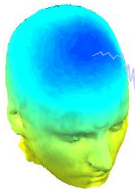
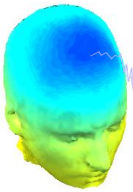
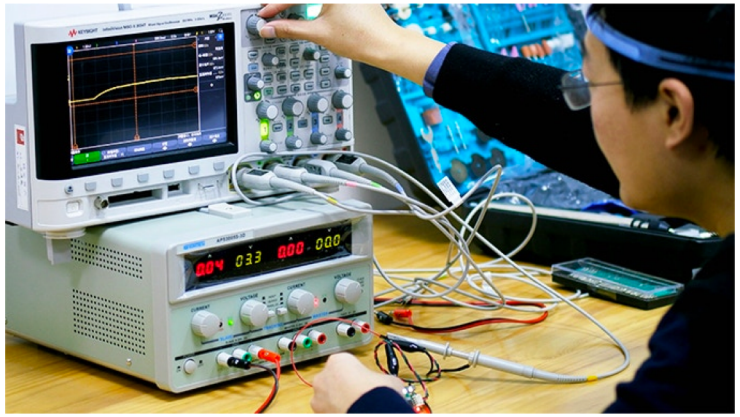


EEG Preprocessing in EEGLAB

Arnaud Delorme

Why preprocess data?





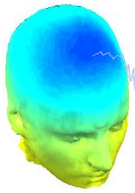
EEG data out of the recording device is a continuous unprocess signal. It is like measuring a difference of potential on an oscilloscope.

To make sense of the data, we need to:

- Extract meaningful measures from it (such as brain oscillations; brain source activations)
- Compare brain data in different conditions
- Assess reliable changes due to external stimuli (event-related potentials)

Before we do all that, we apply a series of transformation to the data.

Pre-processing pipeline



Collect EEG data

Import into EEGLAB

Import event markers and channel locations

Re-reference/ down-sample (if necessary)

High pass filter (~.5 – 1 Hz)

Examine raw data

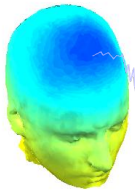
Identify/reject bad channels

Reject large artifact time points

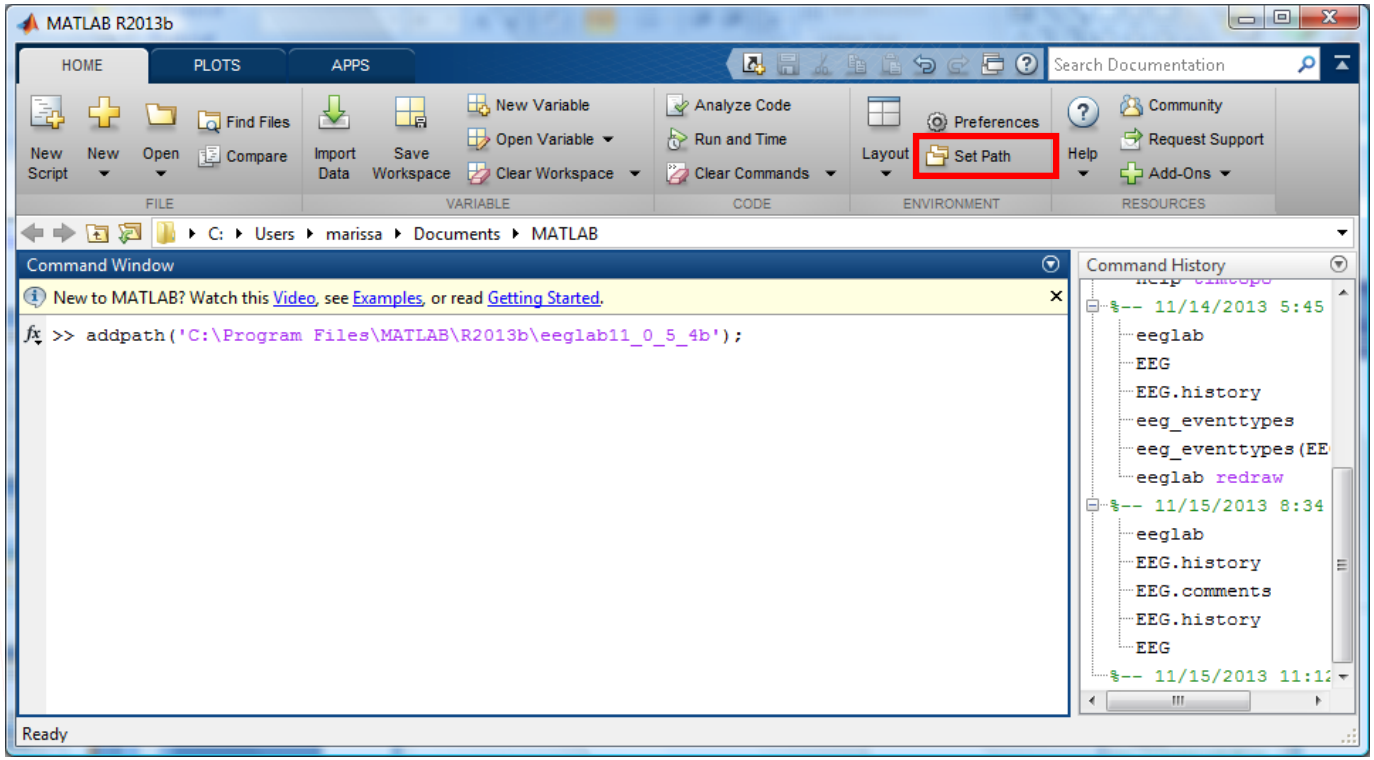
Run ICA and reject components

Done

Installing EEGLAB and data folder

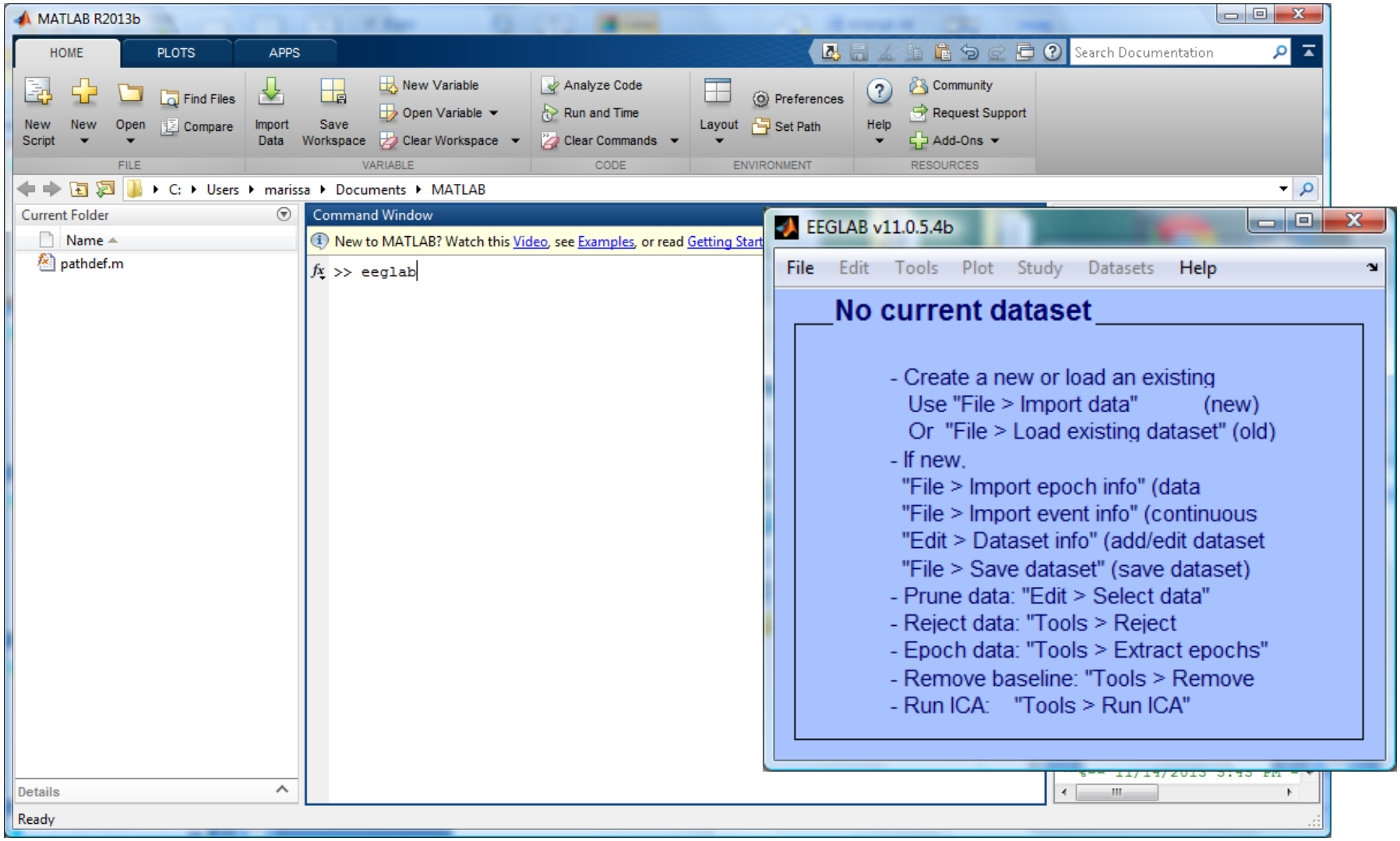


- Download and install Matlab (2008b or later)
- Download EEGLAB (http://www.sccn.ucsd.edu/eeglab)
- Unzip EEGLAB
- Add the EEGLAB folder to your Matlab path:

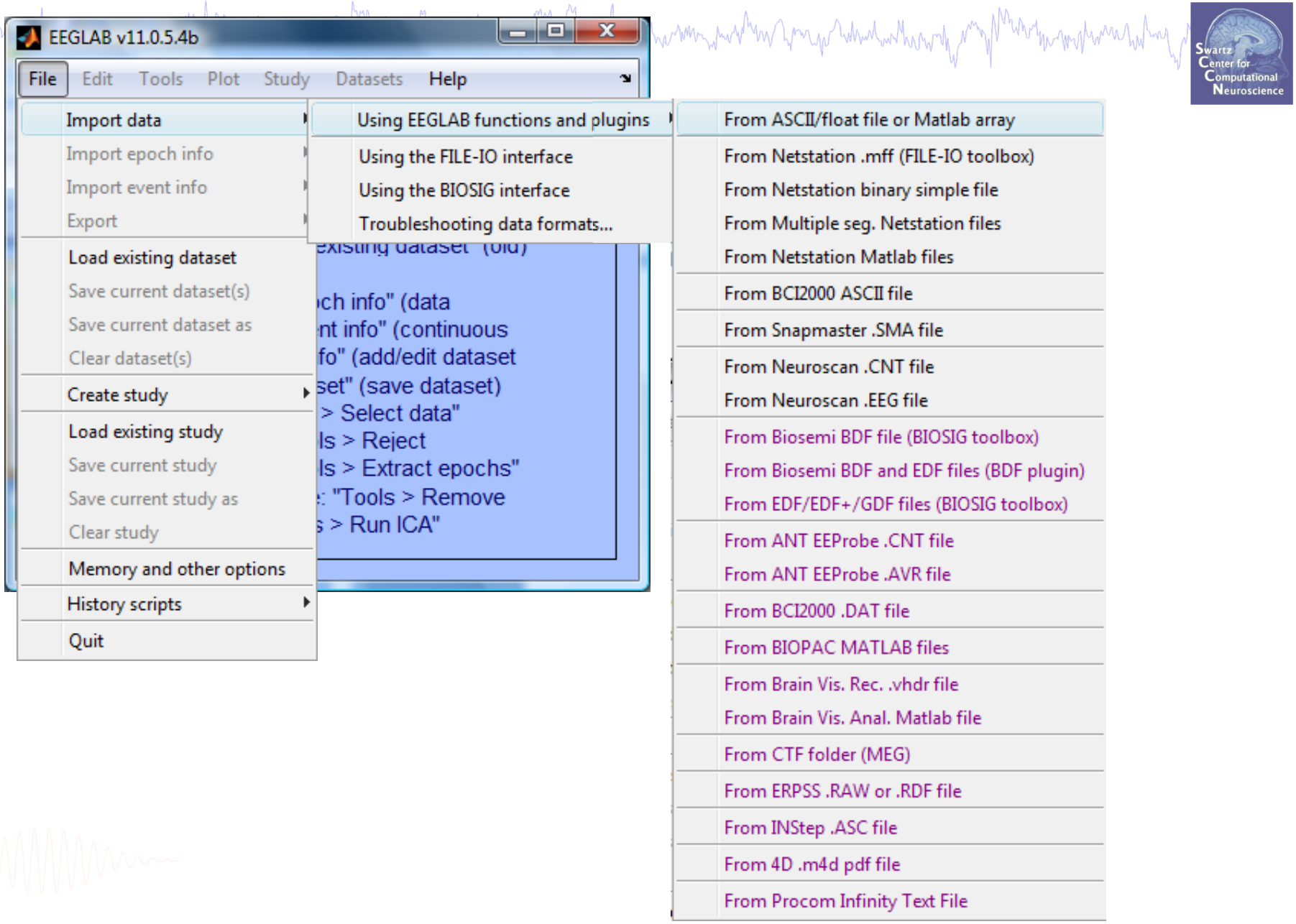


The EEGLAB Matlab software

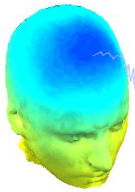
main graphic interface

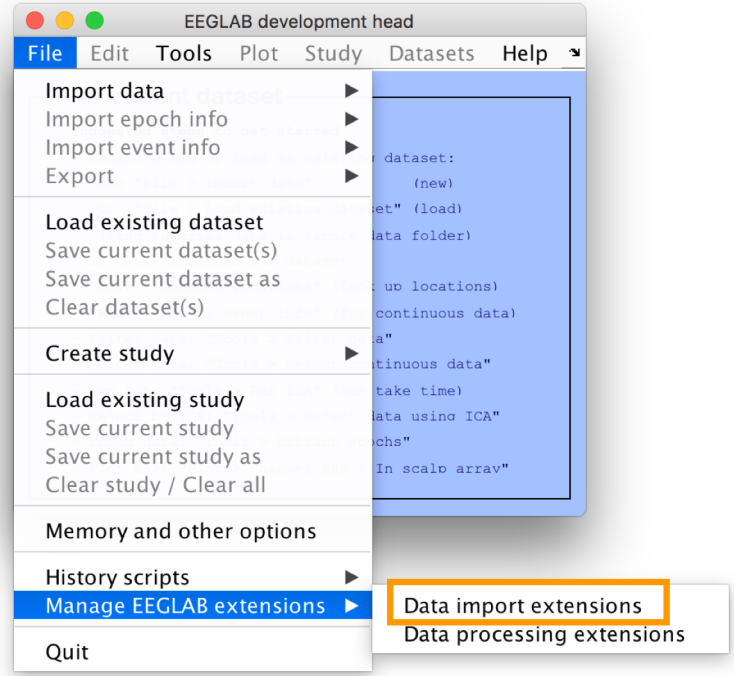


Importing a dataset

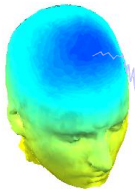


Install extension for importing data files





Supported data formats



EEGLAB tutorial: https://sccn.ucsd.edu/wiki/A01:_Importing_Continuous_and_Epoched_Data

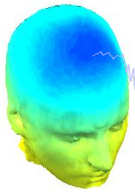
Supported Data Formats

File Format	File Extension	File type	Events	Channel Labels	EEGLAB	Biosig	File IO	Support
ANT EEProbe	.avr	_	_	_	_	_	_	Comments
ANT EEProbe	.cnt	_	_	_	y	y	y	Comments
ASCII	.txt	_	_	_	y	y	_	Comments
BCI2000	.bci2000	continuous	_	_	p	_	_	Comments
BCI2000	.gdf	continuous	_	_	p	_	_	Comments
Biologic	.eeg	_	_	_	_	_	_	Comments
Biopac	.mat/.acq	_	_	_	p (see comments)	_	_	Comments
Biosemi	.bdf	continuous	Channel	_	y	y	y	Comments
Blackrock	.NEV .NSx	_	_	_	see comments	_	_	Comments
Brain Vision Analyzer	.mat	continuous & segmented	Embedded	_	y	y	n	Comments
Brain Vision Analyzer	.vhdr	_	file	_	y	y	n	Comments
BrainStorm	.vsm	_	_	_	_	_	_	Comments
Cogniscan	_	_	_	_	p	_	_	Comments
Compumedics Profusion	.raw	_	_	_	see comments	_	_	Comments
CTF/BrainStorm	.ctf	_	_	_	y	y	y	Comments
EGI/Netstation	.RAW	continuous & segmented	Channel	_	y	y	y	Comments
Elektra (MEG)	.fif	_	_	_	n (see comments)	y	n	Comments
Emotiv	.edf	_	_	_	y (see comments)	y (see comments)	y (see comments)	Comments
ERPSS	.raw	_	_	_	y	n	n	Comments
ERPSS	.rdf	_	_	_	y	n	n	Comments
European Data Format (16-bit)	.edf	_	Channel	_	y	y	n	Comments
EDF+	.edf	_	Channel	_	y	y	n	Comments
INSTEP	.asc	_	_	_	y	n	n	Comments
Matlab Array	.mat	_	Channel	_	y	y	n	Comments
Micromed	_	_	_	_	p	_	_	Comments
Neuroimaging4D	.m4d	_	_	_	y	n	n	Comments
Neuromag	.fif	_	_	_	see comments	n	see comments	Comments
Neuroscan	.avg	_	_	_	_	_	_	Comments
Neuroscan	.CNT	_	Embedded (see comments)	_	y	y	y	Comments
Neuroscan	.eeg	continuous	_	_	y	y	y	Comments
Nihon Kodhen	.eeg	continuous	_	_		y (see comments)		Comments
Profusion	.slp	_	_	_	_	_	_	Comments
Snapmaster	.SMA	_	Channel	_	y	y	n	Comments
Spike2	.mat	_	_	_	y (see comments)	n	n	Comments
Tucker-Davis Technology	.tdt	_	_	_	p	_	_	Comments

