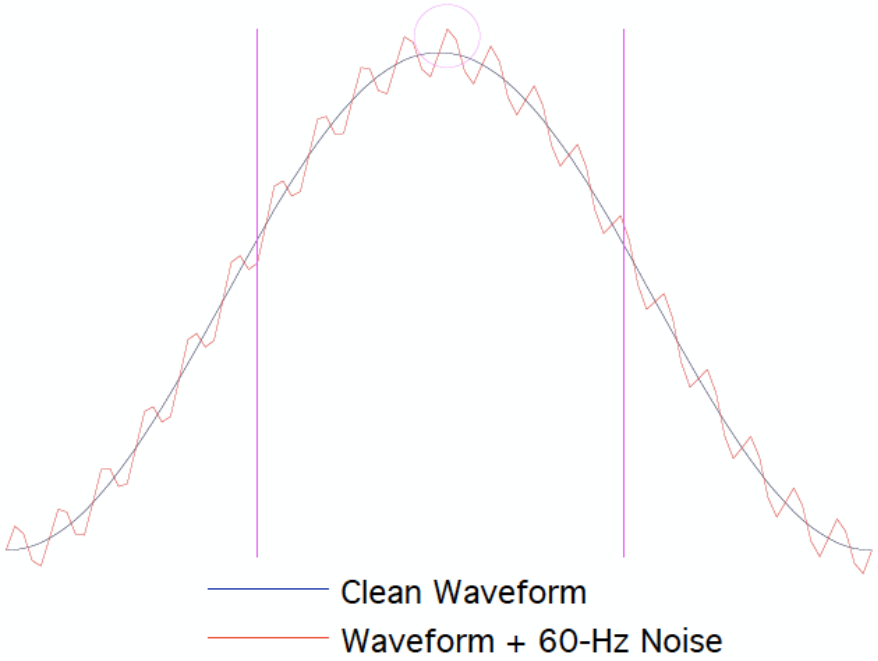
(1) can be affected by overlapping components!!!

- use narrower measurement Window

- but, needs to cover latency variations across electrode sites, conditions, and subjects!

- use local (instead of ‚global') peak amplitude detection mode

Peak Amplitude: Shortcomings



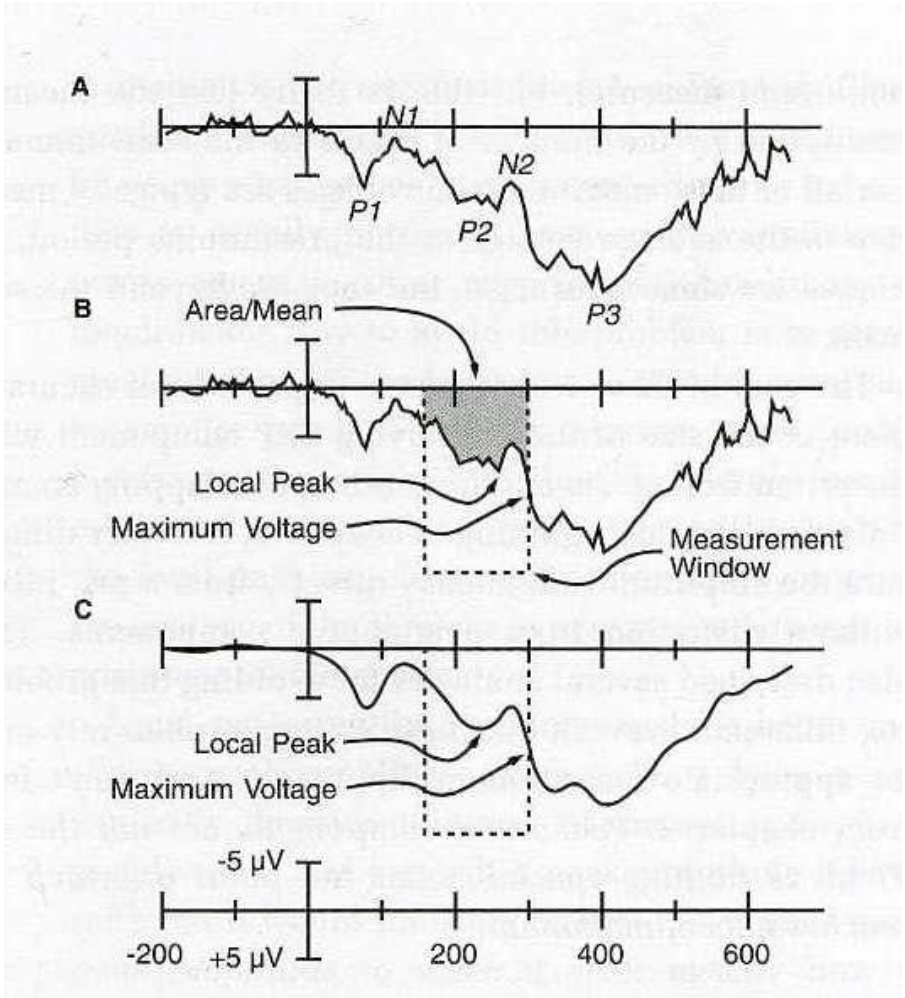
(2) can be significantly distorted by high-frequency noise!!!

- ... peak amplitudes measures are artificially increased for noisy data ...

- never valid to compare peak amplitudes from averages of different number of trials!

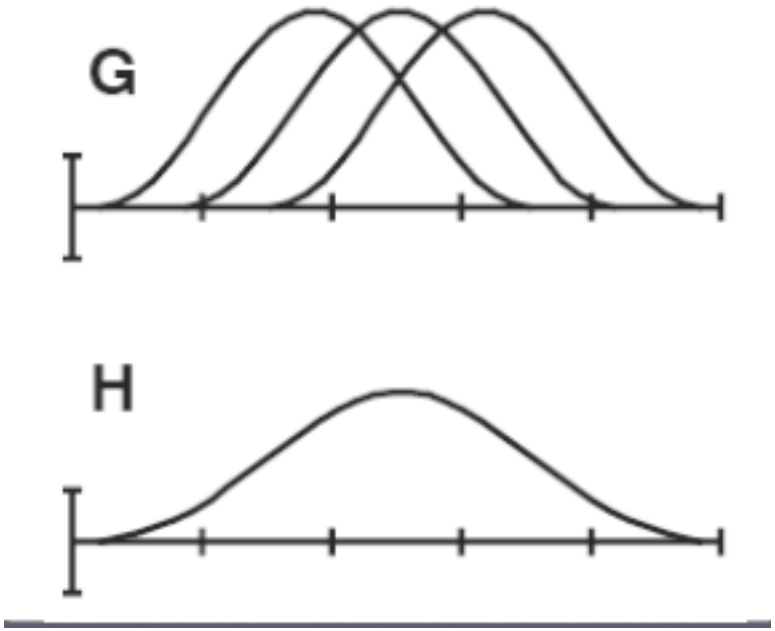
- eventually low pass filter waveforms, if ERPs are too noisy

Peak Amplitude: Shortcomings



(3) uses a single point to re-present a component that may last several hundred milliseconds

Peak Amplitude: Shortcomings



(4) is a non-linear measure that may NOT correspond well with grand-average Waveforms

‣ e.g., latency differences across electrode sites due to the relative amplitudes of the overlapping components

Mean Amplitude: Advantages

(1) allows use of narrower time windows to reduce influence of overlapping components

(2) less sensitive to high frequency Noise

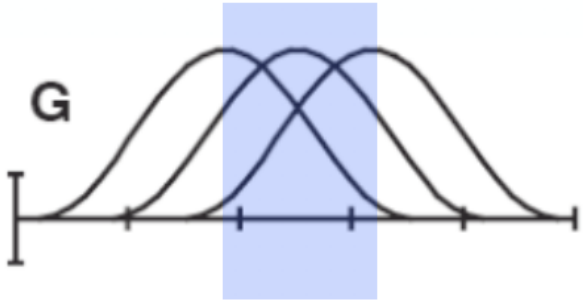
(3) ... is a linear measure >> corresponds well with grand-average waveforms

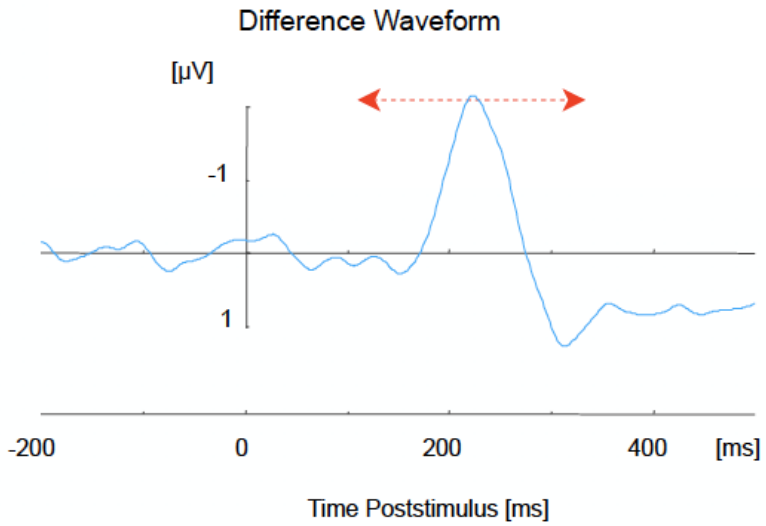
Mean Amplitude: Disadvantages

(1) fixed windows useless if under-lying process does indeed differ in timing!

(2) Can encourage fishing for significant results by trying different windows

‣ use symmetric time windows based on grand-averages!





So ... what to choose then?

#1 - peak amplitude

... find the maximum amplitude in pre-defined time window

#2 - mean amplitude

calculate the mean voltage in pre-defined time window

First, find the maximum amplitude in predefined time window based on visual inspection

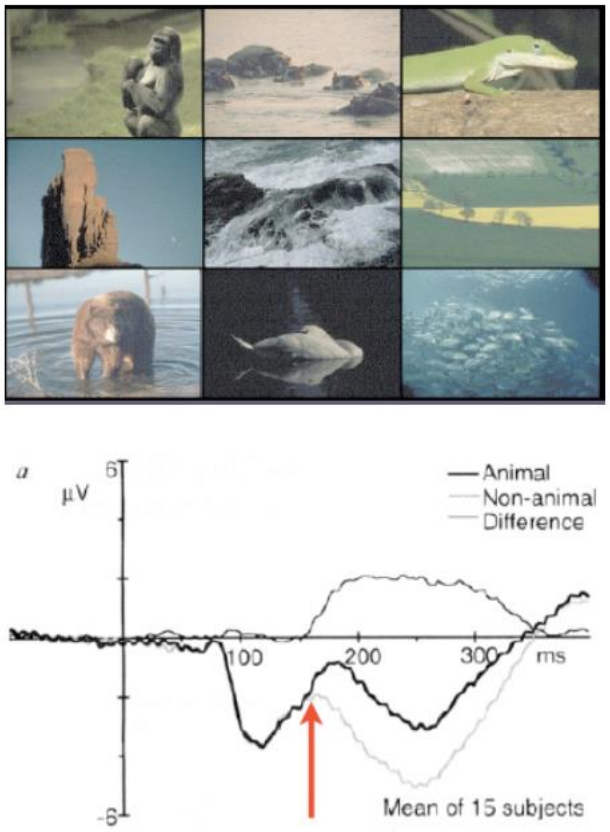
Second, average plus/minus xxx sample points before and after the maximum deflection

How to find the right measurement window?

First, make sure whether you want to analyze your data in a component-dependent or component-independent manner (crucial for interpretation)!

For component analysis: use time window - as symmetrical as possible - around the peak of grand-averaged ERPs!

Consider different measurement windows for different subjects (e.g., CDA triggered by young versus old participants ...)



THORPE ET AL., 1996, NATURE

Overview

1. Averaging single trials into specific conditions
2. Plotting ERP data
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4. Measuring ERP latencies
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6. Statistical analysis (SPSS/R/Python)

3 ways to reveal the component‘s timing:

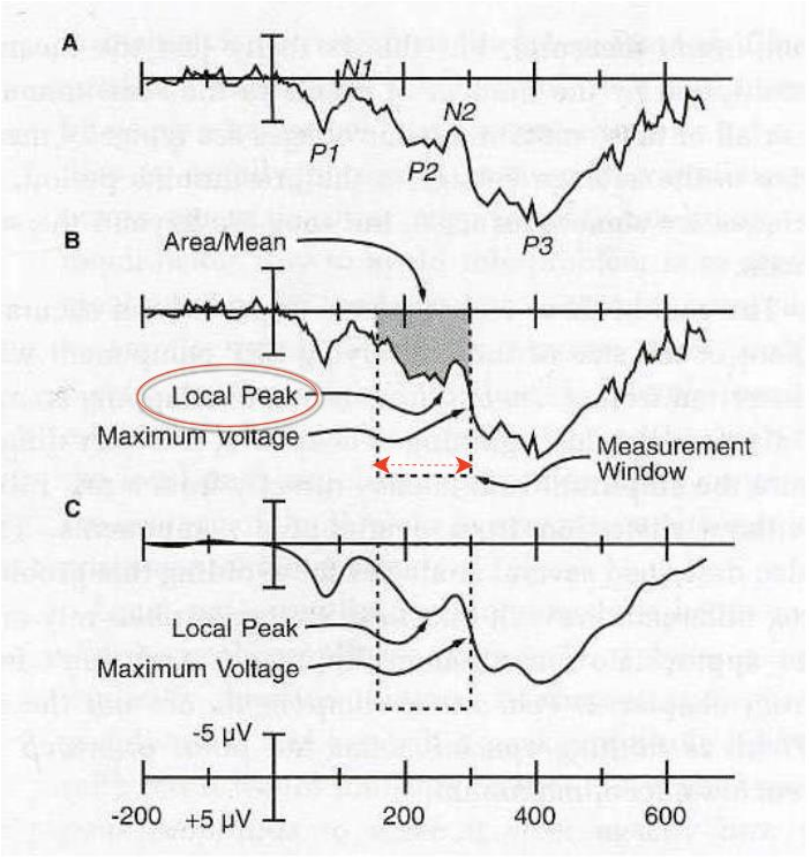
#1 - peak latency

#2 - fractional area latency

#3 - onset latency

Peak Latency: Shortcomings

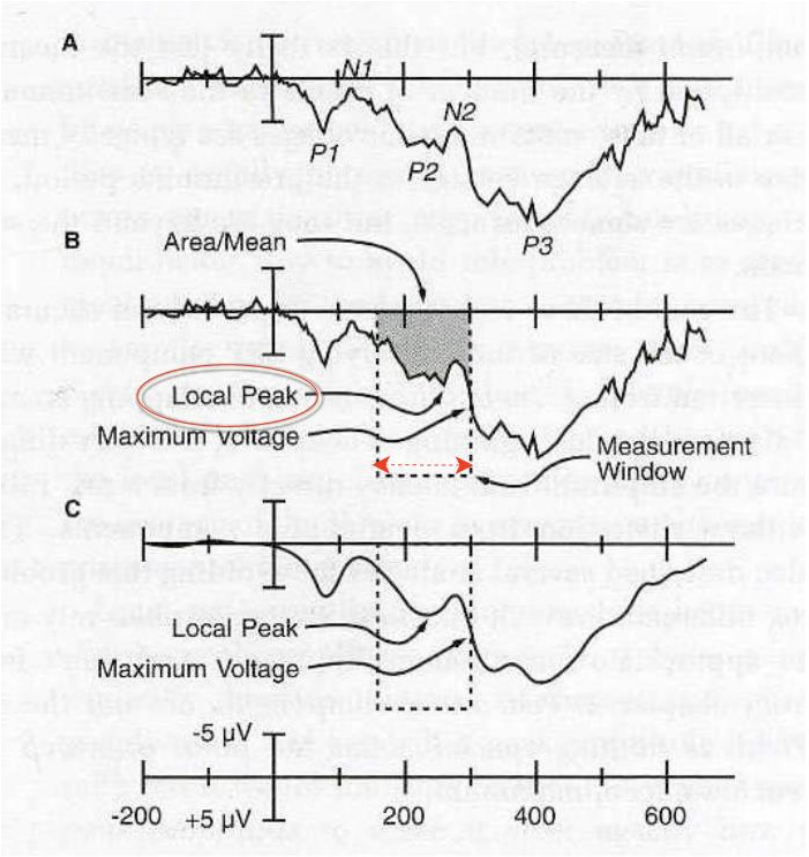
same shortcomings as for peak amplitude measure:



- (1) affected by overlapping Components
- (2) highly sensitive to high frequency Noise
- (3) encourages the mistaken view that peaks and components are the same thing ...

Peak Latency: Precautions

there just aren‘t many good alternatives ...
Thus:



(1) filter out high-frequency Noise

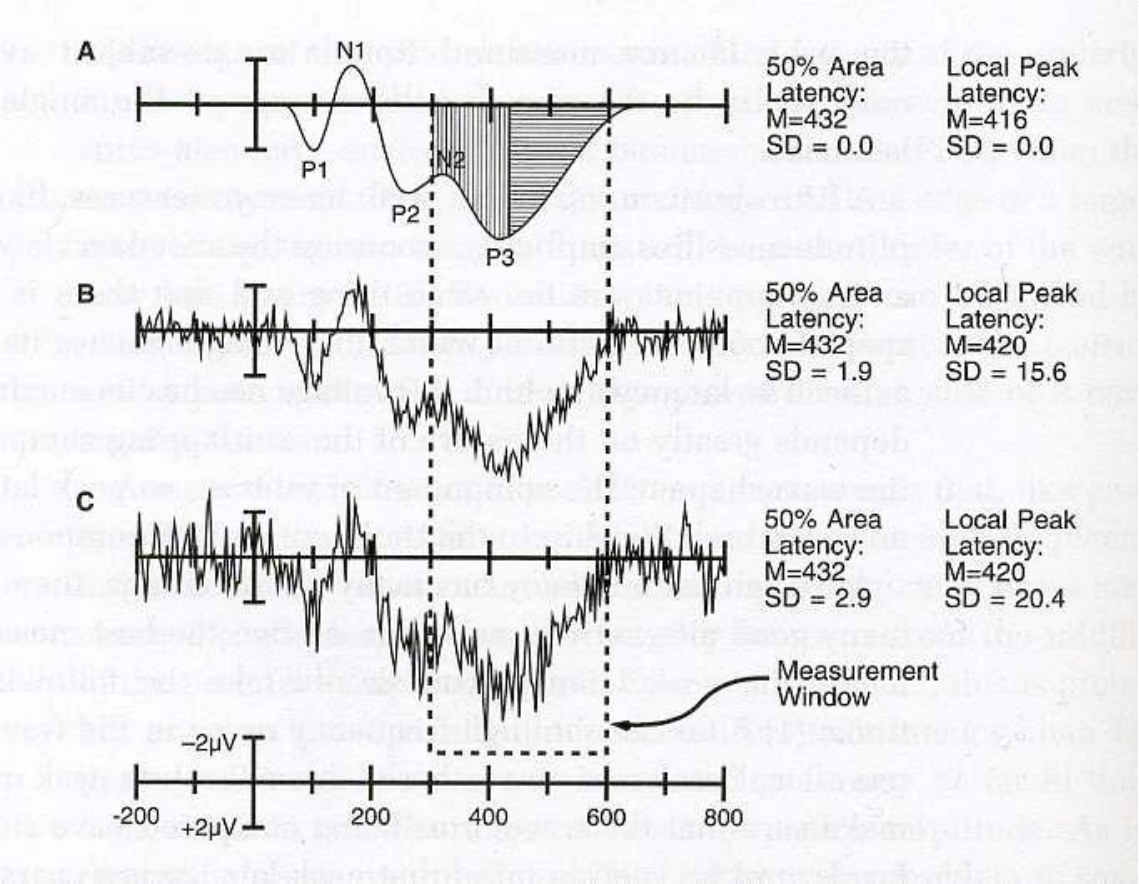
(2) use local rather than absolute peak measure