BIOSIG: http://pub.ist.ac.at/~schloegl/biosig/TESTED

File-IO: http://www.fieldtriptoolbox.org/development/fileio

Sample data: basic P300 paradigm



File

SimpleOddball.set

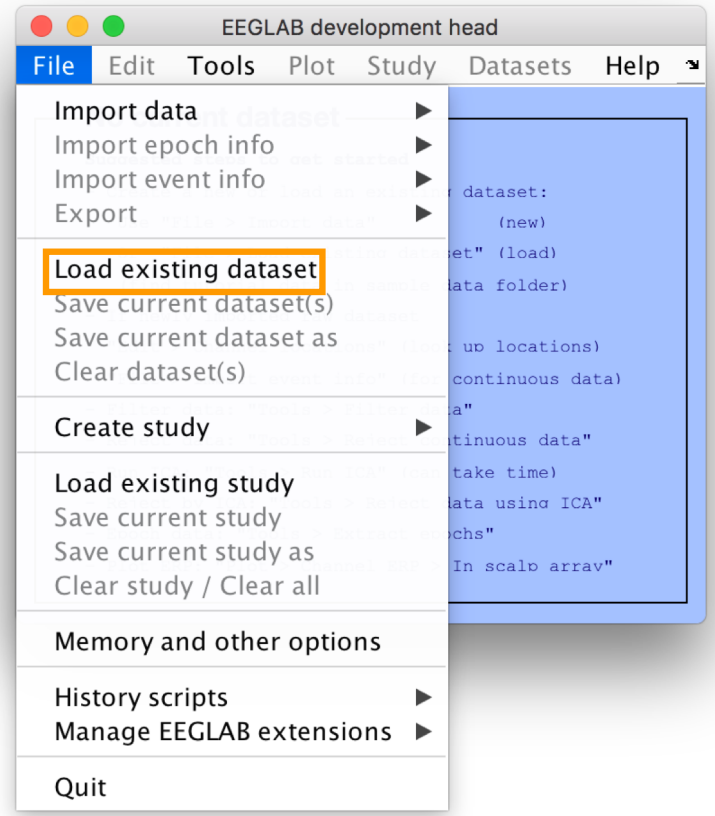
Data

68 channel EEG, 256 Hz sampling rate, Biosemi system, re-referenced during import to averaged left and right mastoid electrodes

Task

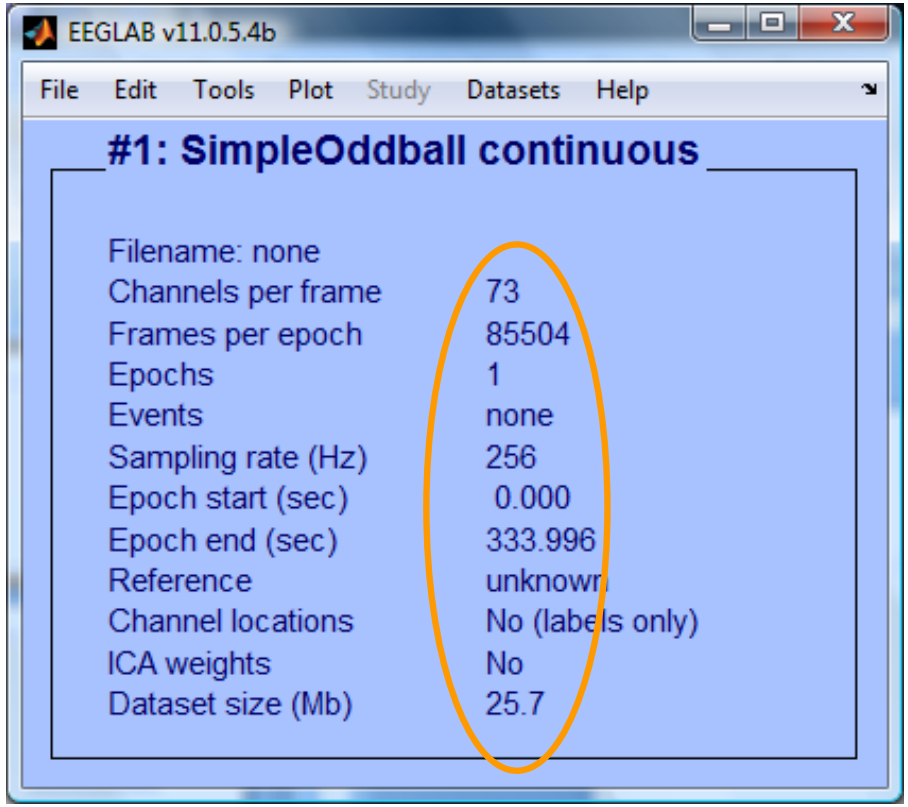
speeded button press response to star shape (no response to circle shape), 100 ms presentation duration, 200 trials

Load a dataset

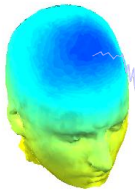


Load "SimpleOddball.set"

Imported EEG data



Pre-processing pipeline



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High pass filter (~.5 – 1 Hz)

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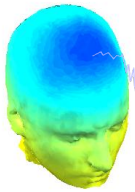
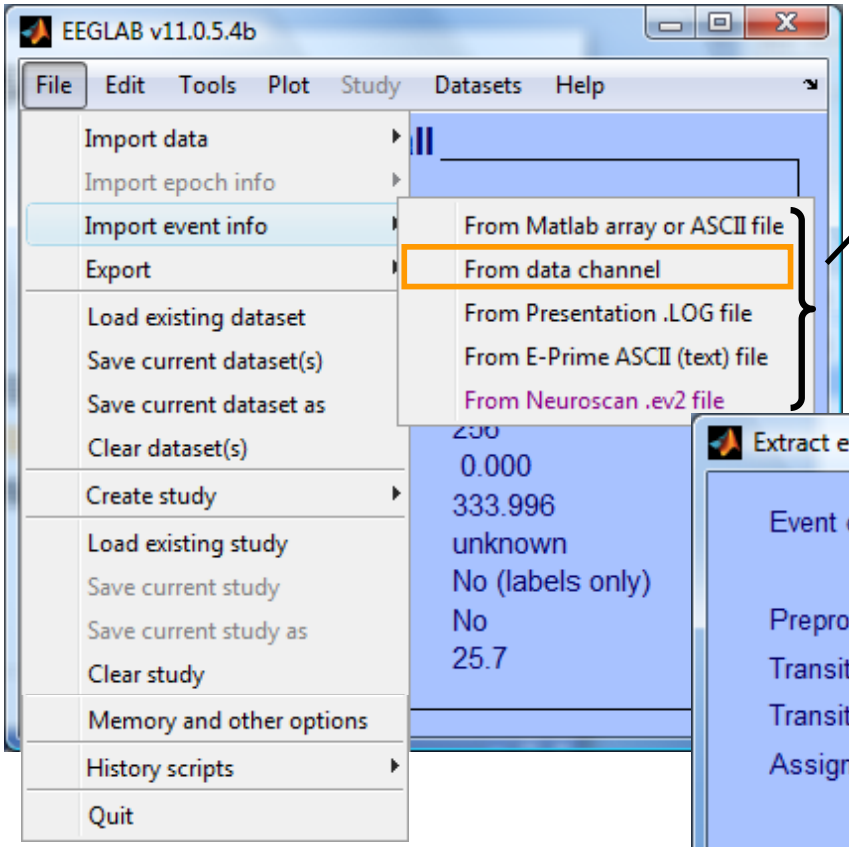
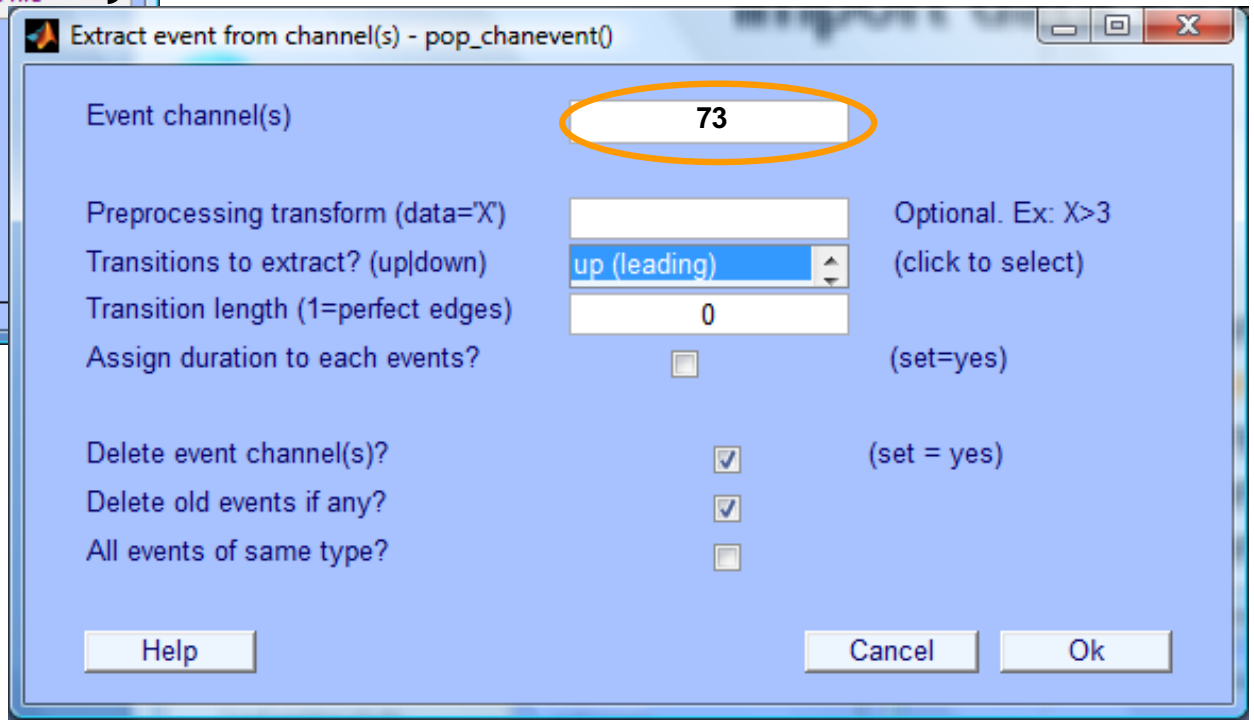
Import data events



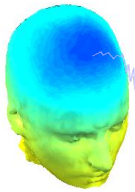


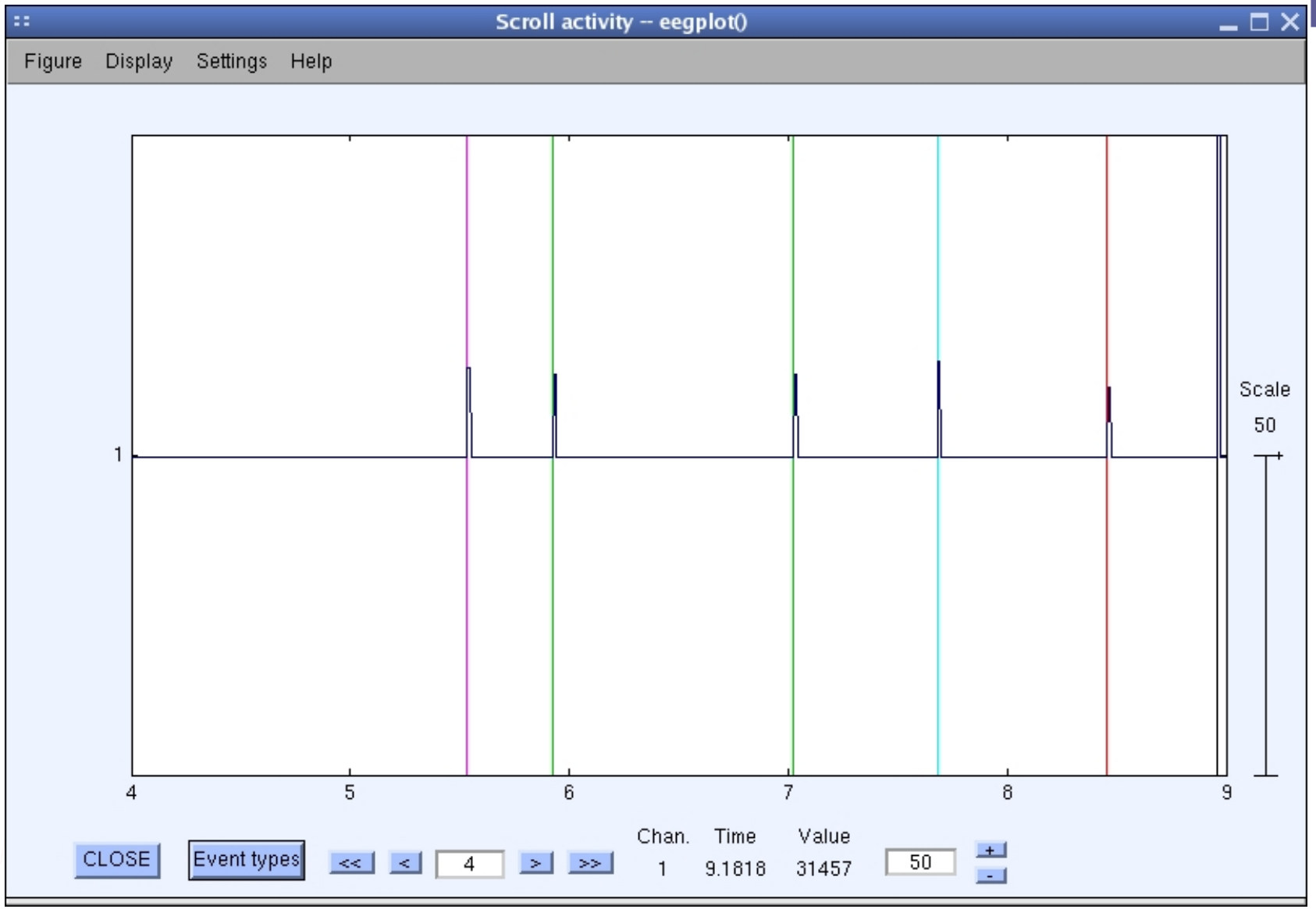
- Import events from Matlab array or ASCII file
- Import events from data channel
- Import from Presentation event file
- Import events from E-Prime event file
- Import events from Neuroscan event file



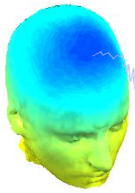
(Often imported automatically during data import)

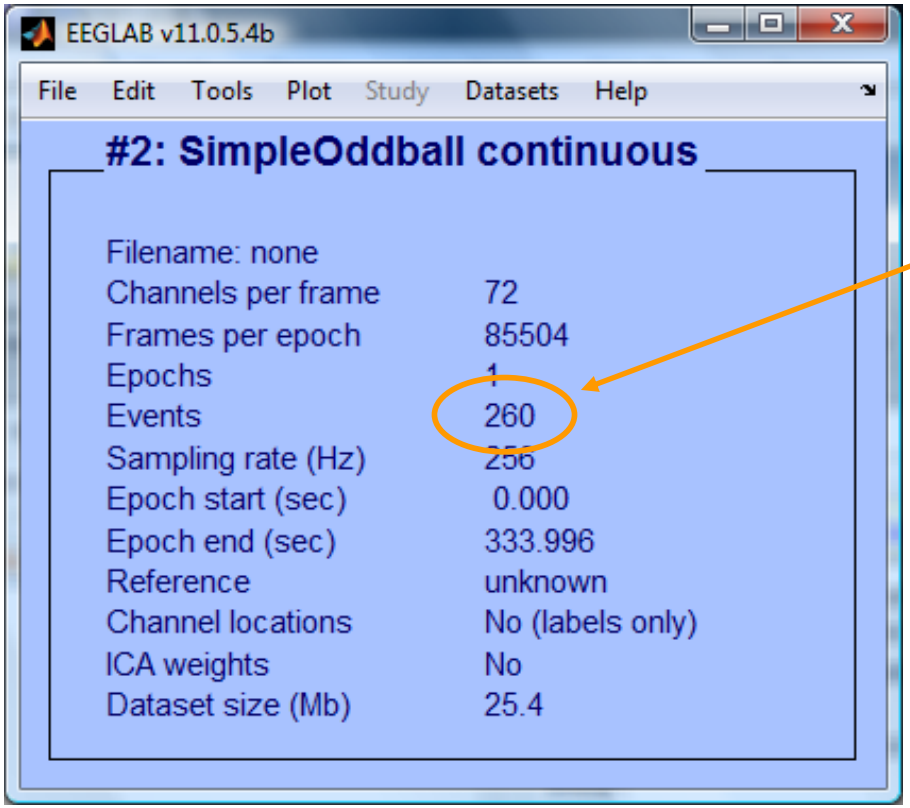
Appearance of an event channel in raw data





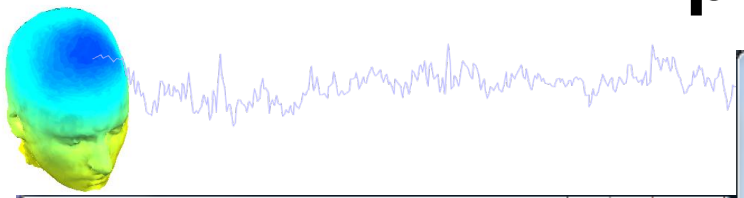
Imported data events

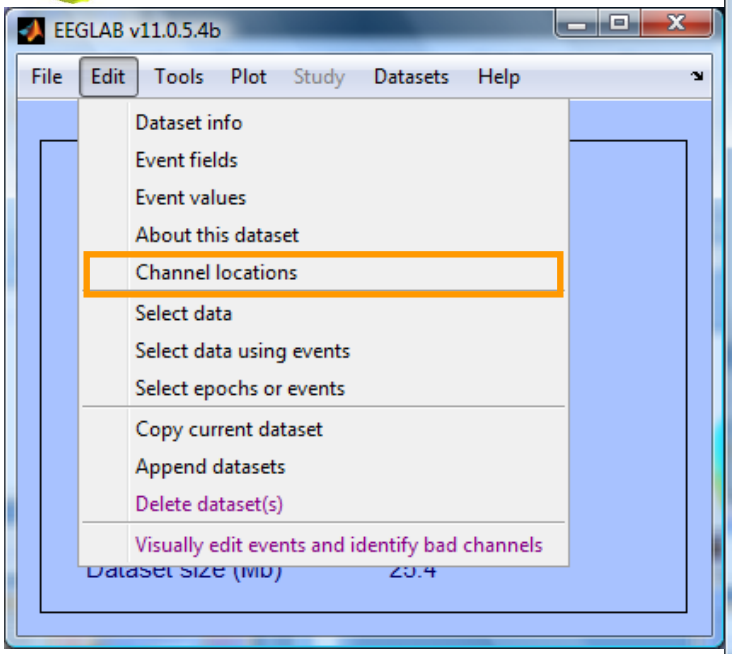


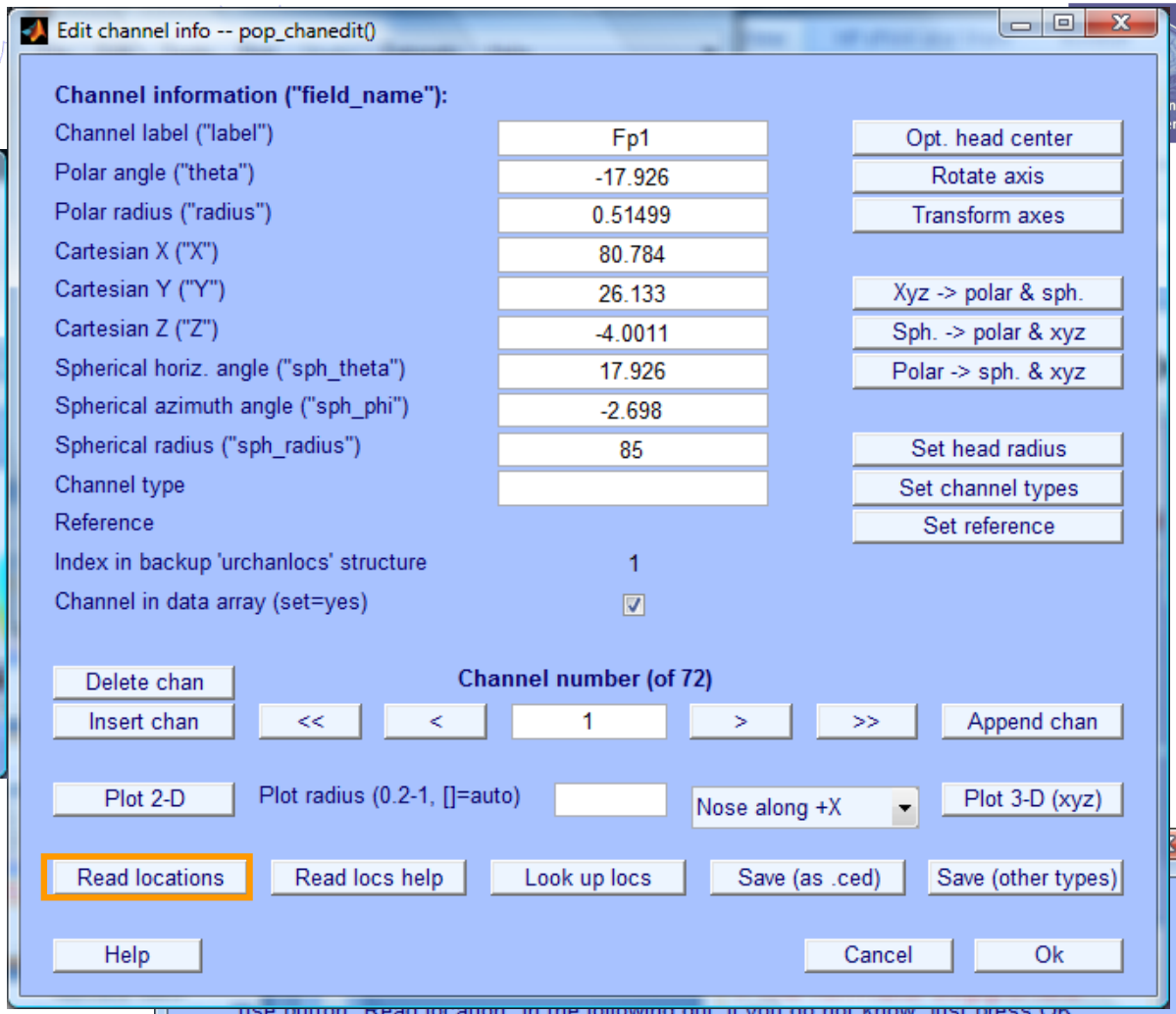


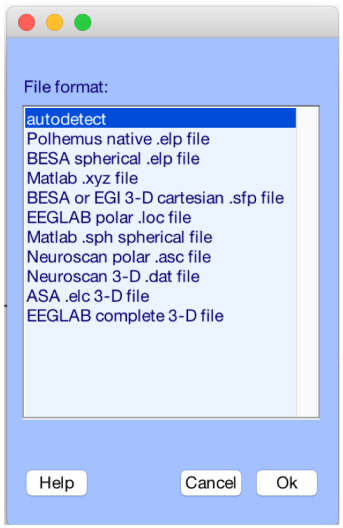
If event import was successful, you will see an appropriate number here

Import channel locations

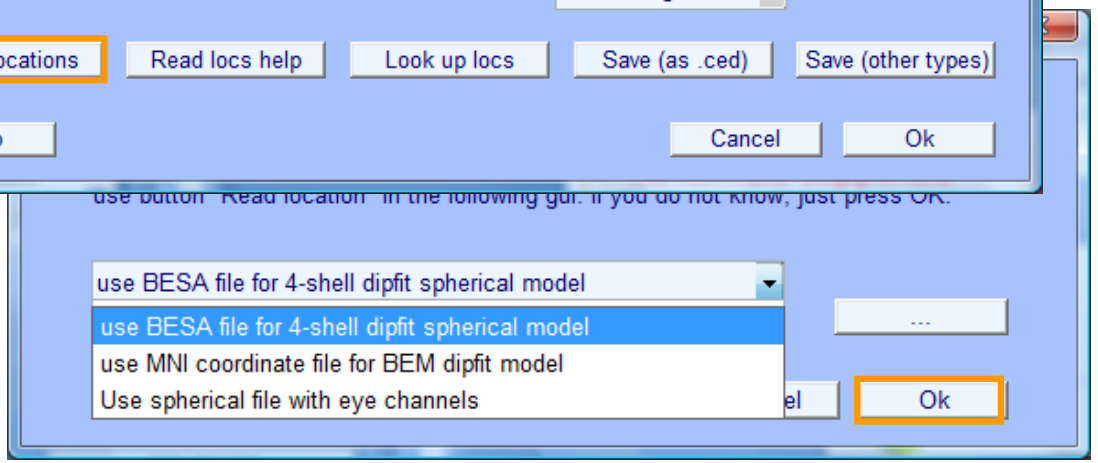


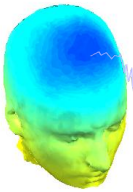






10 file formats supported (Polhemus, BESA, …)





Edit channel info -- pop_chanedit()

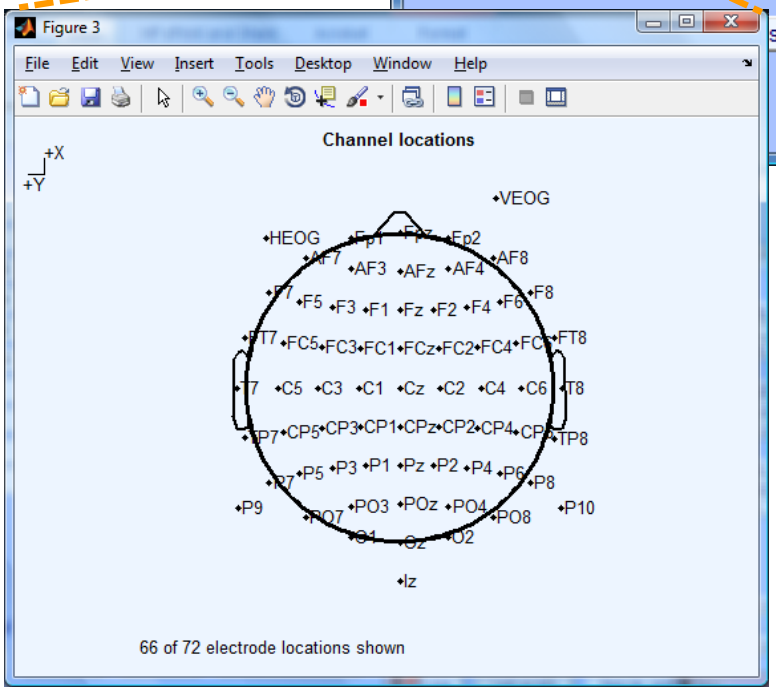
Channel information ("field_name"):

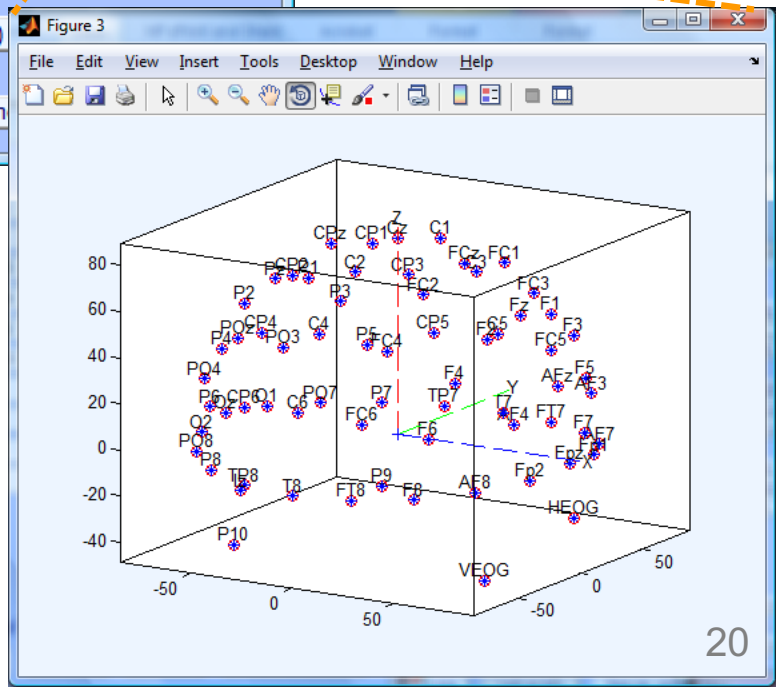
Channel label ("label")	HEOG	Opt. head center
Polar angle ("theta")	-42	Rotate axis
Polar radius ("radius")	0.65556	Transform axes
Cartesian X ("X")	55.7734	
Cartesian Y ("Y")	50.2186	Xyz -> polar & sph.
Cartesian Z ("Z")	-39.9051	Sph. -> polar & xyz
Spherical horiz. angle ("sph_theta")	42	Polar -> sph. & xyz
Spherical azimuth angle ("sph_phi")	-28	
Spherical radius ("sph_radius")	85	Set head radius
Channel type		Set channel types
Reference		Set reference
Index in backup 'urchanlocs' structure	68	
Channel in data array (set=yes)	☑	

Delete chan | Insert chan | **Channel number (of 72)** | << | < | 68 | > | >> | Append chan

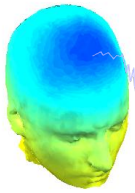
Plot 2-D | Plot radius (0.2-1, []=auto) | | Nose along +X | Plot 3-D (xyz)

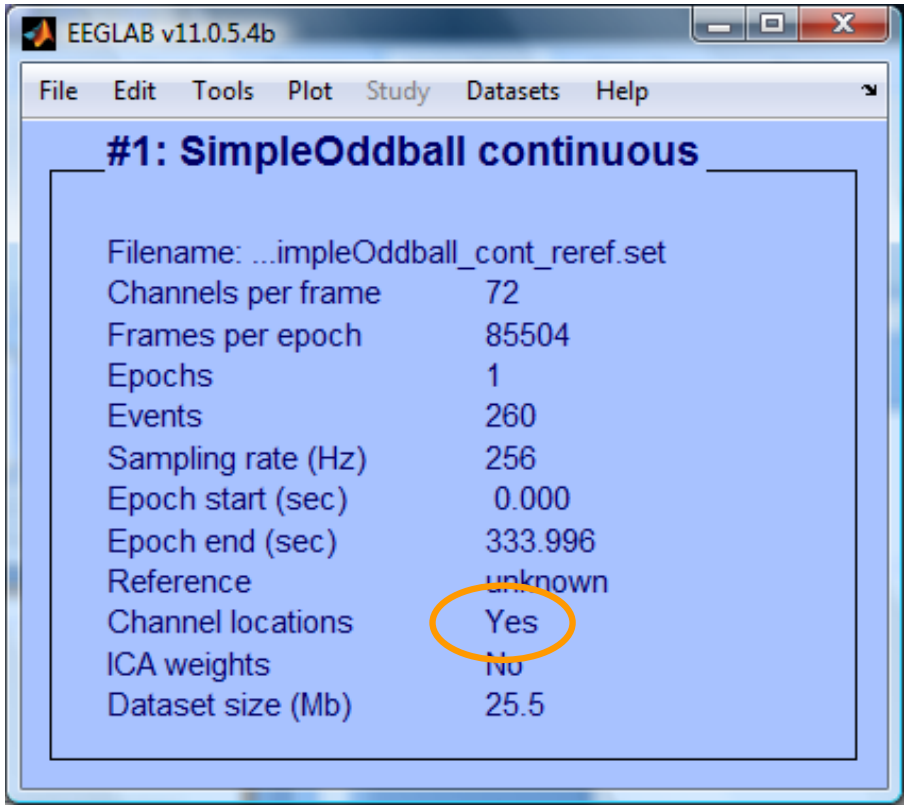
s help | Look up locs | Save (as .ced) | Can



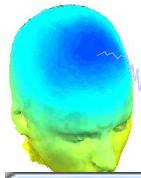


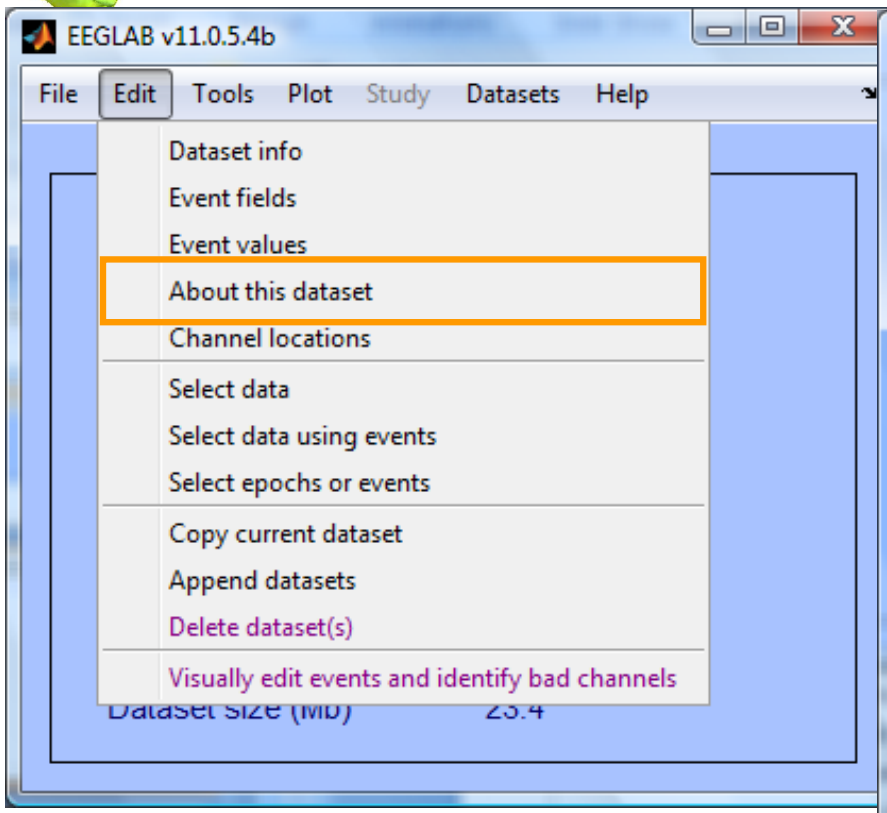
Imported channel locations

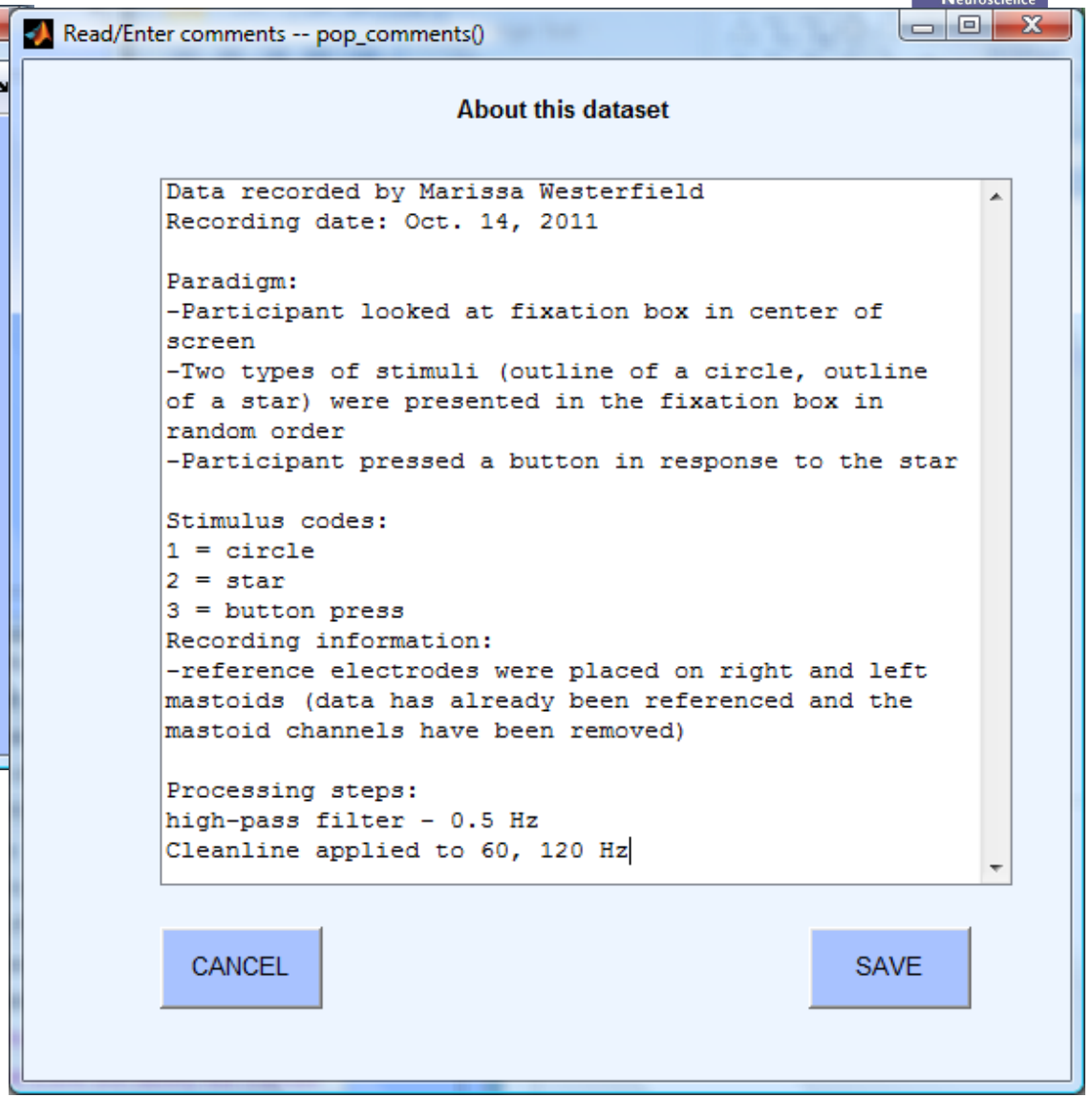




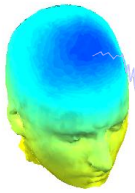
Comments and dataset history

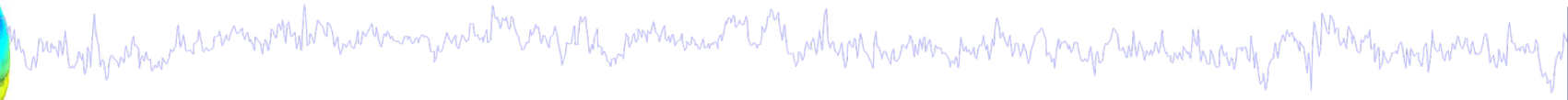






Pre-processing pipeline





Swartz Center for Computational Neuroscience

Collect EEG data

Import into EEGLAB

Import event markers and channel locations

Re-reference/ down-sample (if necessary)