(3) waveforms being compared should have similar noise levels

(4) Always visually inspect your peak detections!

Fractional area Latency

analogous to mean amplitude measures



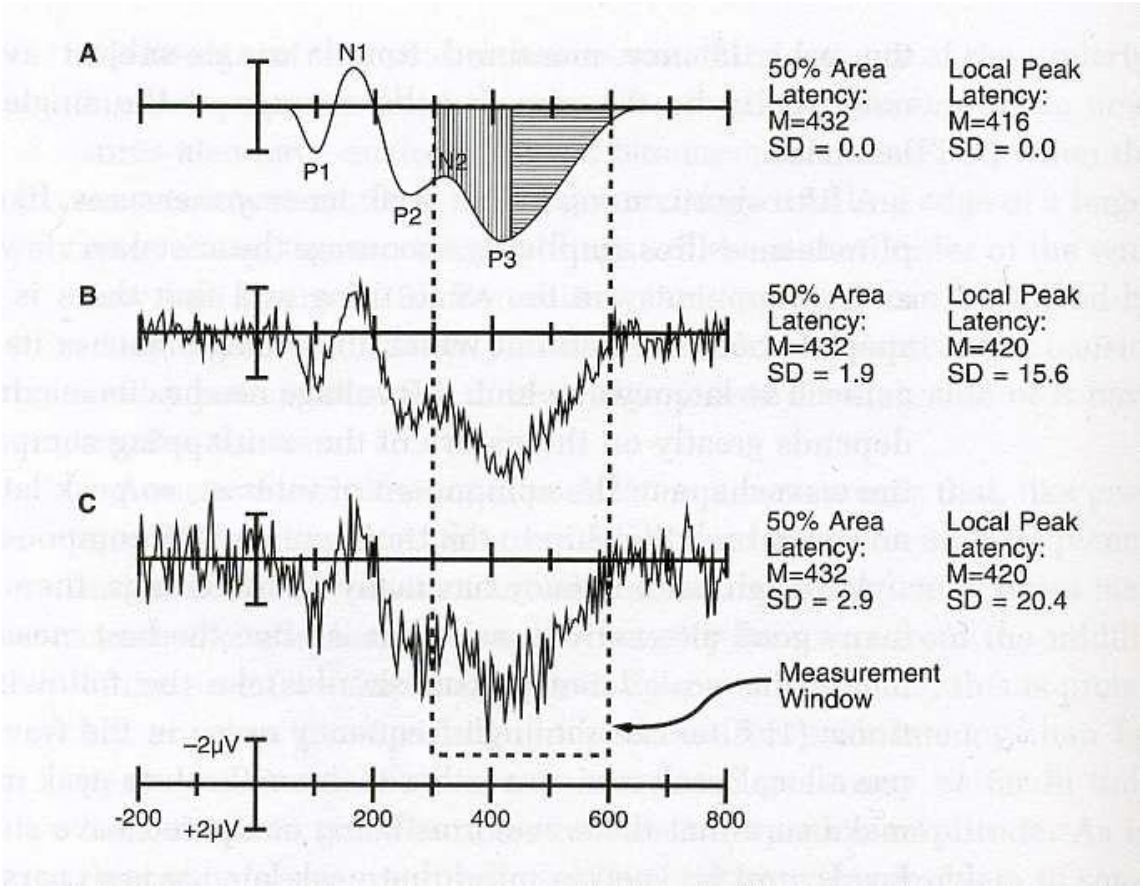
- first used by Hanson & Hillyard, 1980:

- computes the area under the ERP wave over a given time Window

- then, find the time point which divides area into a pre-specified fraction

Fractional area Latency

analogous to mean amplitude measures



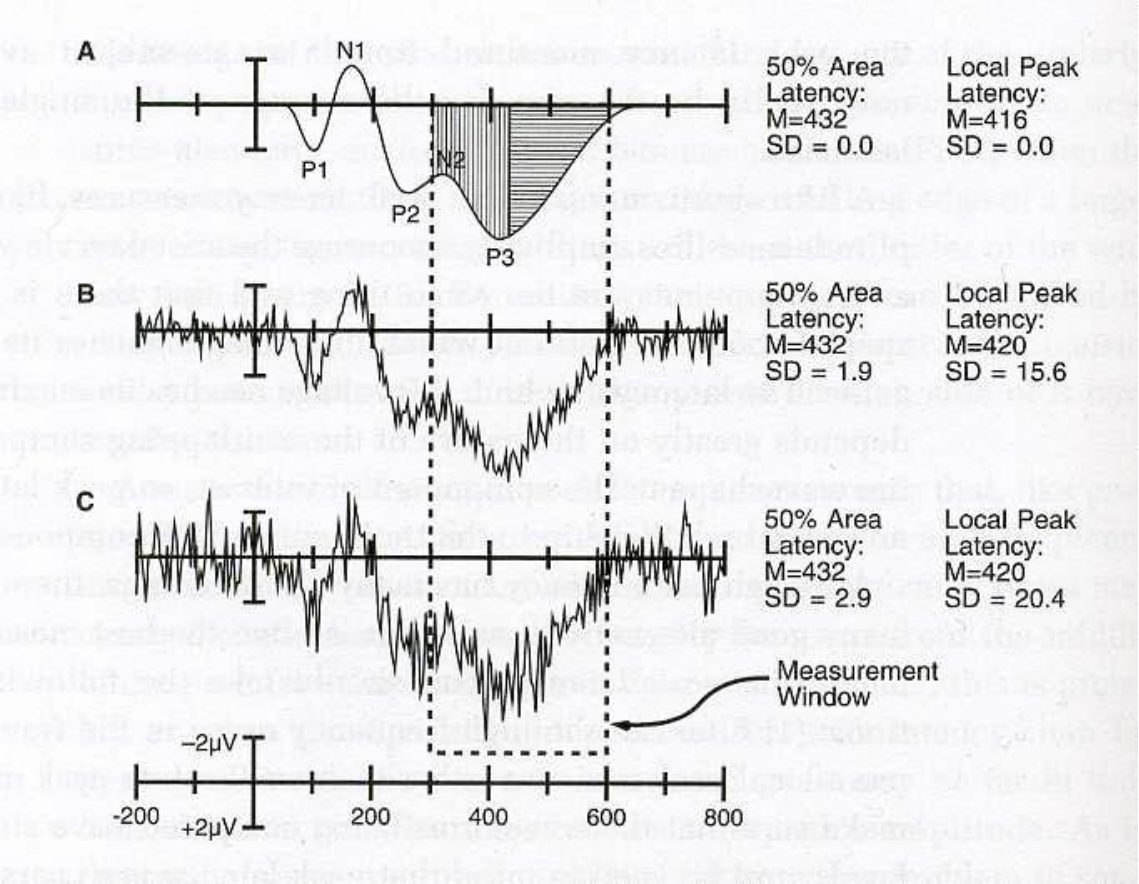
Limitations

rather time-consuming, needs recalculation for each individual Subject

(in BVA) manually, depending on visual inspection

Fractional area Latency

analogous to mean amplitude measures



Disadvantages

distorted when the latency range does not contain most of the ERP component, or …