High pass filter (~.5 – 1 Hz)

Examine raw data

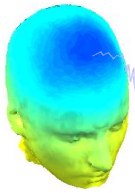
Identify/reject bad channels

Reject large artifact time points

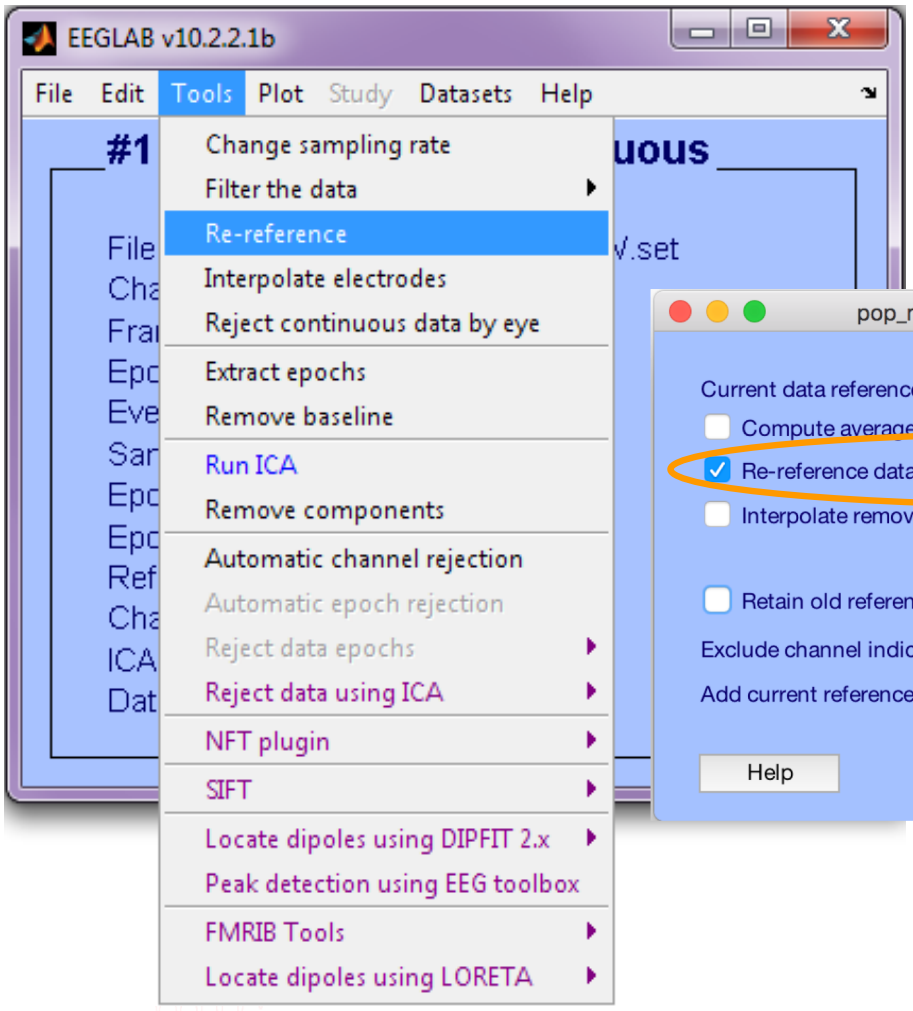
Run ICA and reject components

Done

Re-reference data (if necessary/desired)

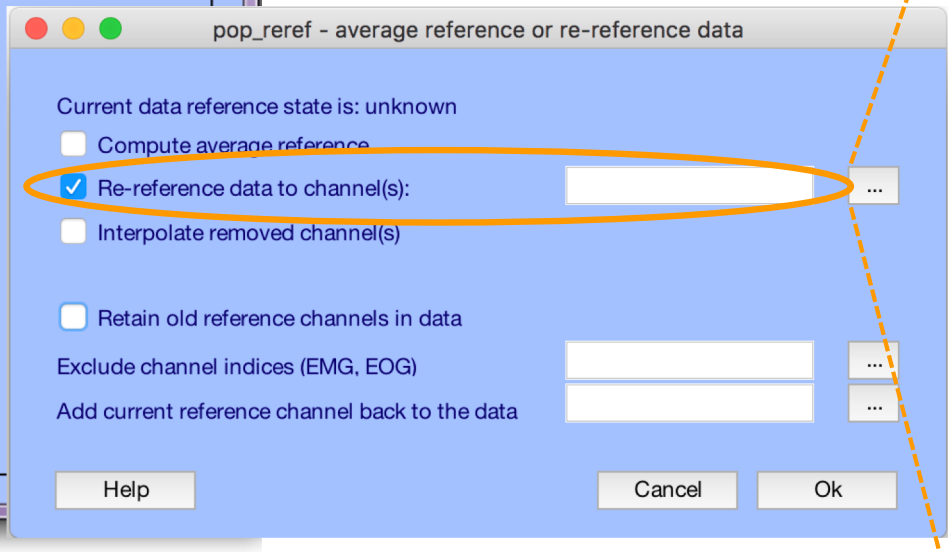


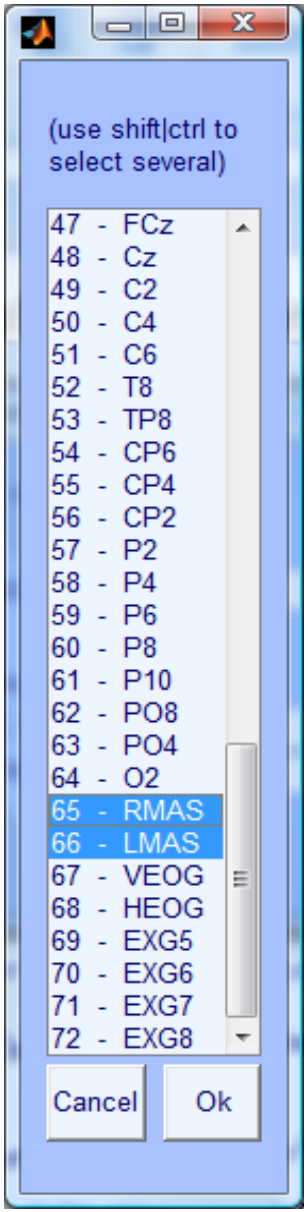
Swartz Center for Computational Neuroscience



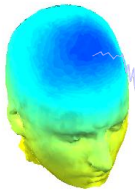
Re-reference to

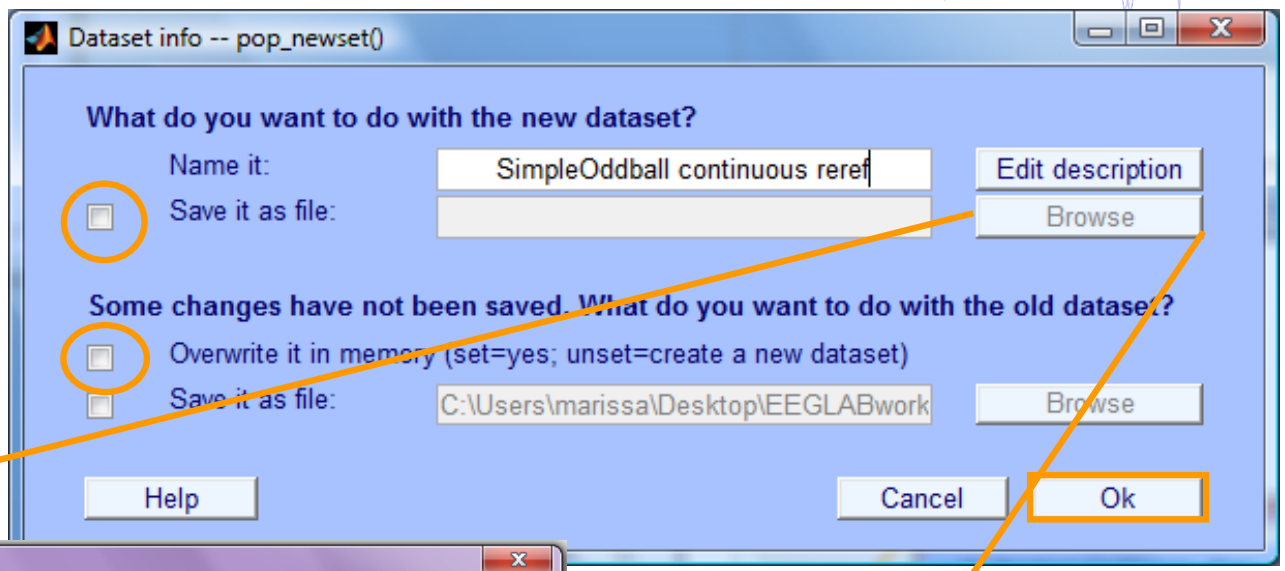
(e.g.) 'linked mastoids'

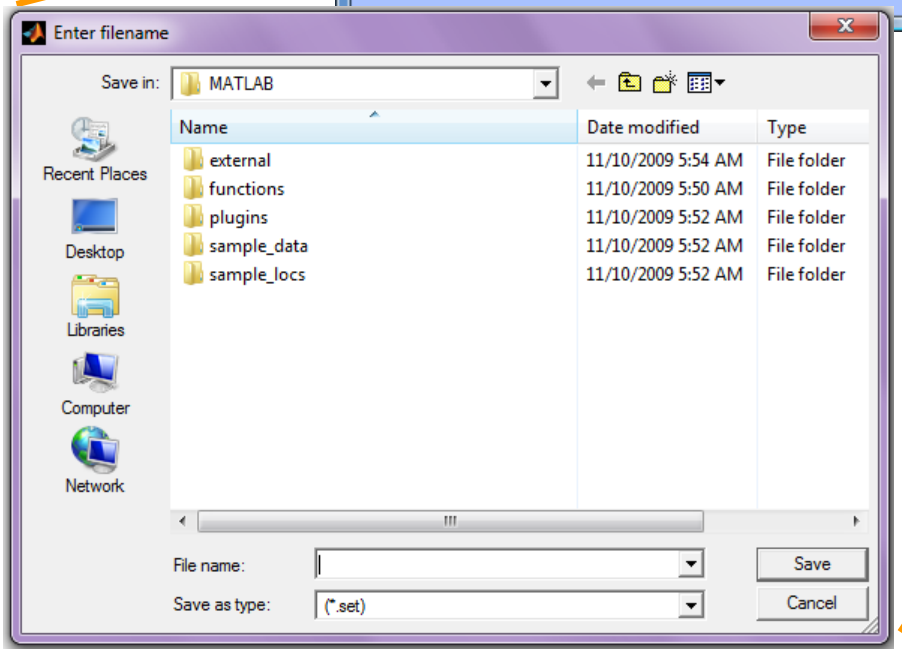


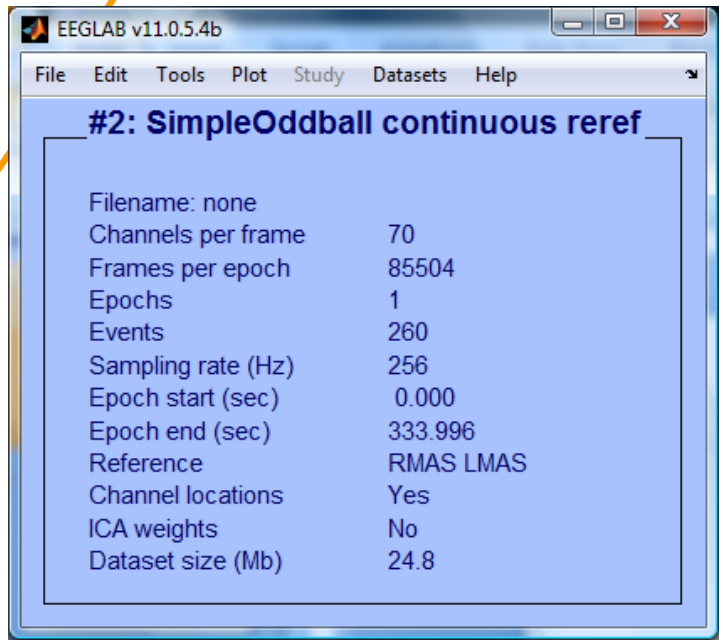


Save new dataset, keep old one

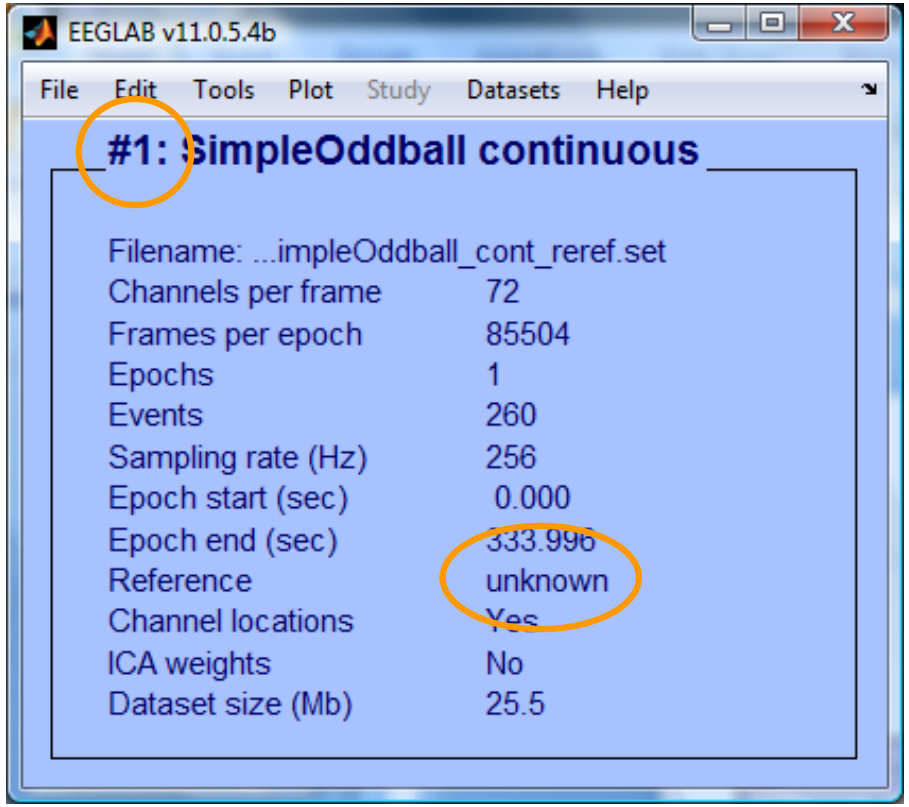


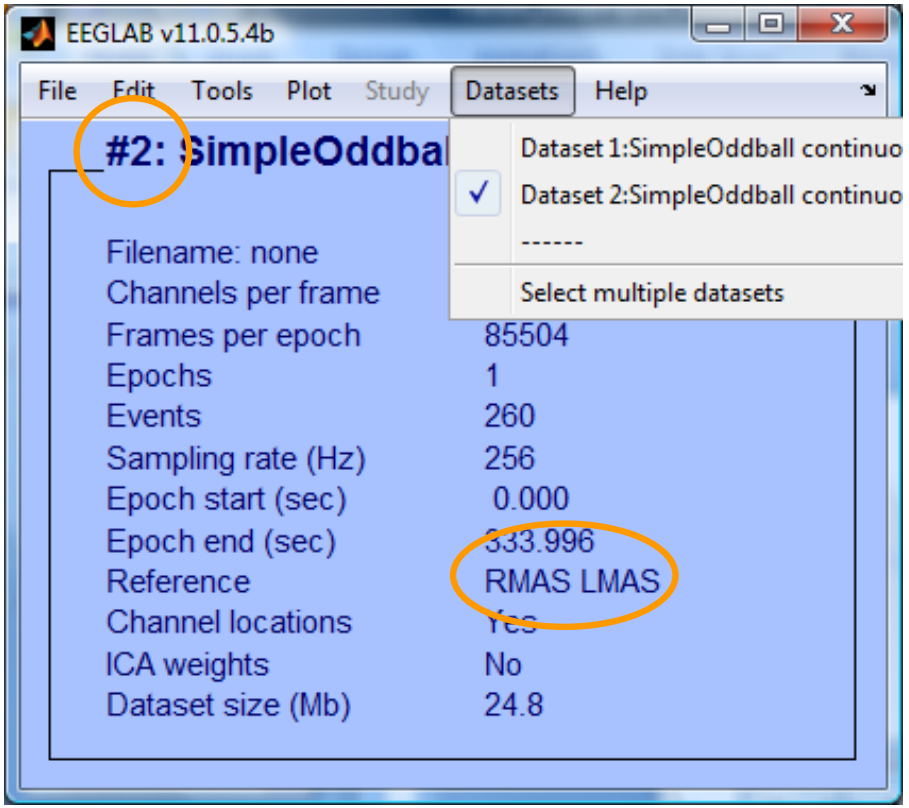




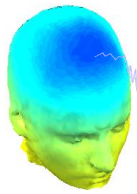


Multiple active datasets





Re-reference data (if necessary/desired)



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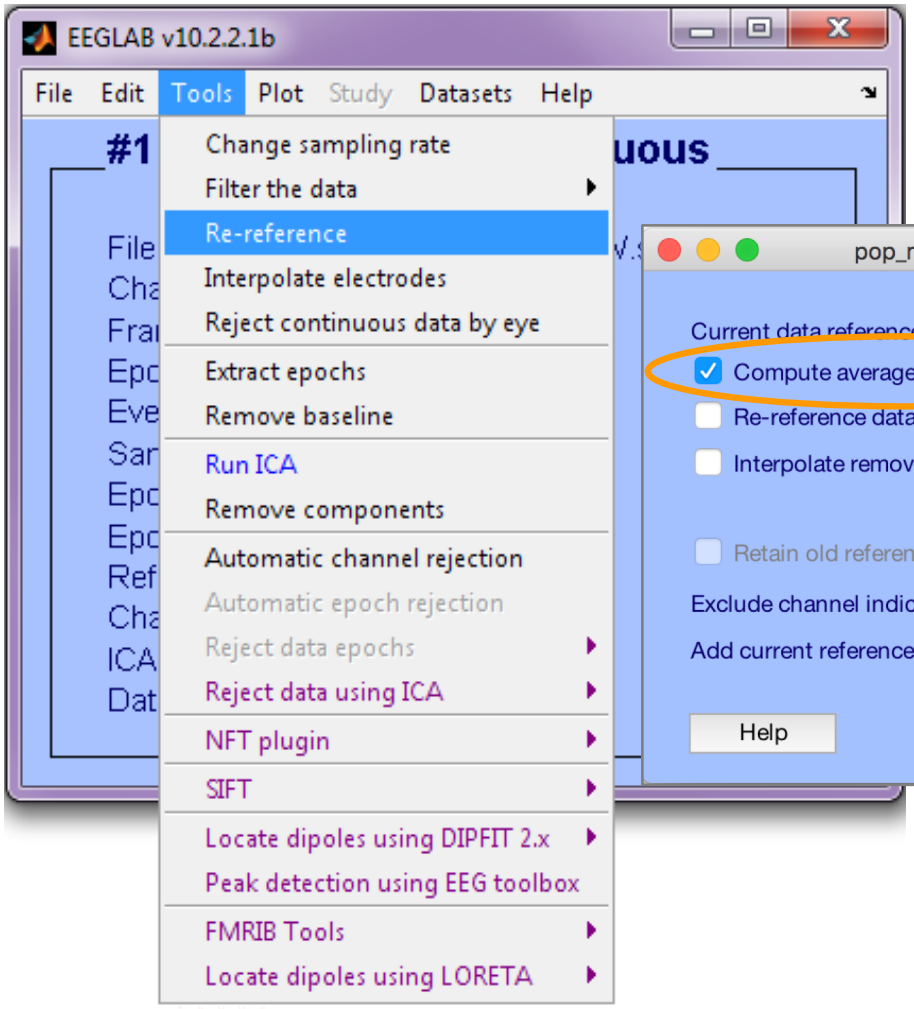
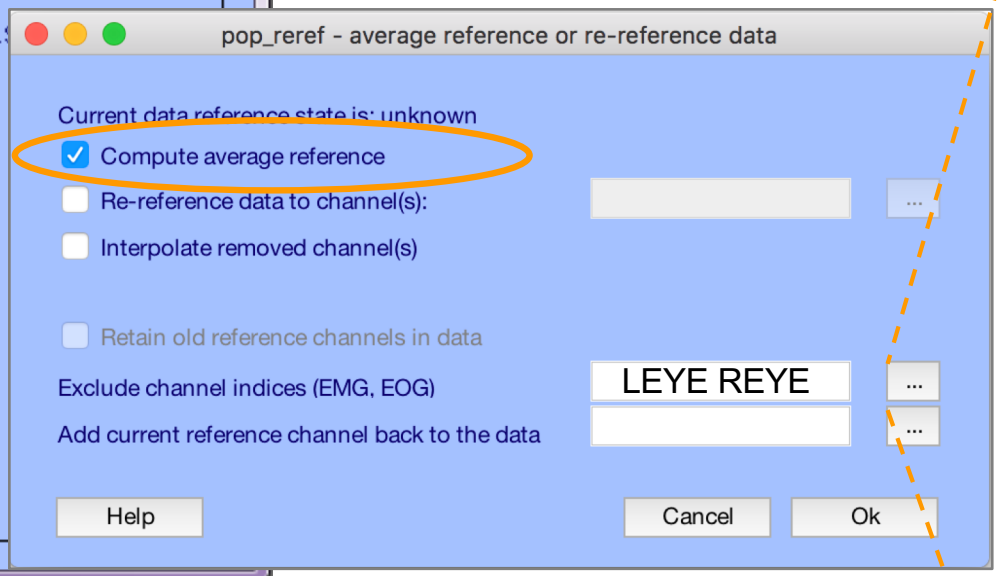


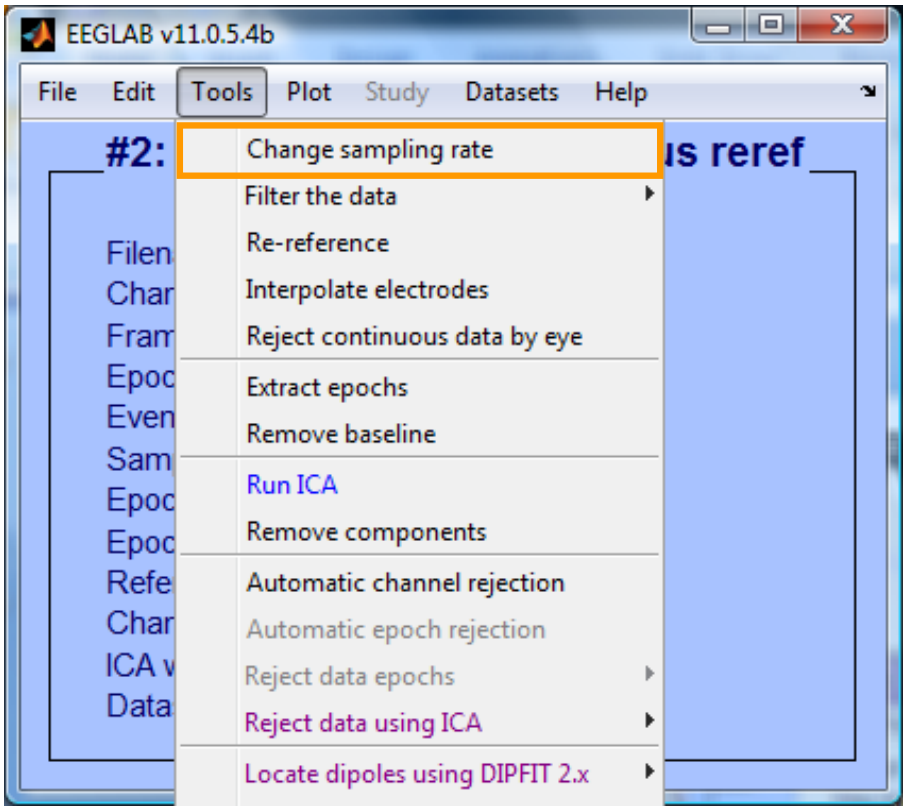
Or,

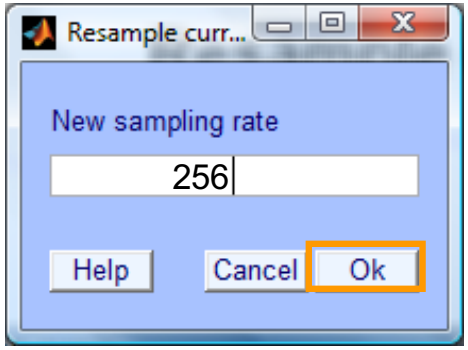
average reference



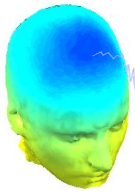
Resample data (if desired)

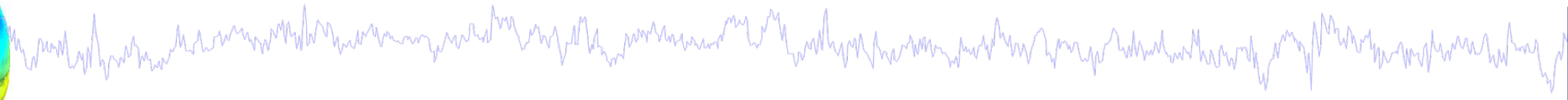
Reason: Reduce space, time.





Pre-processing pipeline





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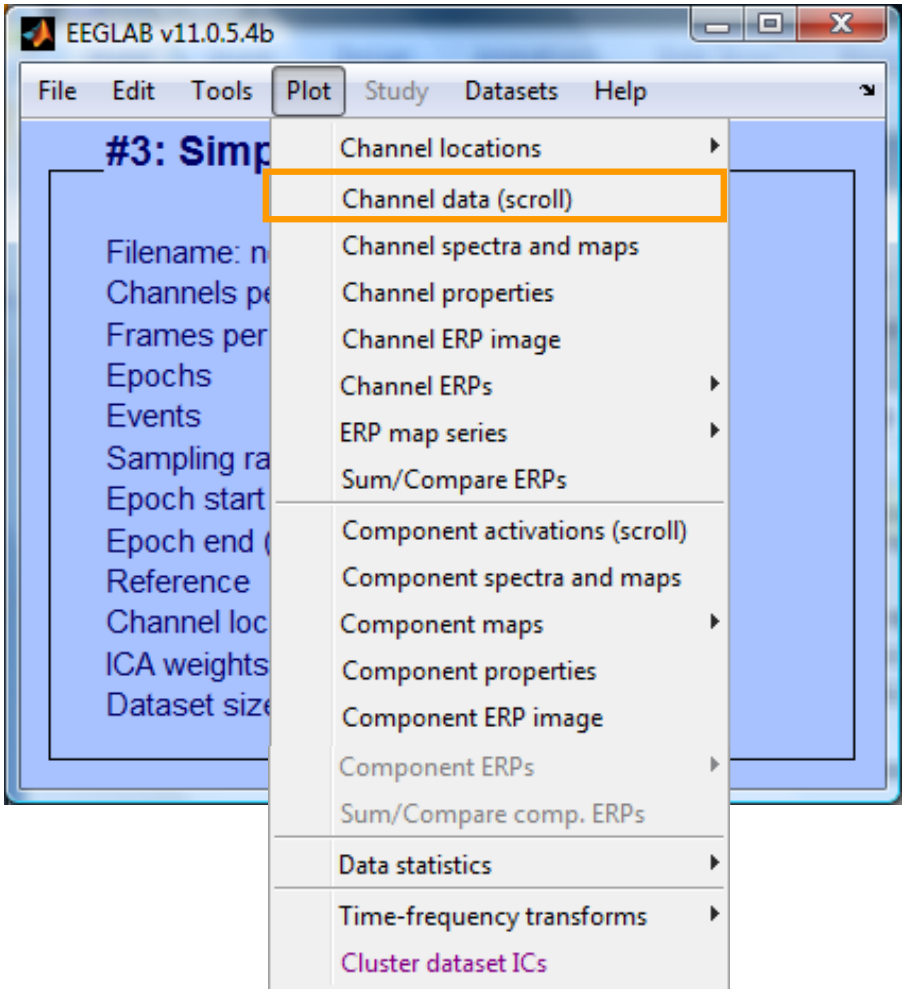
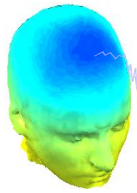
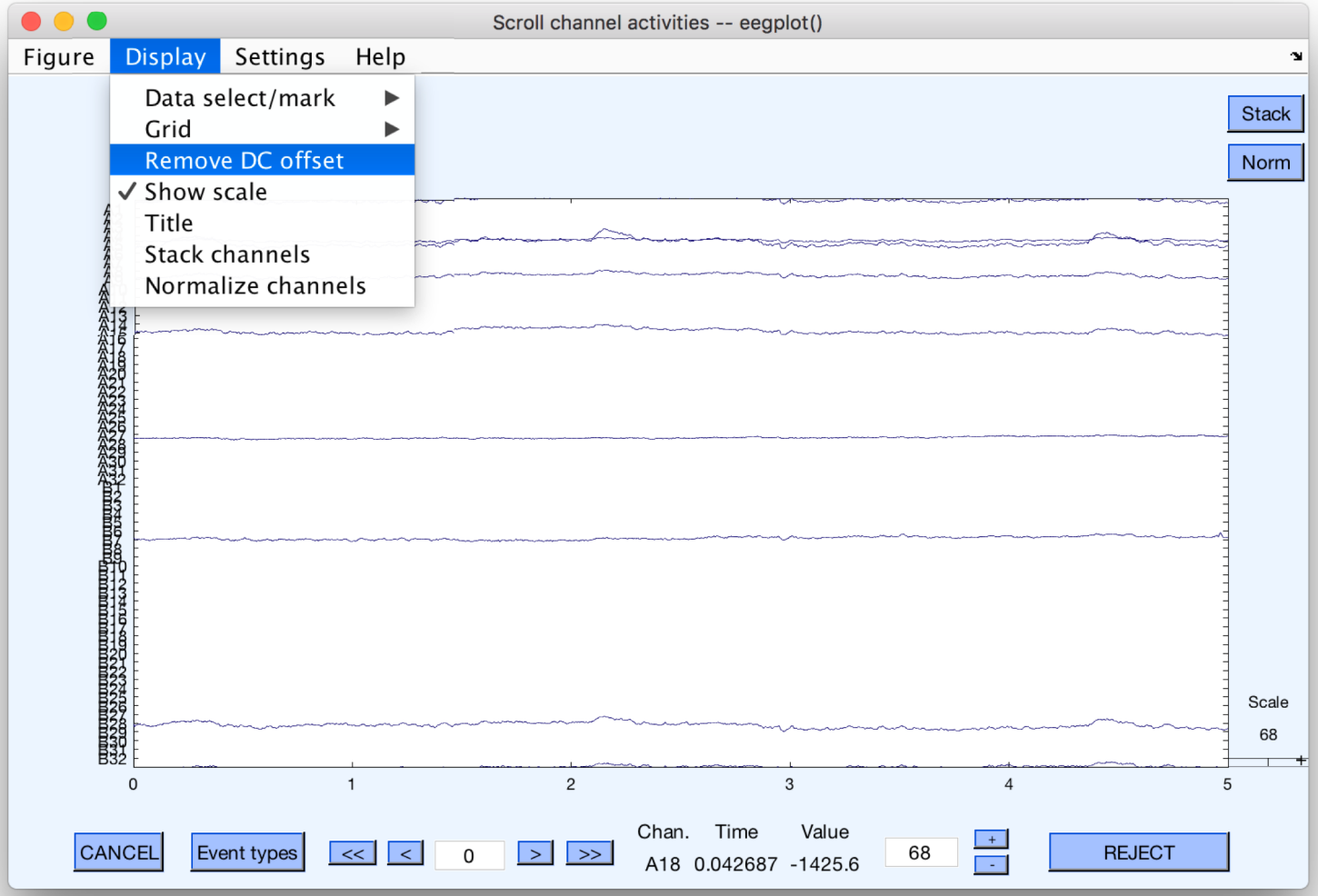
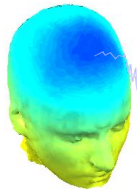
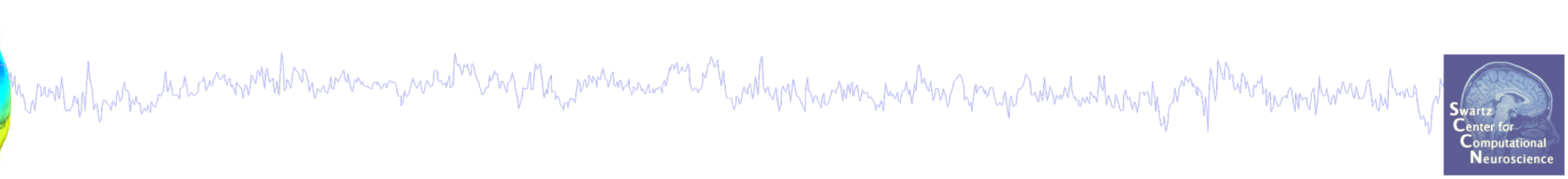





Scroll channel activities -- eegplot()
Figure
Display
Settings
Help
Data select/mark
Grid
Remove DC offset
Show scale
Title
Stack channels
Normalize channels
Stack
Norm
Scale
68
0
1
2
3
4
5
CANCEL
Event types
<<
<
0
>
>>
Chan. Time Value
A18 0.042687 -1425.6
68
REJECT





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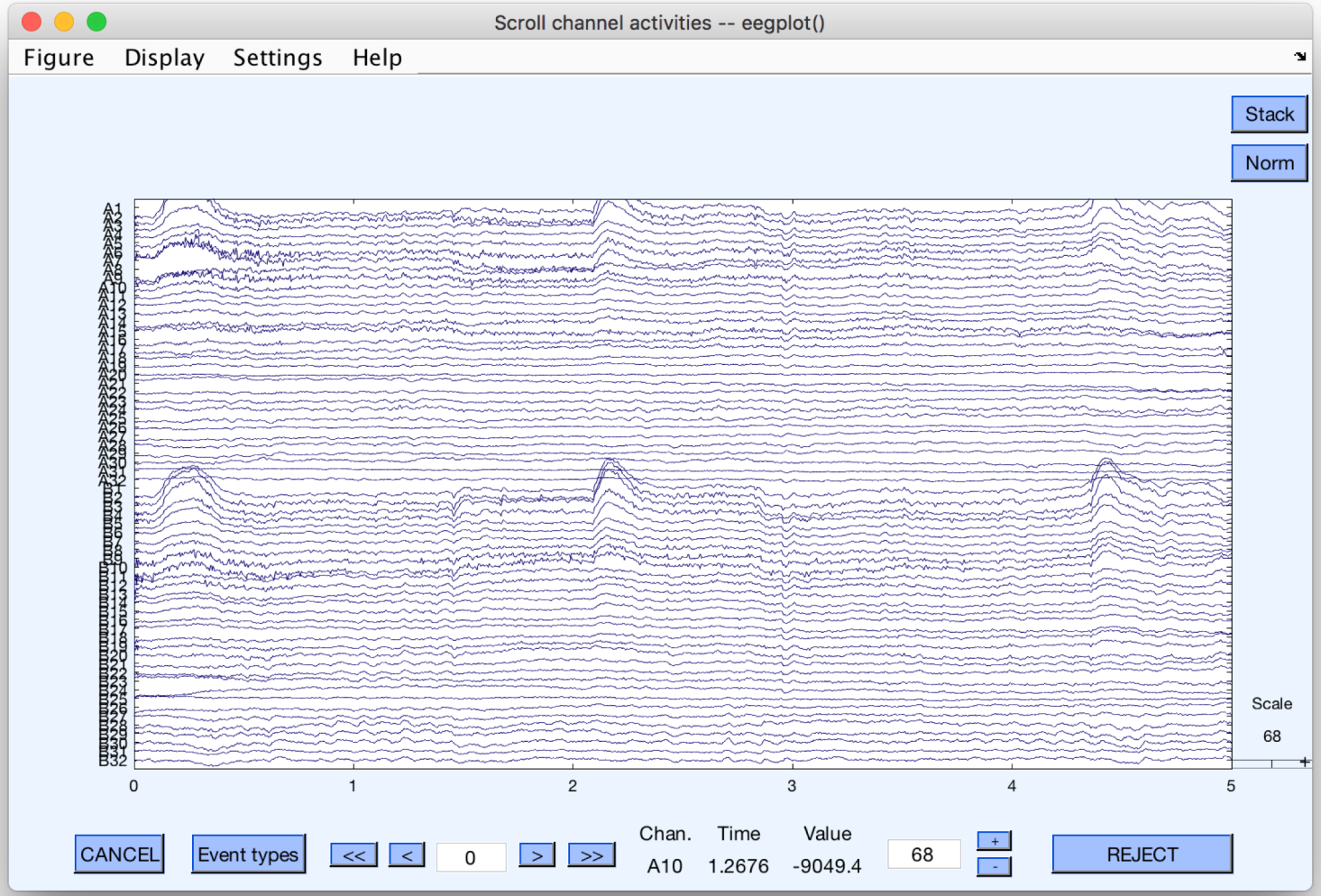
Neuroscience