- … includes large contributions of overlapping components

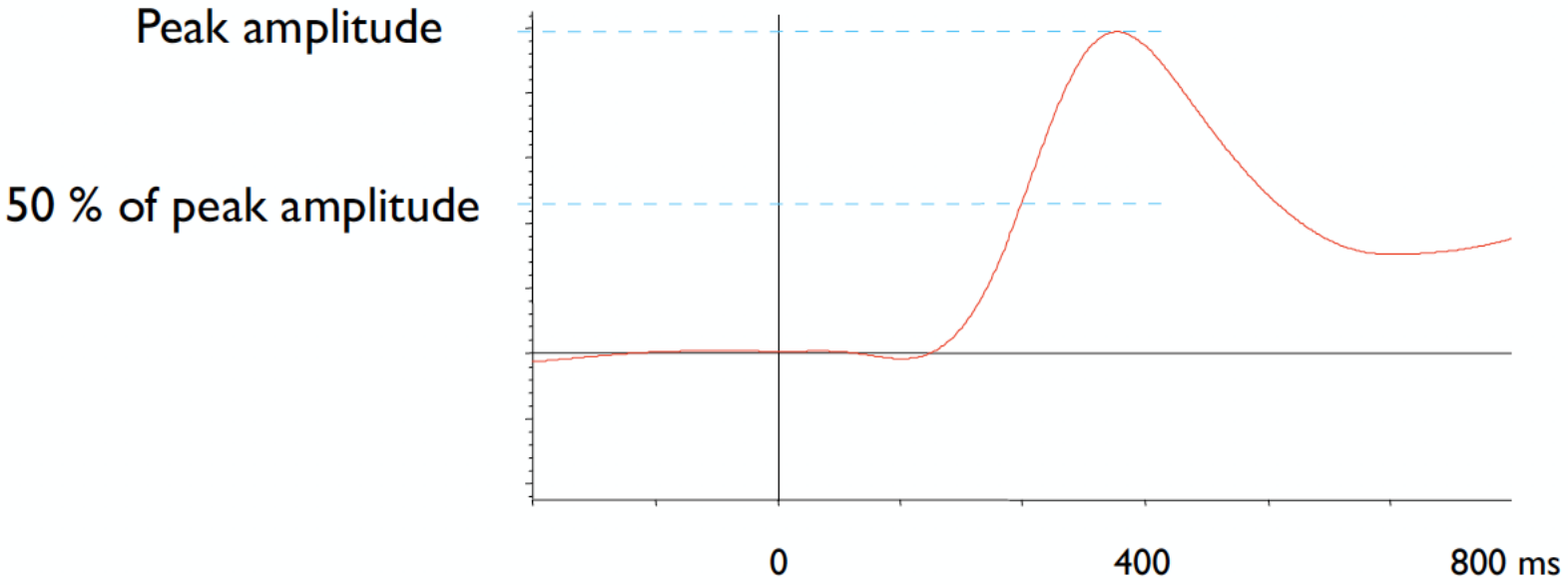
- more useful for late ERPs (P3, N400) or difference waves than for early ERPs (P1, N1, P2)

Onset Latency

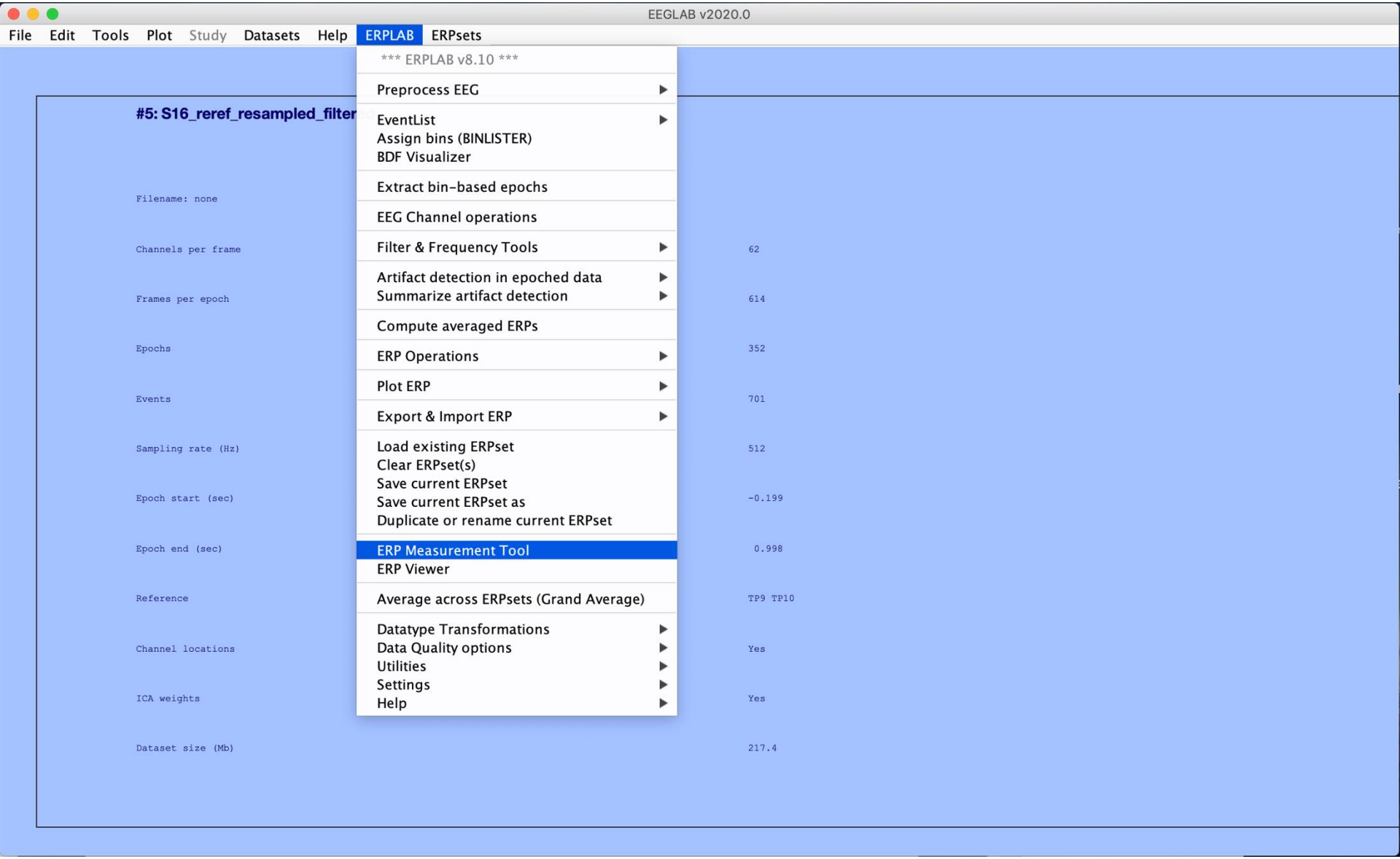
determines onset as point in time when ERP wave reaches a specific criterion:

50% of maximum amplitude for stimulus-locked ERPs

90% of maximum amplitude for response-locked LRPs



ERP measurement tool



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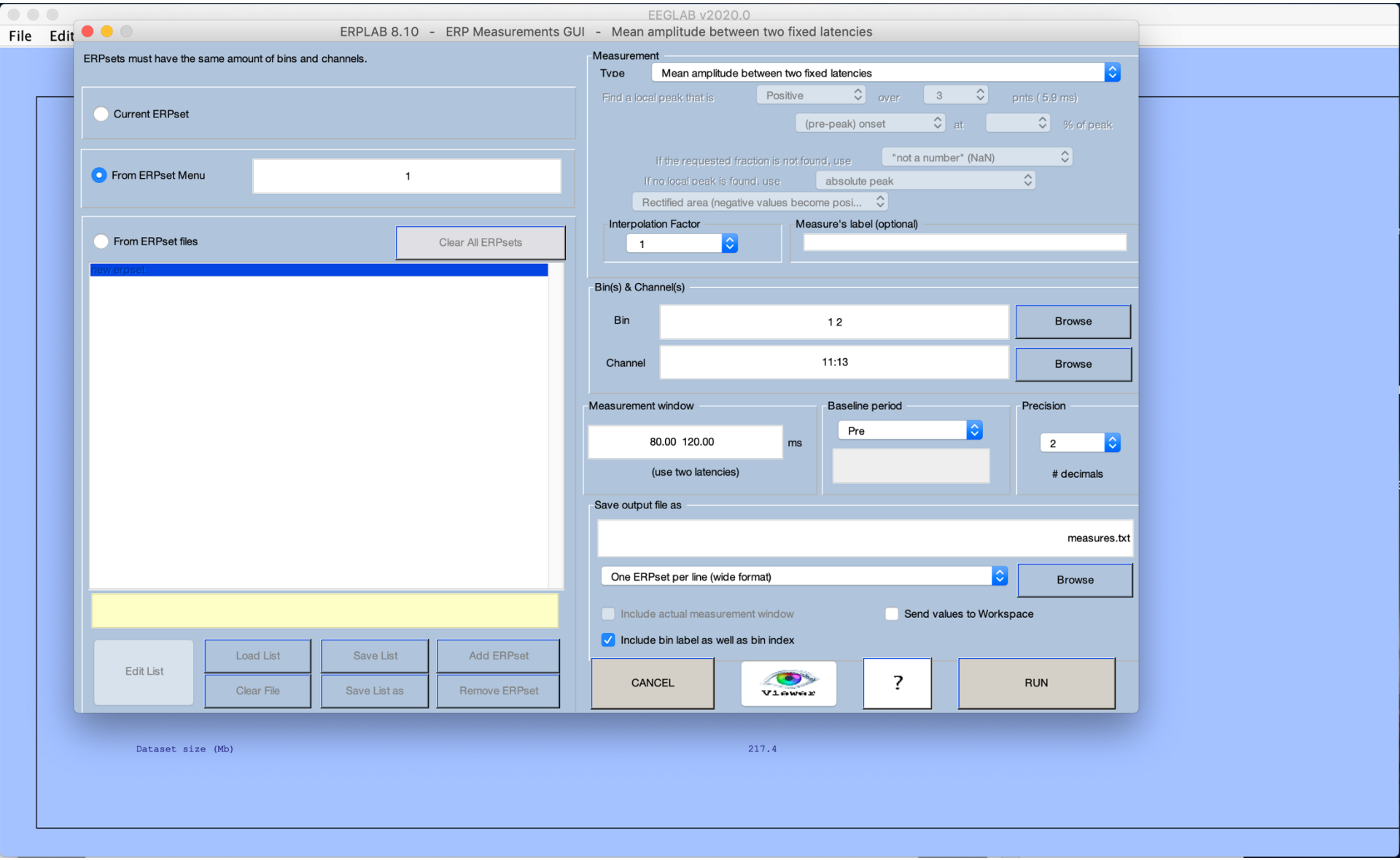