Scroll channel activities -- eegplot()
Figure
Display
Settings
Help
Stack
Norm
Scale
68
0
1
2
3
4
5
CANCEL
Event types
<<
<
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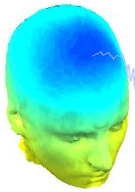
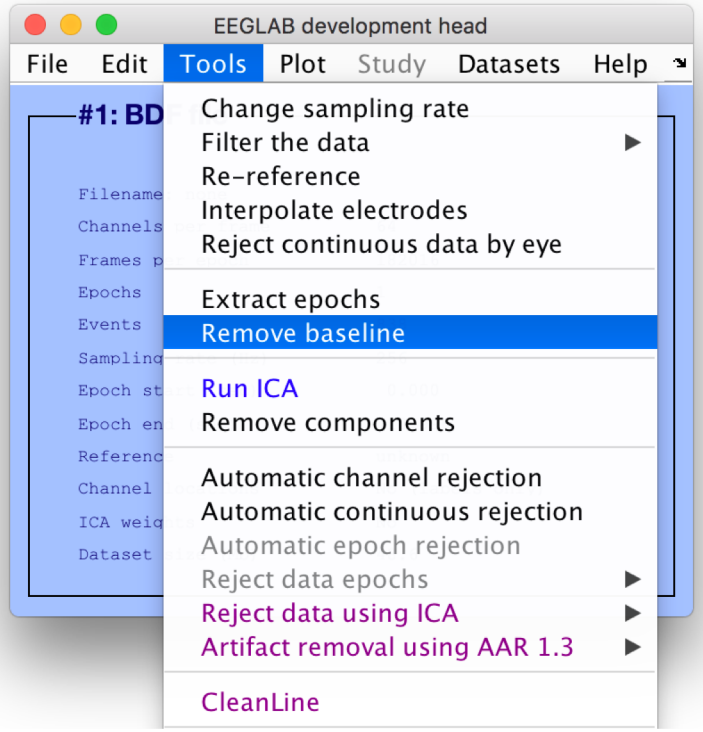
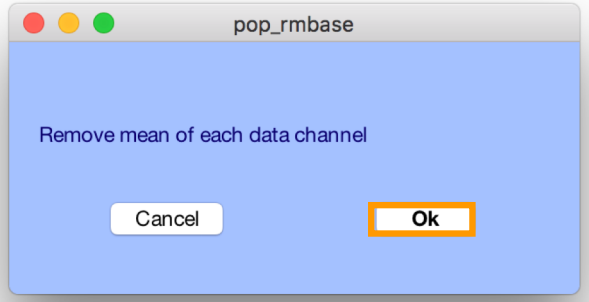
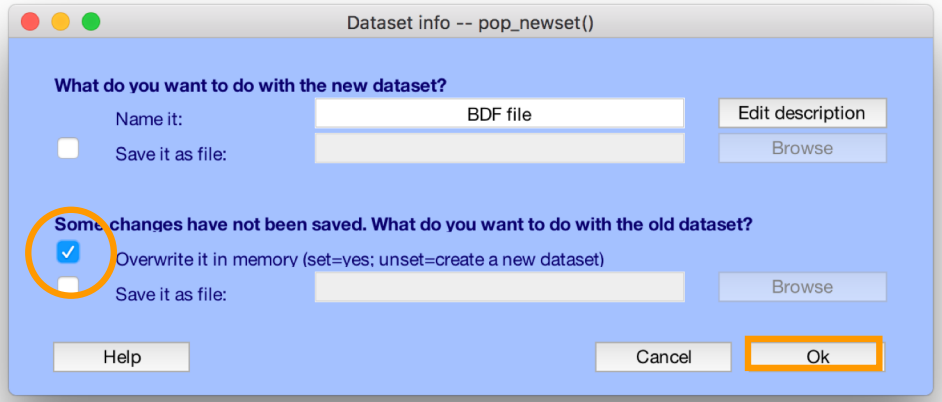
>
>>
Chan.
Time
Value
A10
1.2676
-9049.4
68
+
-
REJECT

Remove DC offset



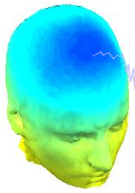






DC offsets introduce large filter artifact at signal boundaries, so it better to remove them prior to filter the signal.

High-Pass Filter the data



Reason: remove slow, possibly large amplitude, drift

EEGLAB v11.0.5.4b

File Edit Tools Plot Study Datasets Help

#1:

Filen
Char
Fram
Epoc
Even
Sam
Epoc
Epoc
Refe
Char
ICA v
Data

Change sampling rate
Filter the data
Re-reference
Interpolate electrodes
Reject continuous data by eye
Extract epochs
Remove baseline
Run ICA
Remove components
Automatic channel rejection
Automatic epoch rejection
Reject data epochs
Reject data using ICA
Locate dipoles using DIPFIT 2.x
Peak detection using EEG toolbox
FMRIB Tools
Locate dipoles using LORETA
CleanLine

Basic FIR filter
ERPLAB Butterworth Filter
ERPLAB Polynomial Detrending
Short non-linear IIR filter

Filter the data -- pop_eegfiltnew()

Lower edge of the frequency pass band (Hz) 0.5
igher edge of the frequency pass band (Hz)
IR Filter order (Mandatory even. Default is automatic*)
See help text for a description of the default filter orde
lanual definition is recommended.
Notch filter the data instead of pass band
Use minimum-phase converted causal filter (non-li
Plot frequency response
Channel type(s) ...
OR channel labels or indices ...

High-pass needed for ICA

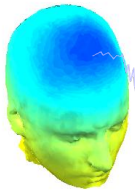
Help Cancel Ok

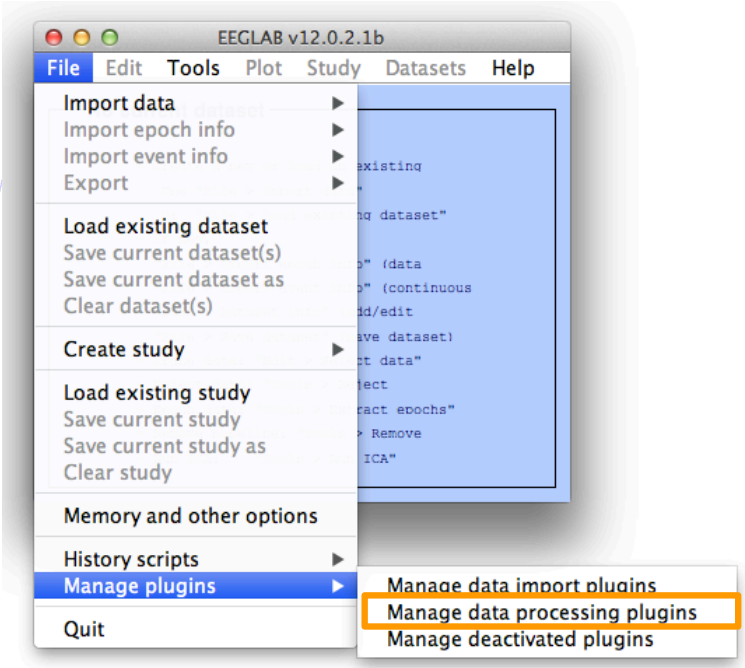
Dataset info -- pop_newset()

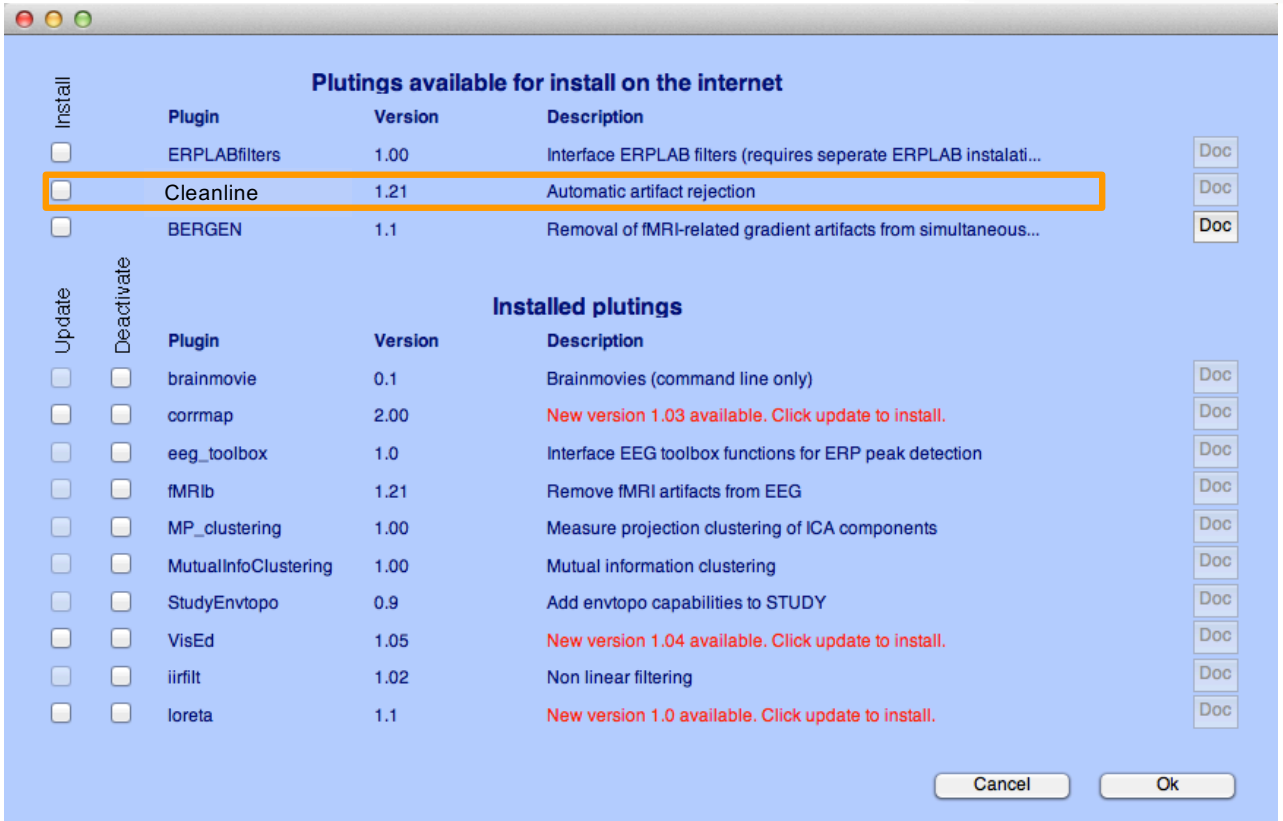
What do you want to do with the new dataset?
Name it: BDF file Edit description
Save it as file: Browse

Some changes have not been saved. What do you want to do with the old dataset?
Overwrite it in memory (set=yes; unset=create a new dataset)
Save it as file: Browse

Help Cancel Ok



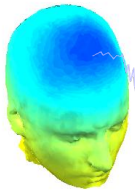


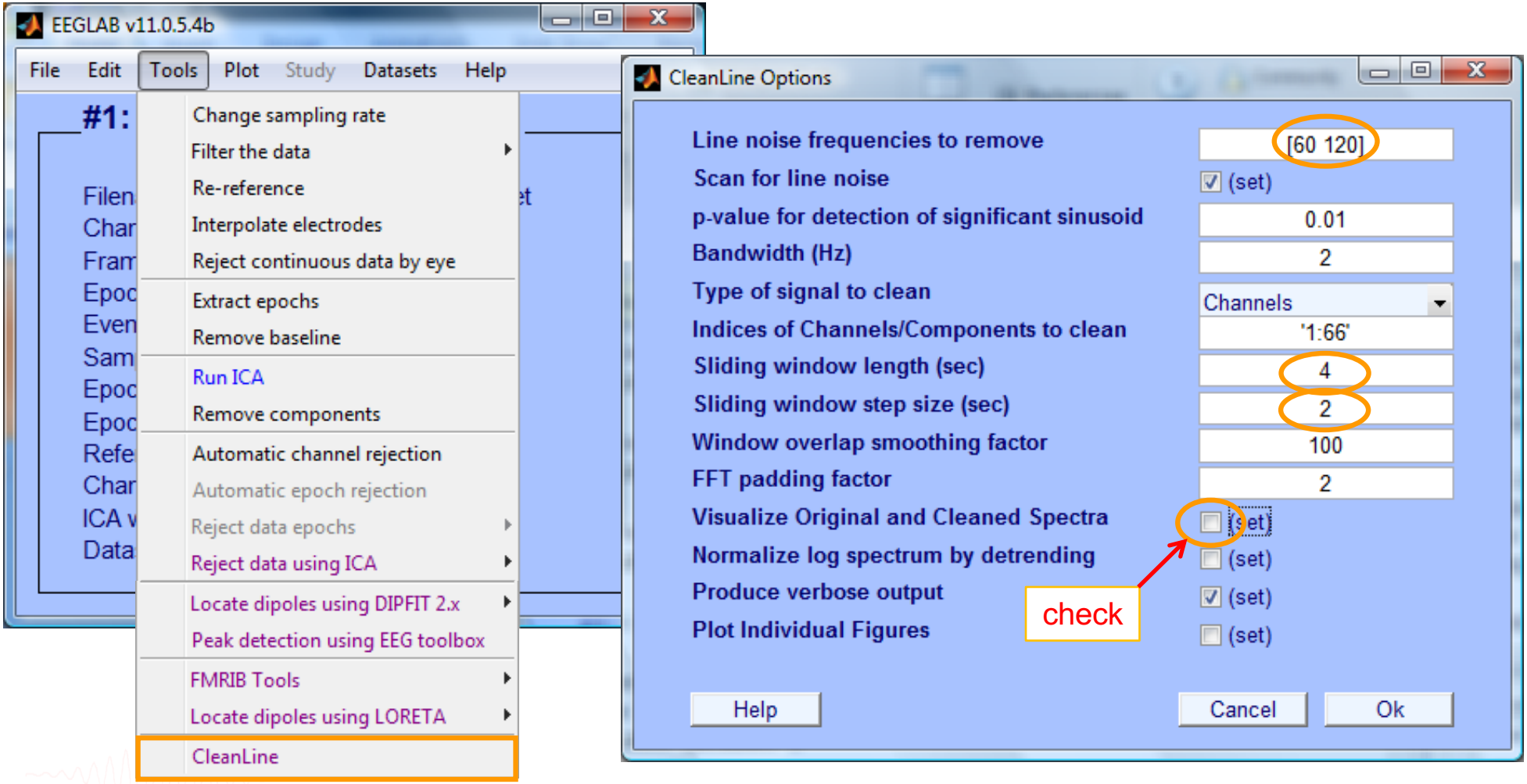


CleanLine uses an approach for line noise removal advocated by Partha Mitra and Hemant Bokil in

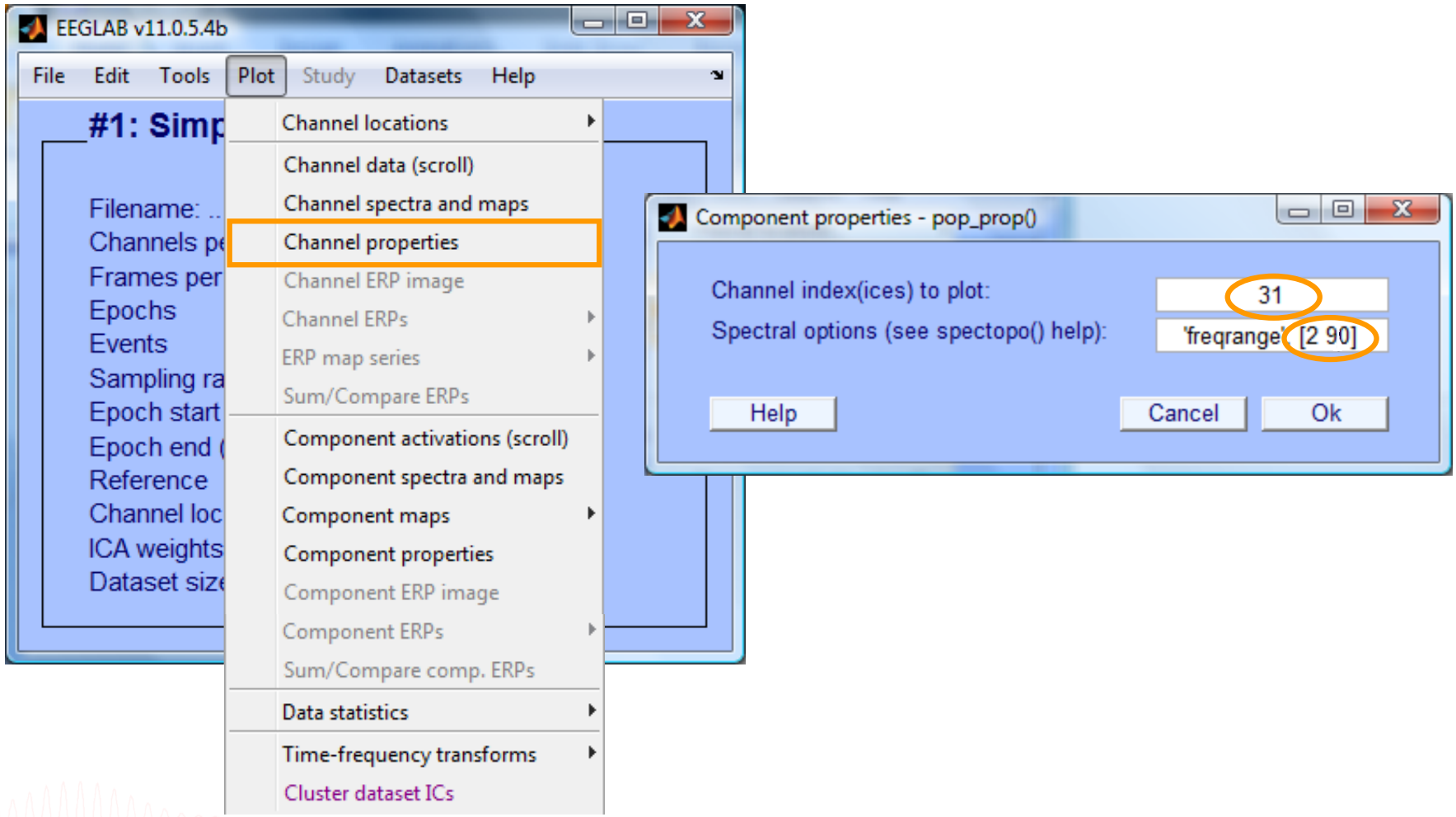
"Observed Brain Dynamics" (2007), Chapter 7.3.4.

Remove line noise (Cleanline)

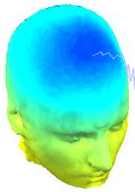




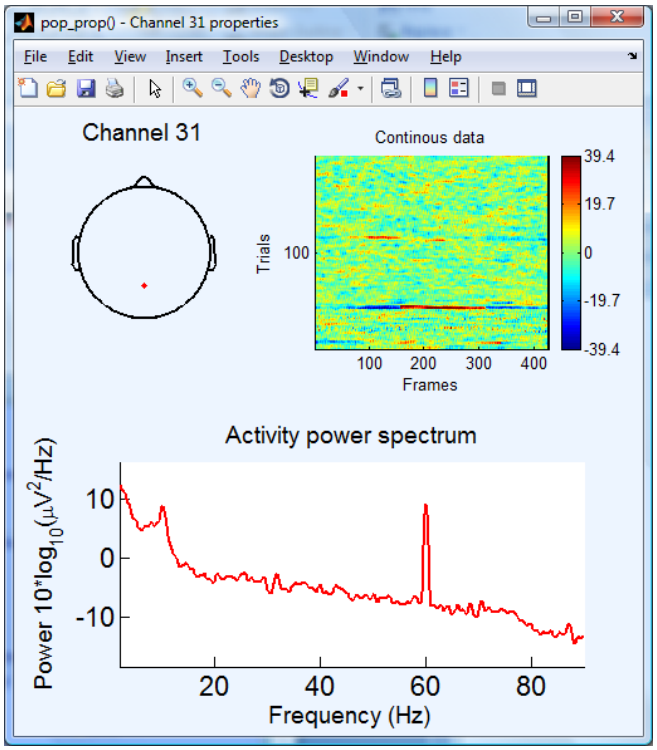
Plot channel properties



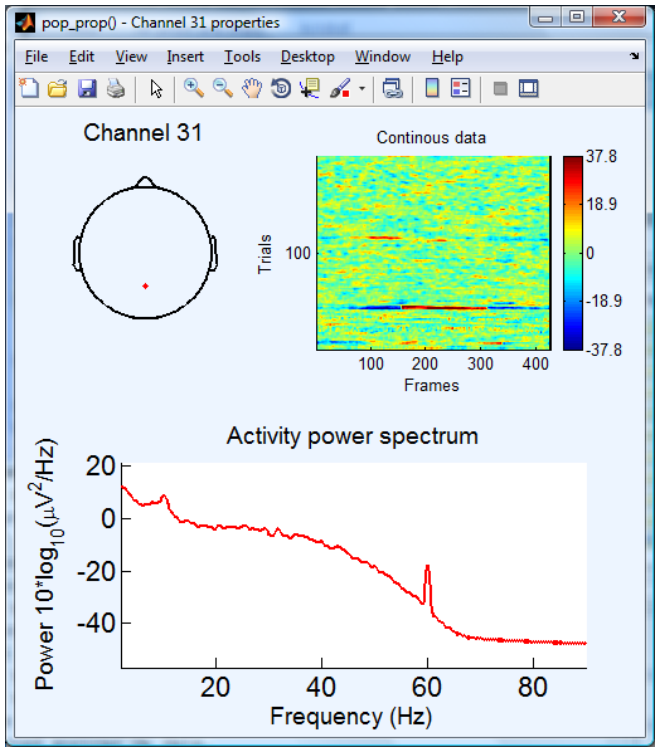
Filter comparisons



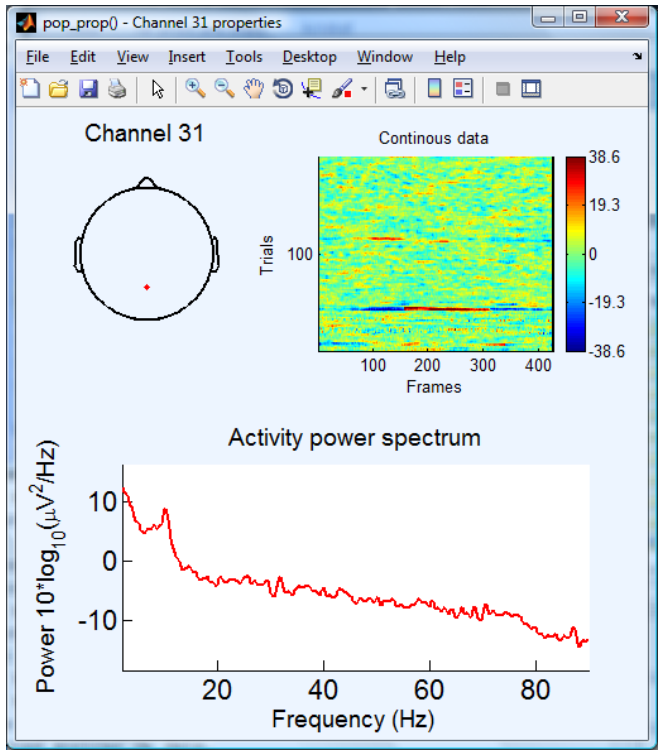
0.5 Hz high-pass filter



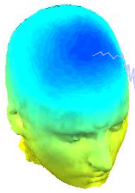
0.5 Hz high-pass filter
50 Hz low-pass filter



0.5 Hz high-pass filter
Cleanline



Pre-processing pipeline



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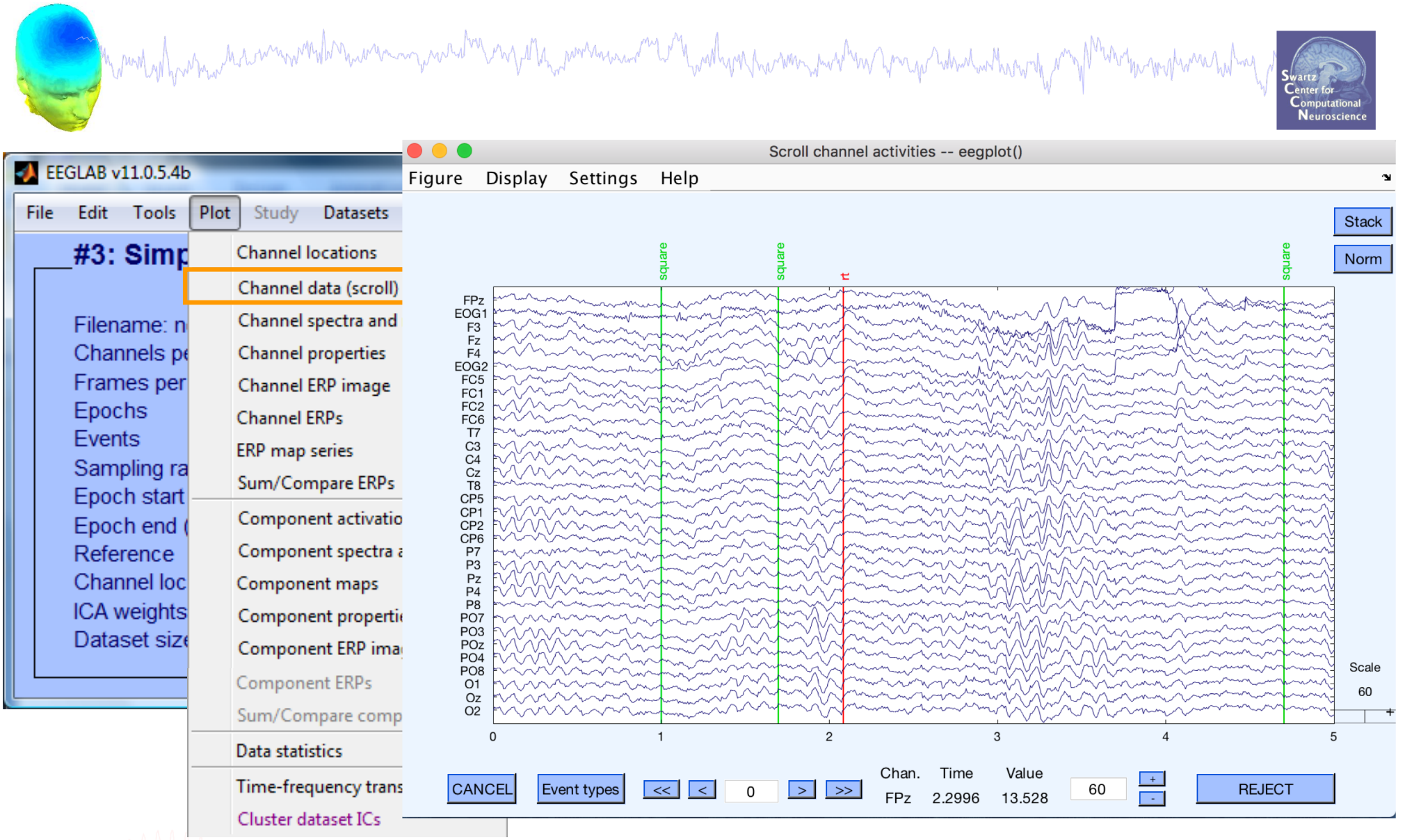
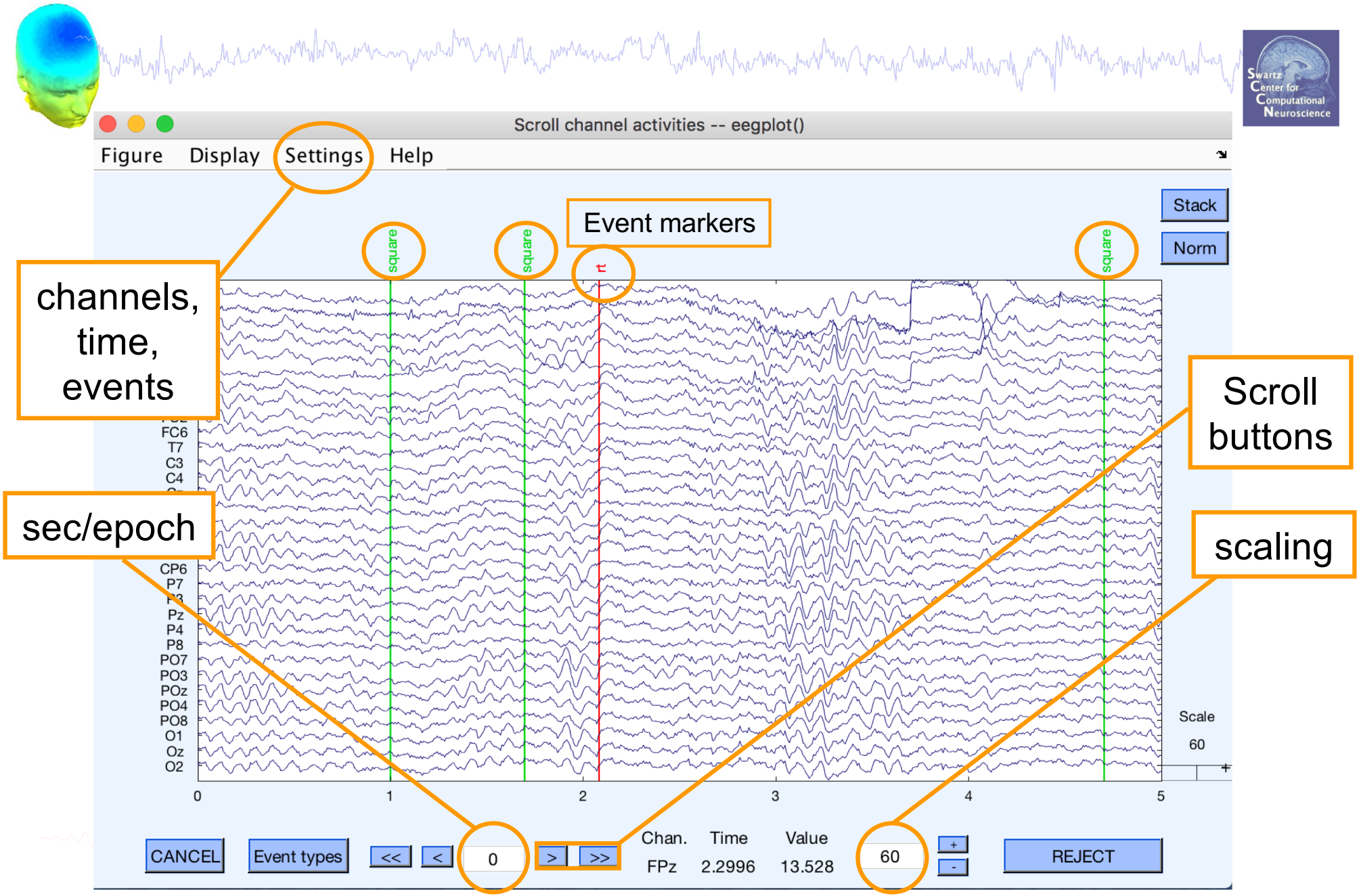
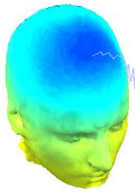


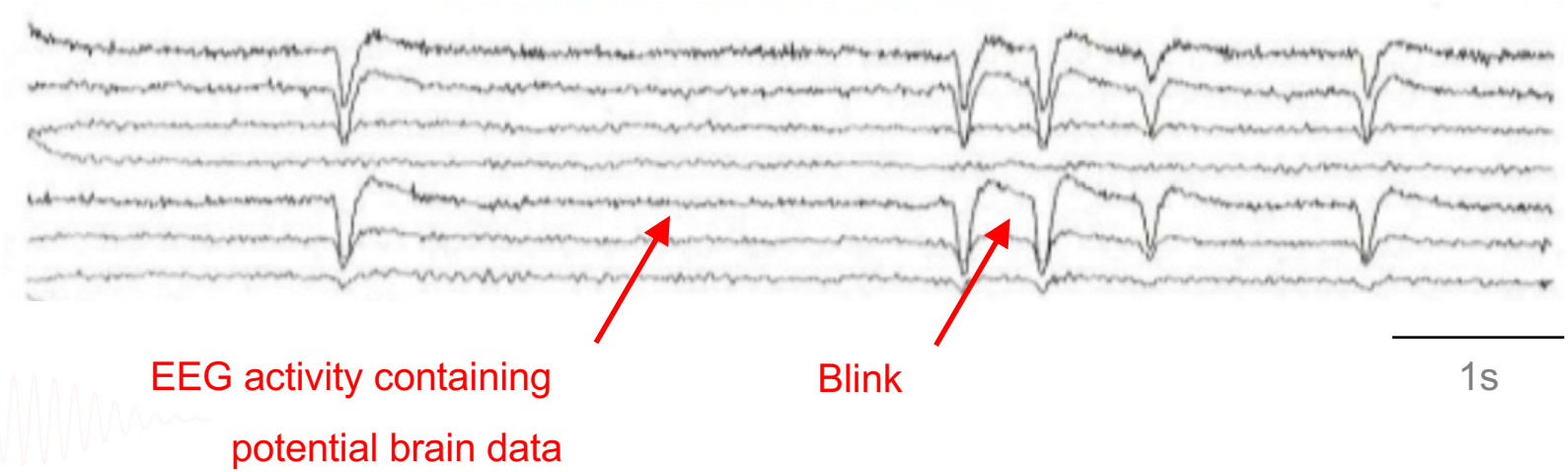
Scroll channel data



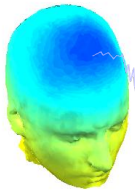
EEG artifacts

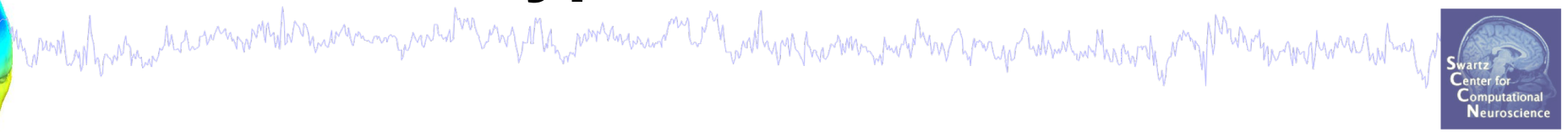


The amplitude of artifacts (such as eye movements) is often larger than the amplitude of brain data which potentially decrease signal/noise ratio, bias data analysis and potential results



Type of artifacts

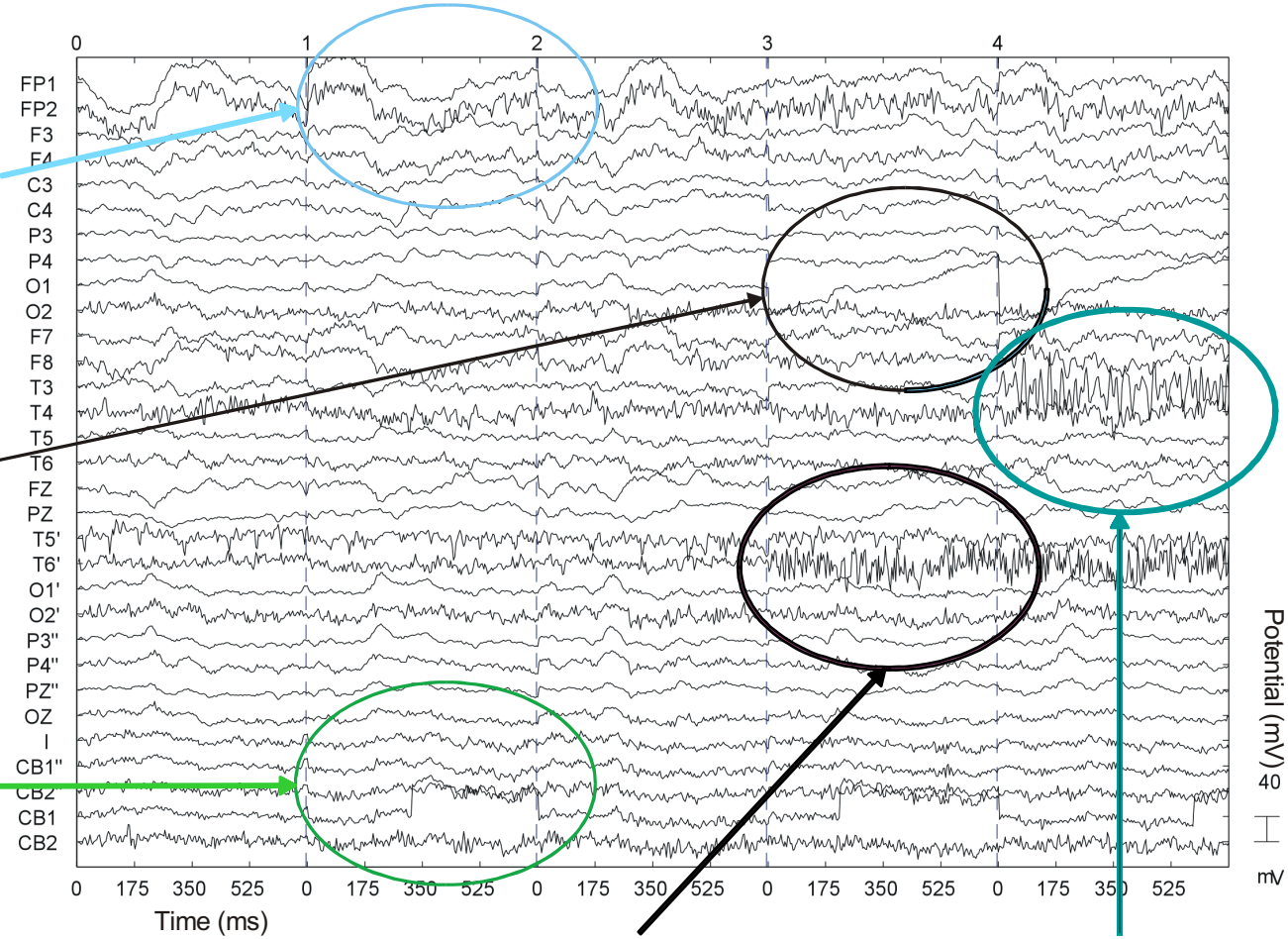




2 - Low frequency event (eye movements)