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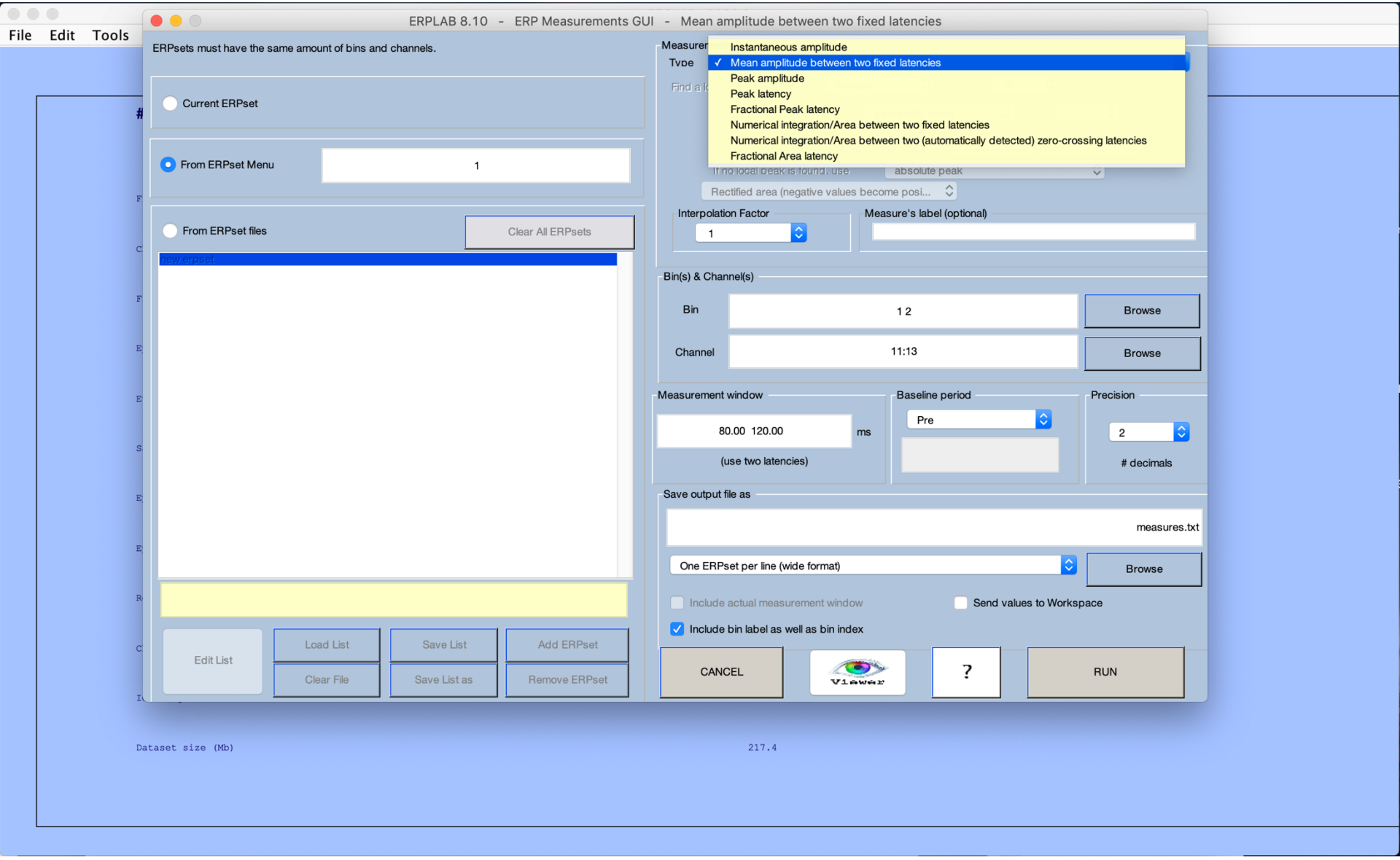

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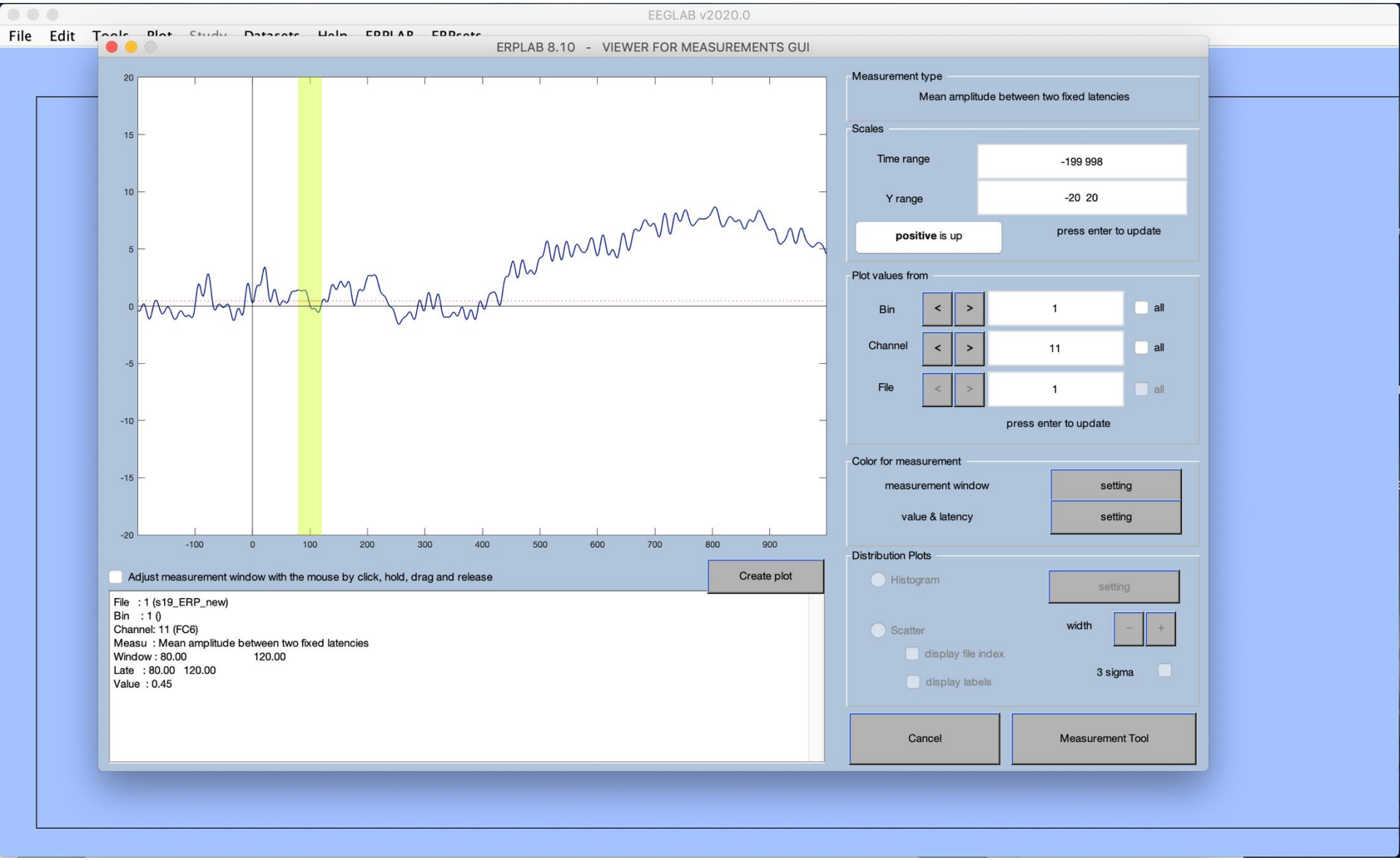

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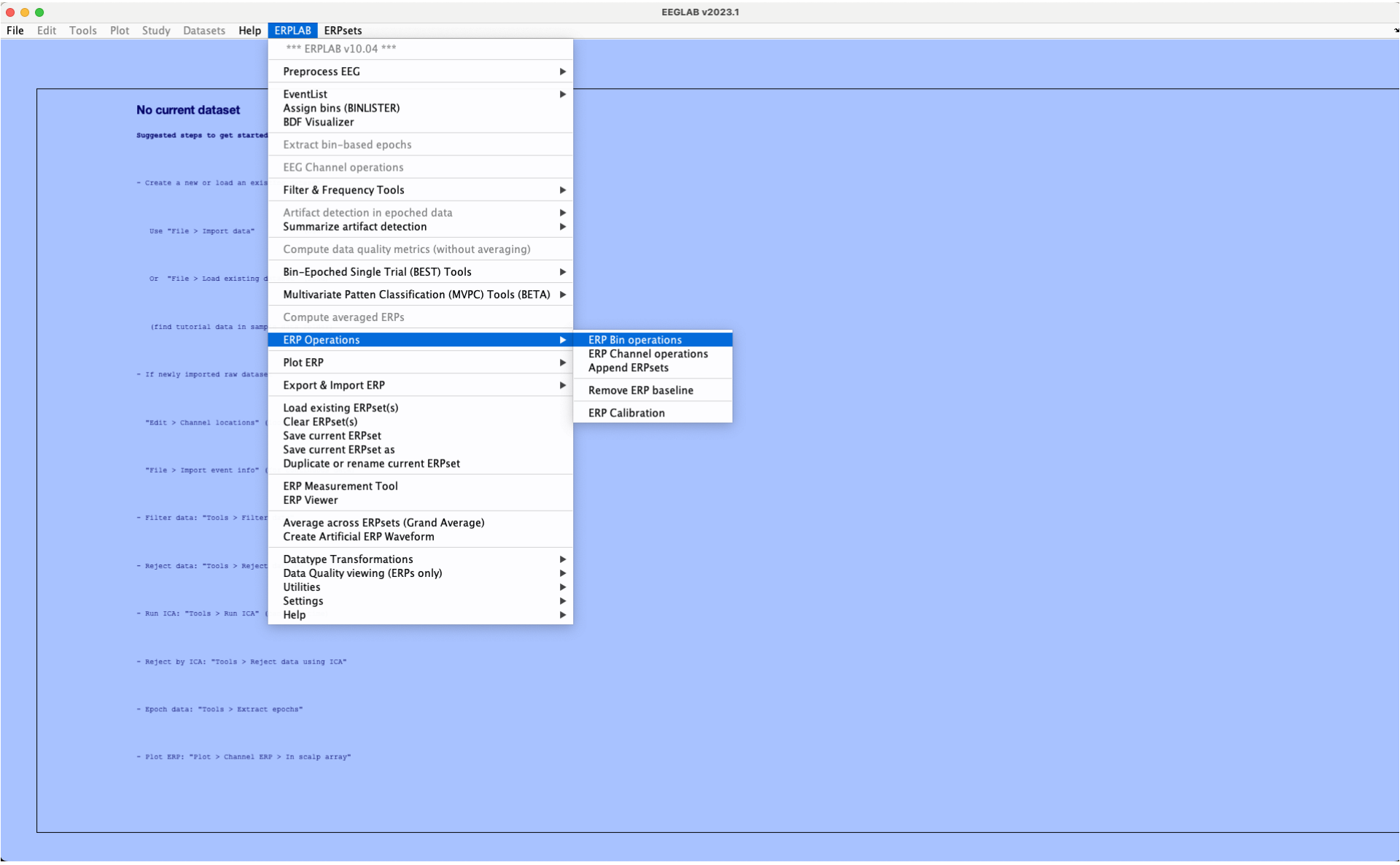
ERP Bin operations



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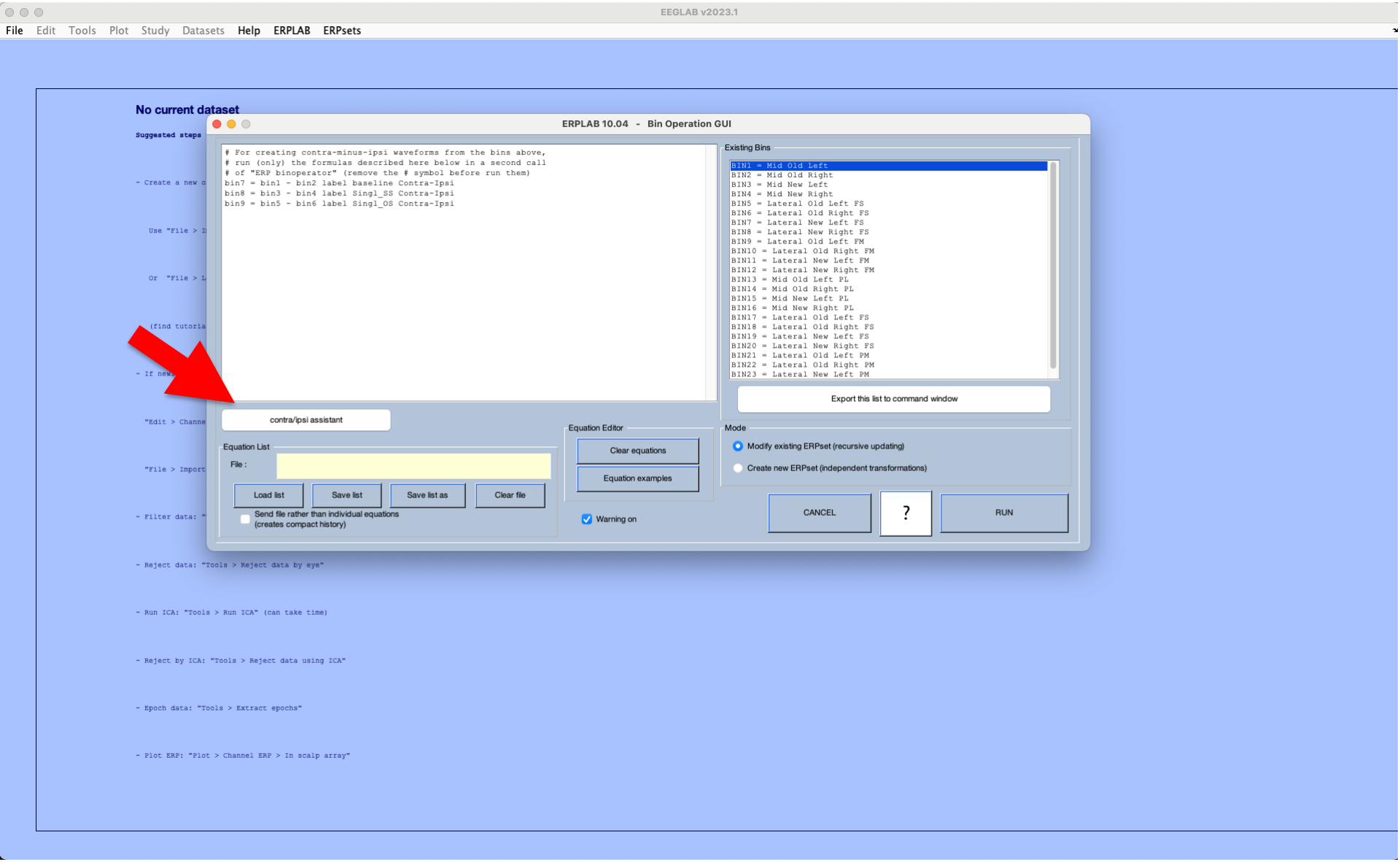

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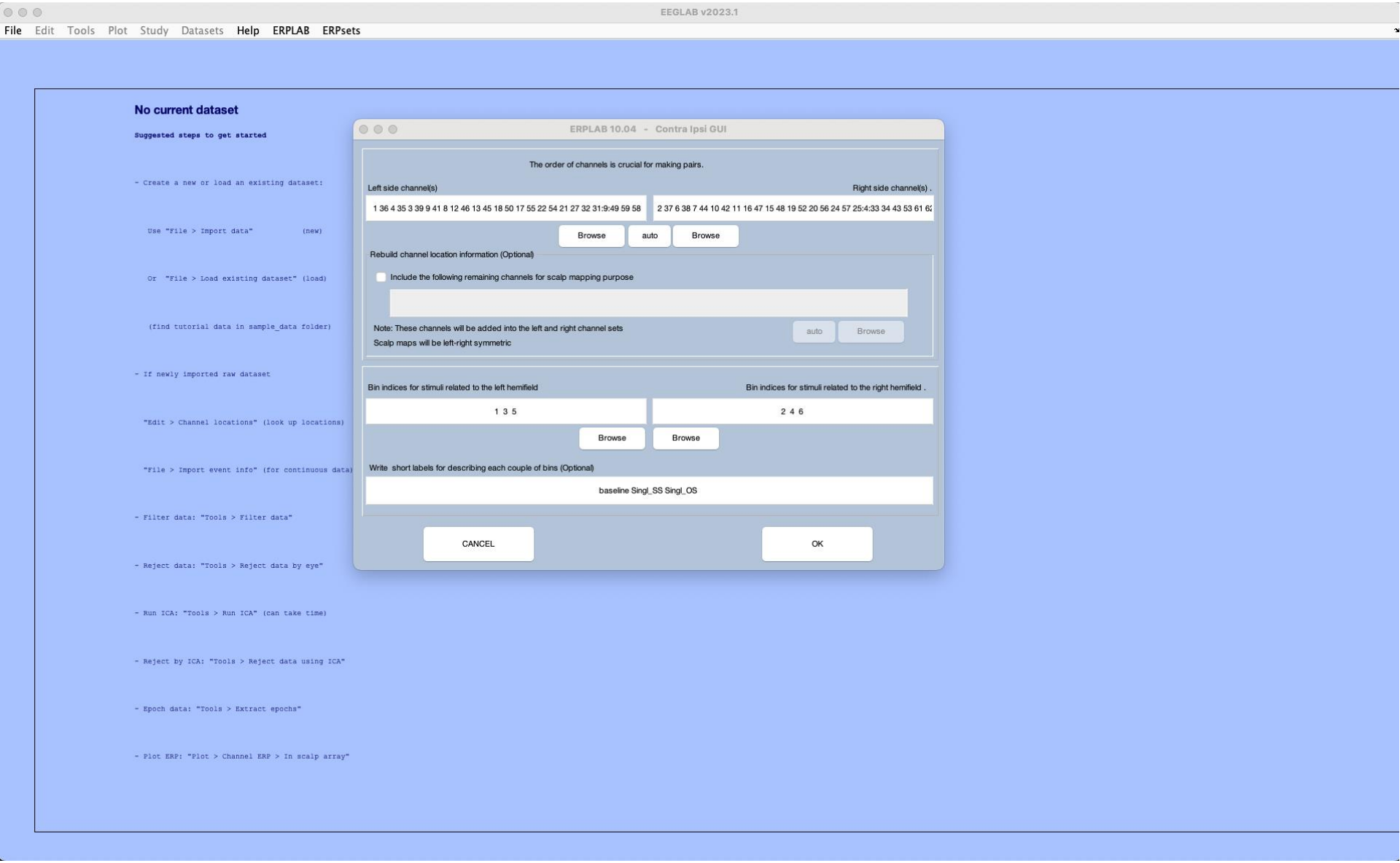
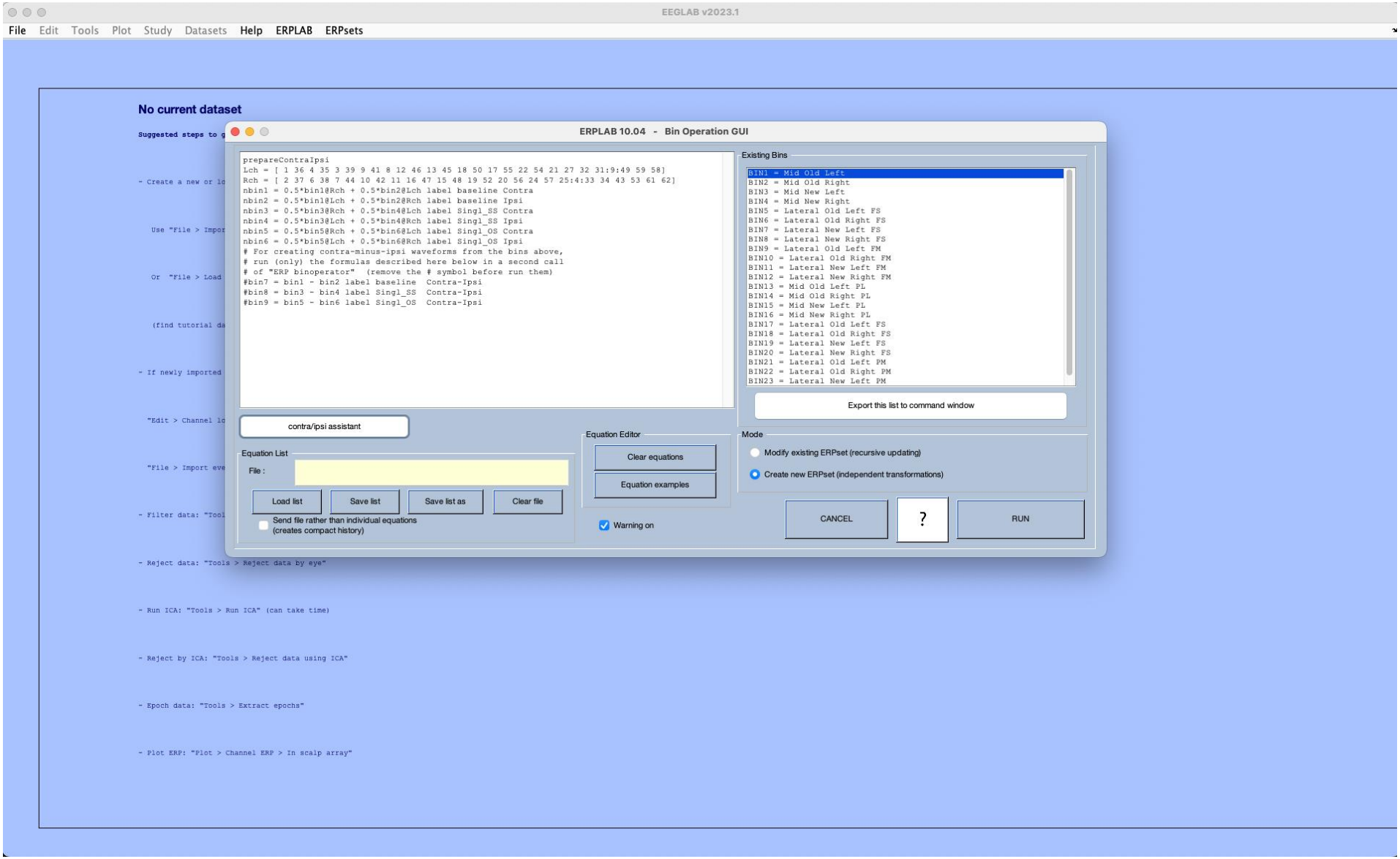
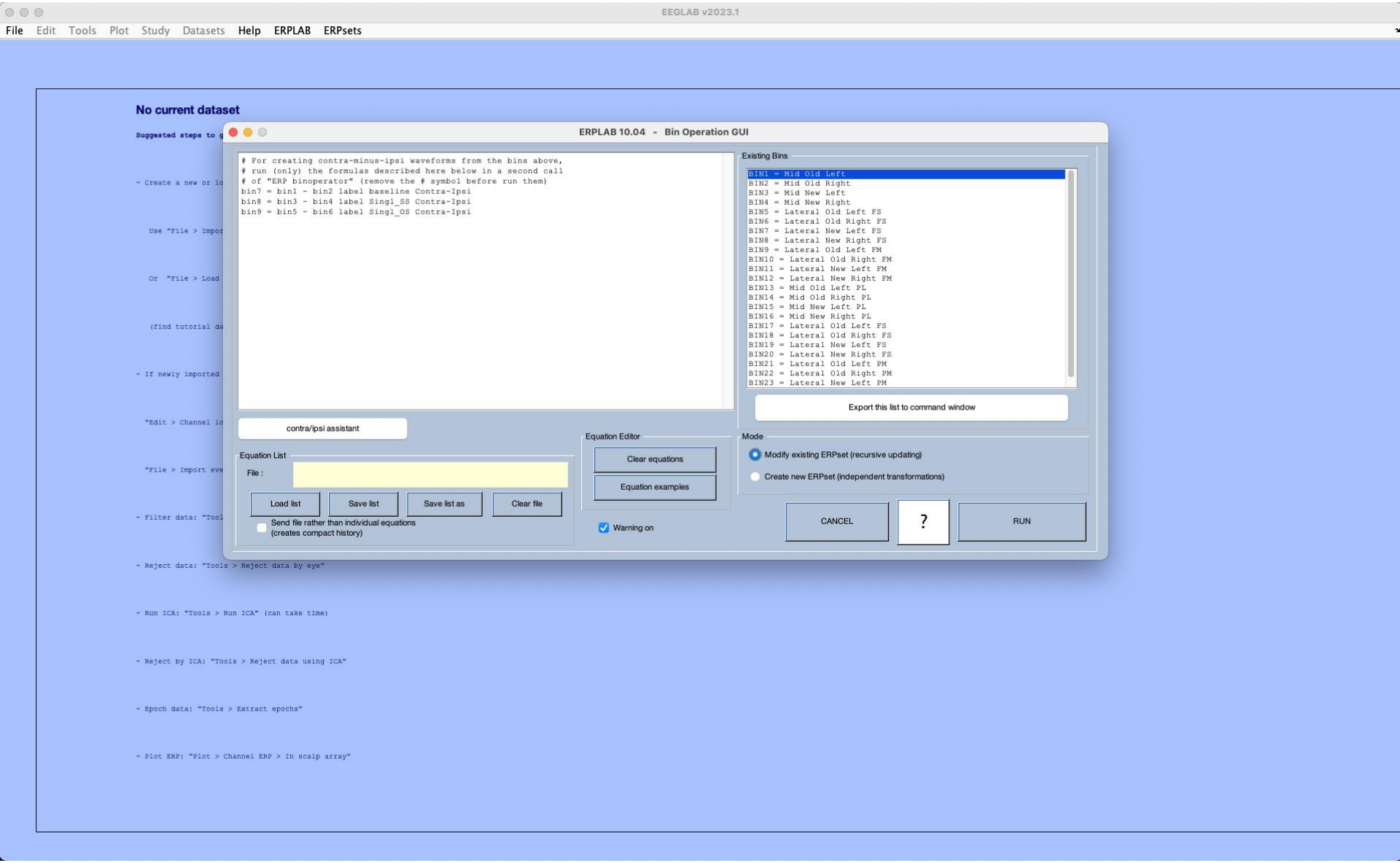


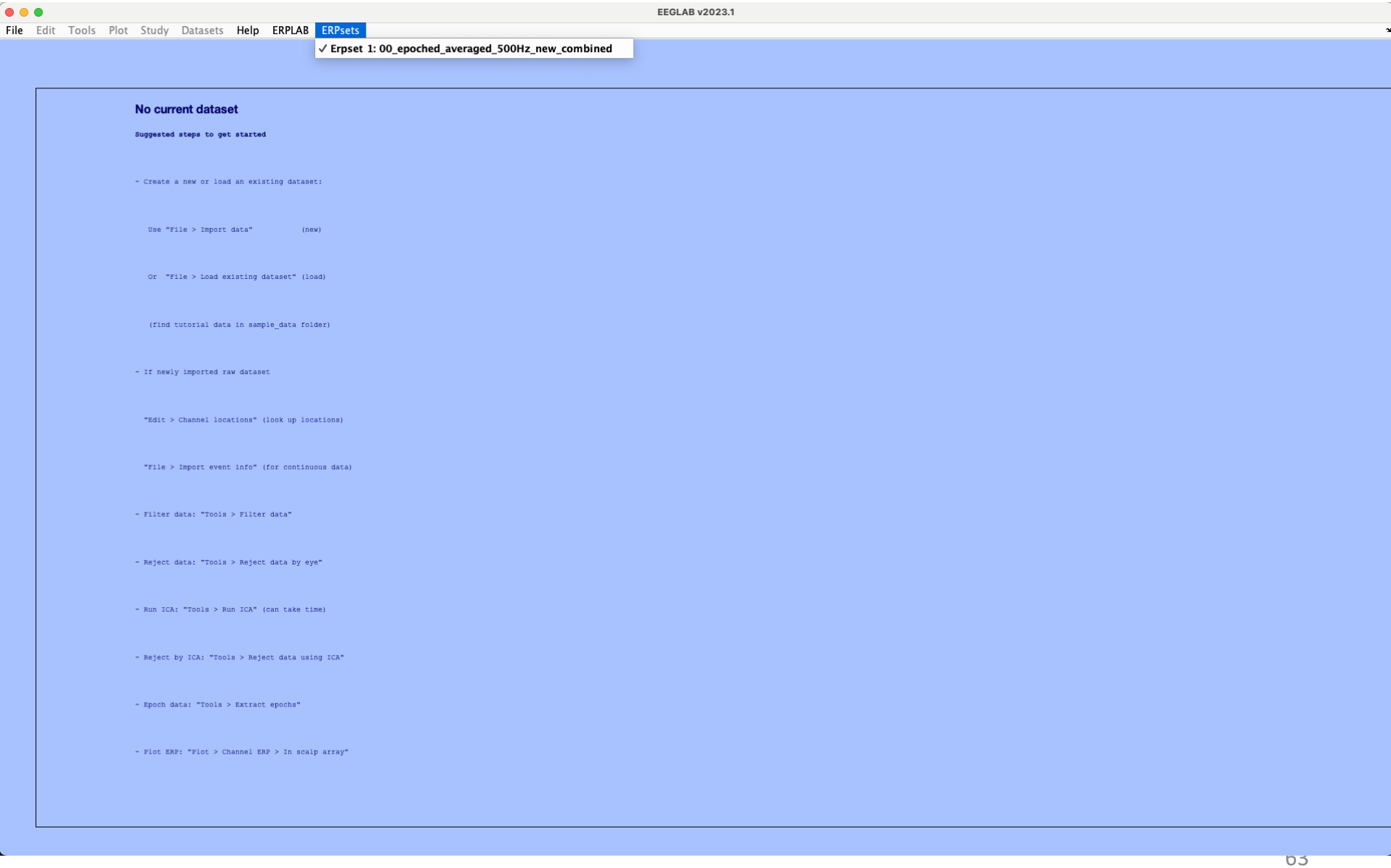
ERP Bin operations



ERP Bin operations



ERP Bin operations



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Why do we need statistics?

... to see whether a particular experimental manipulation has a significant effect on a dependent measure (e.g., peak amplitude).

if yes ... then effect might be generalized from the sample to an entire population

typical „magical border“: $p < .05$ (alpha level)

‣ Note, however, that .06 just means there is a 6% probability that the observed effect was due to chance!

Luck‘s (2005) Recommendations:

1. Design your experiments so that the exp. effects are ‚large‘ relative to the noise level

2. Use the best statistic: replication!

‣ effects relatively immune to „bad subjects“

‣ run follow-up experiments that replicate the results and also extend it

The Standard Approach

ANOVA

= analysis of variance (ANOVA)

allows to analyze main effects and/or interactions in a completely crossed factorial design

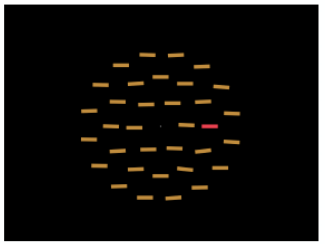
The main idea is to test whether variance between exp. conditions (or groups) is larger than variance within exp. conditions or (groups)

Thus, one can conclude whether partitioning of groups makes sense or, respectively, whether groups differ significantly?

The Standard Approach

ANOVA

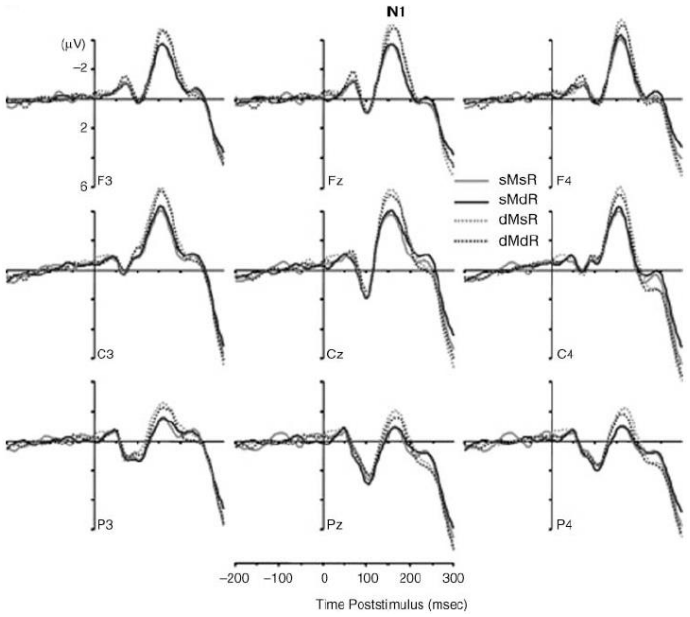
- **First step: collapse across irrelevant factors**
  - if conditions are counterbalanced, collapse to avoid physical stimulus differences
  - fewer p-values, spurious interpretations, etc.



- **Conduct separate ANOVA for each component**
  - Don‘t use component as a repeated-measure factor
  - Separate ANOVAs for amplitude and latency

Violations of ANOVA assumptions

homogeneity of covariance (i.e. sphericity)



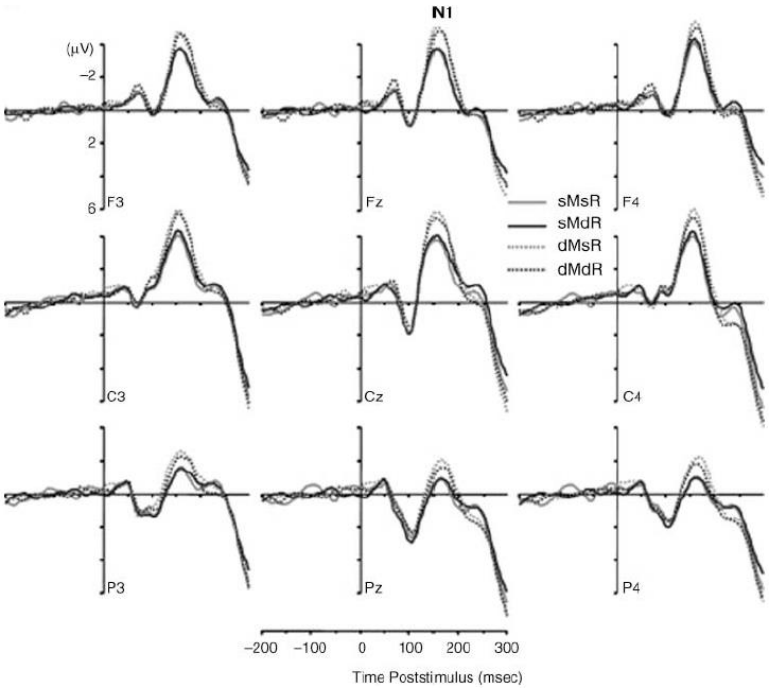
- (within-subject ANOVAs:) applies only when there are at least three levels of a factor ...

- assumes that degree of correlation between level 1 and level 2 is equal to the degree of correlation between level 2 and level 3, and between level 1 and level 3

- often violated in ERP research when „Electrode Site“ (e.g., Fz, Cz, Pz) is used as a factor

- can be corrected using the „Greenhouse-Geisser“ adjustment

How many electrodes into statistics?



do not artificially increase statistical power by including large number of electrodes!

for well-known components, select only electrode sites where the ERP is known to be most prominent

otherwise, divide electrodes into separate factors representing different spatial dimensions, e.g.,:

„Anterior-posterior Electrode Pos.“ (Frontal, Central, Posterior)

„Left-right Electrode Pos.“ (Left, Midline, Right)