5 - Linear trend

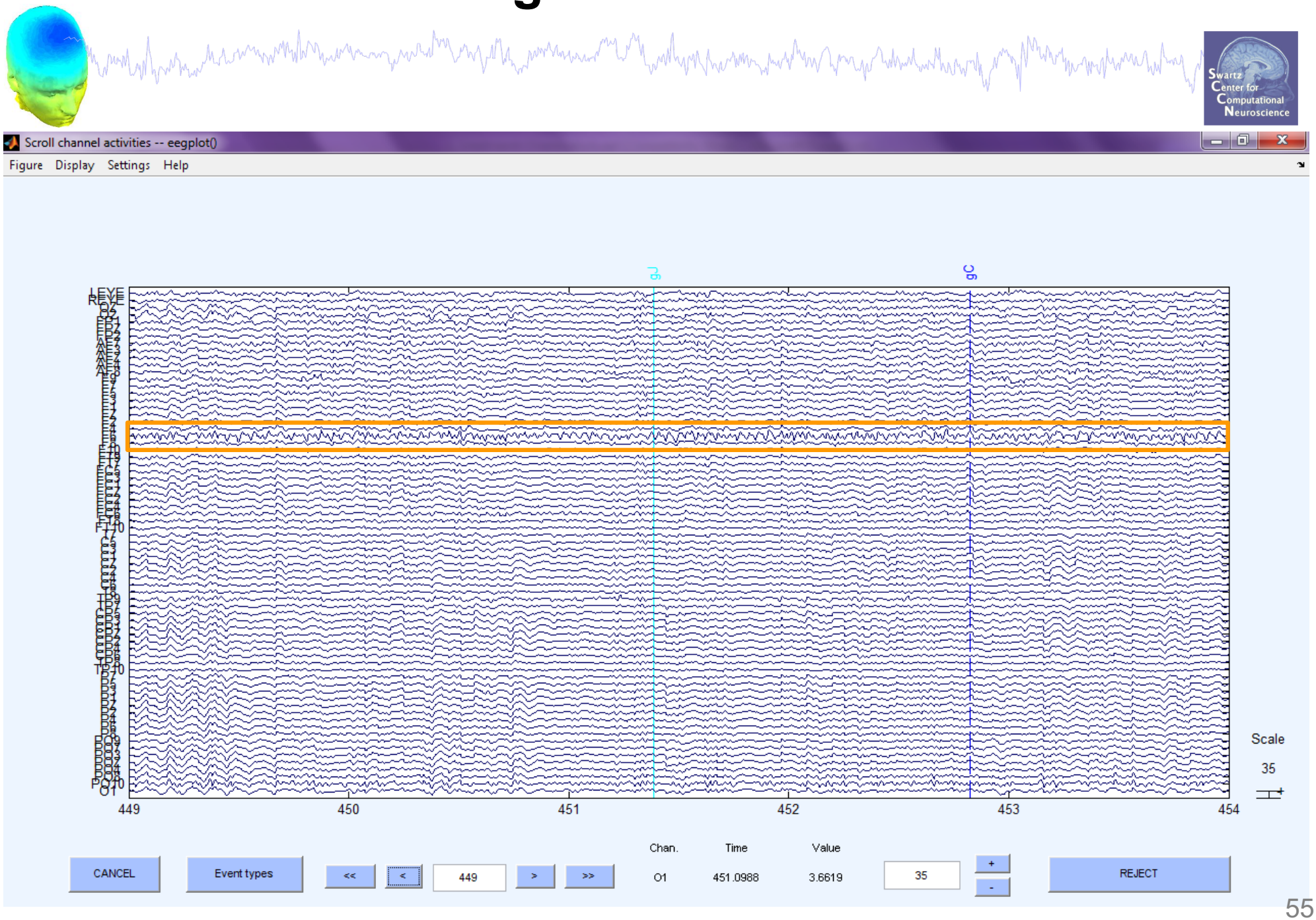
3 - Discontinuity



4 - High noise

1 - Transient high frequency event (muscle)

Looking for bad channels



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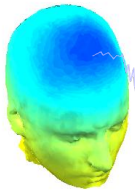

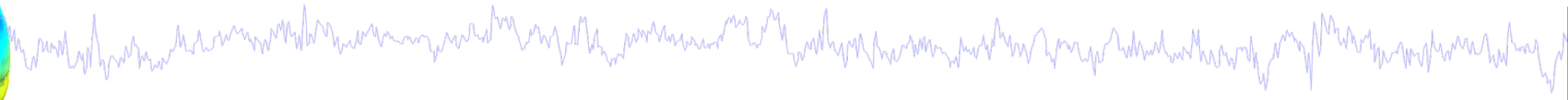

Swartz Center for Computational Neuroscience

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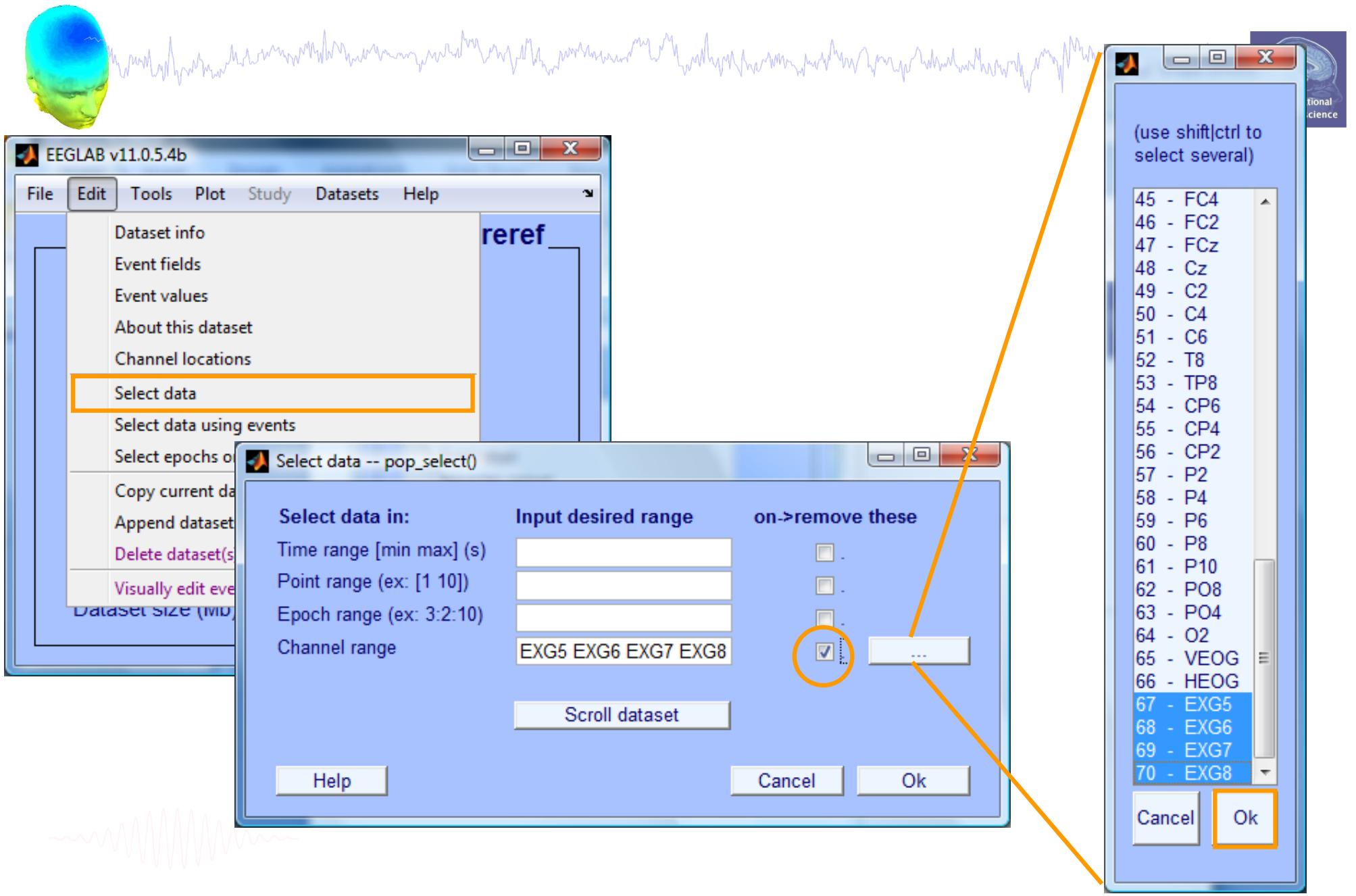
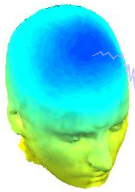
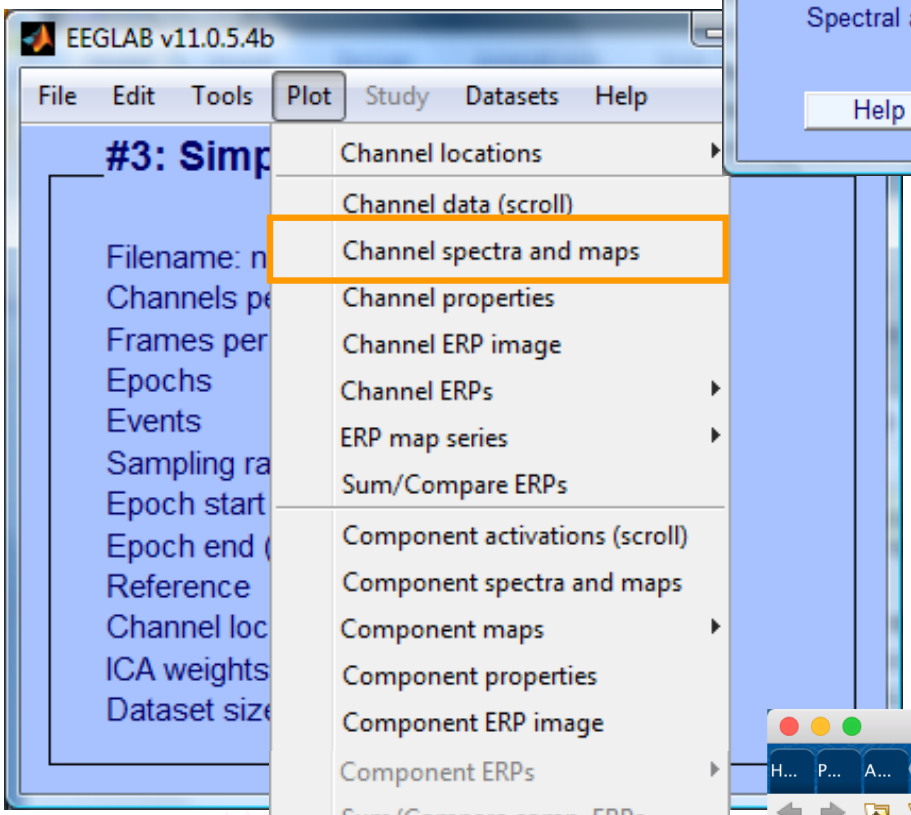
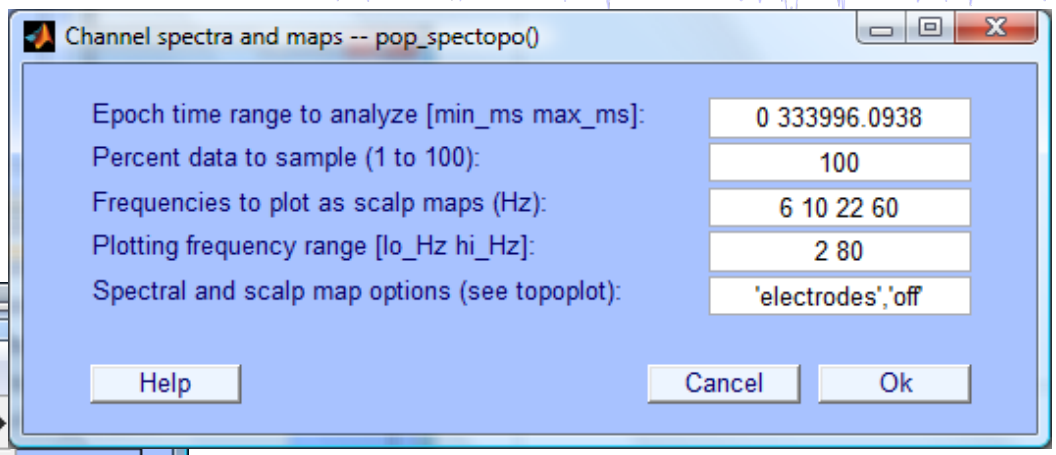
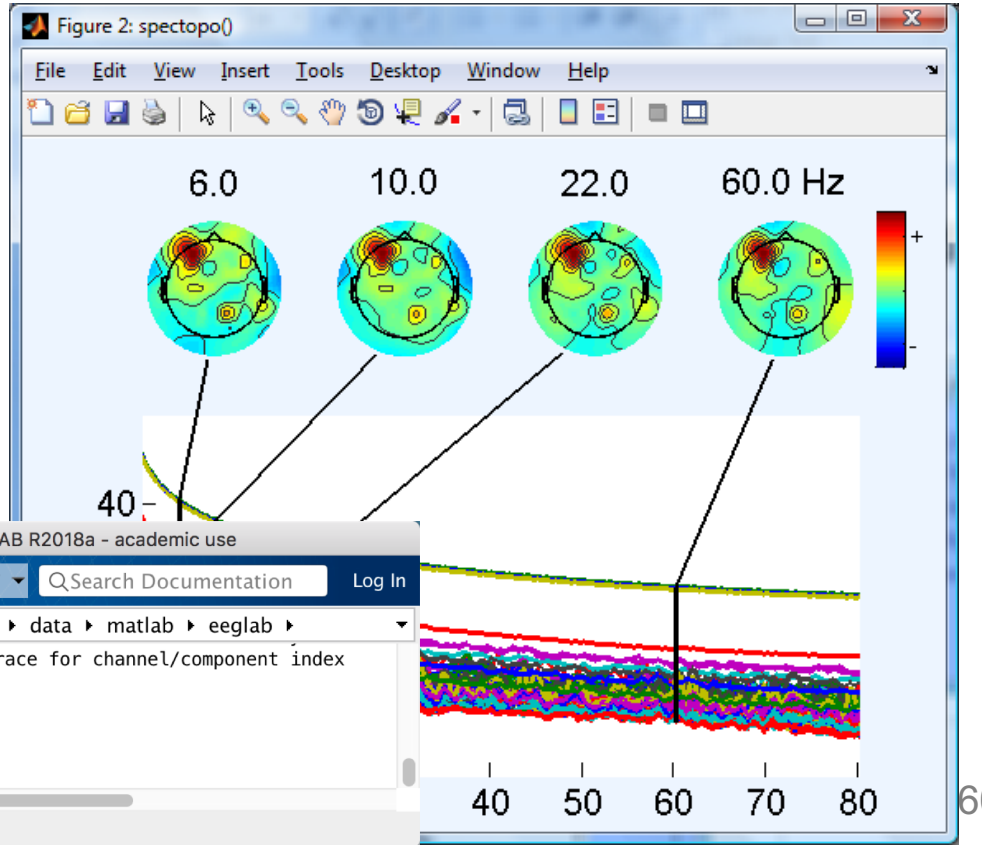


Manually identifying bad channels

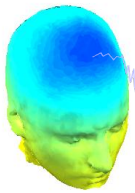


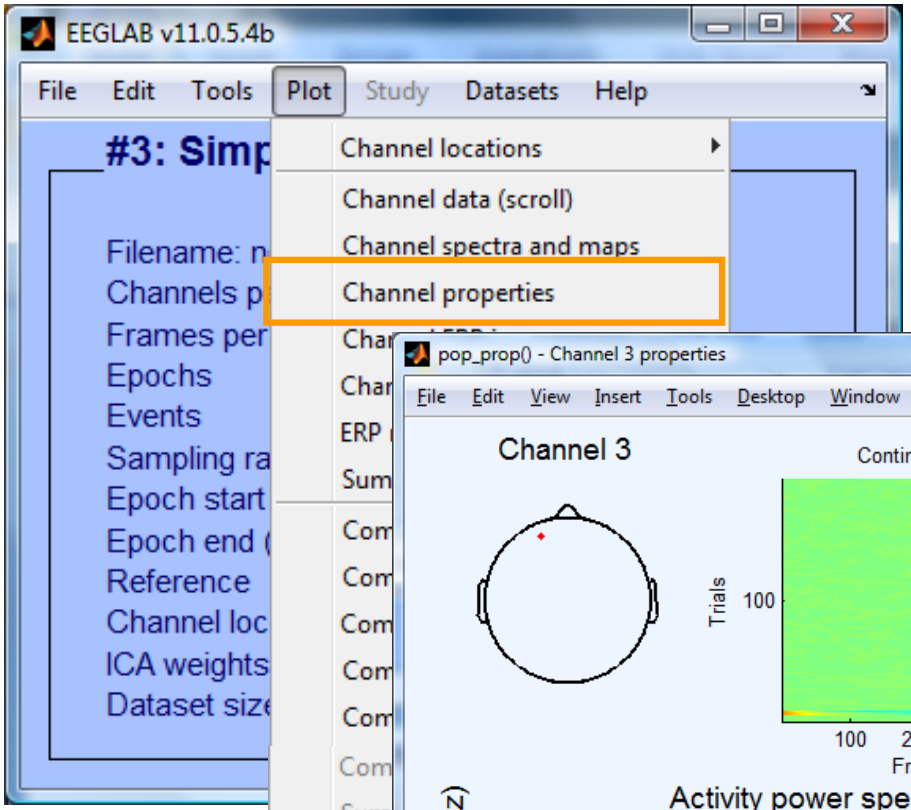


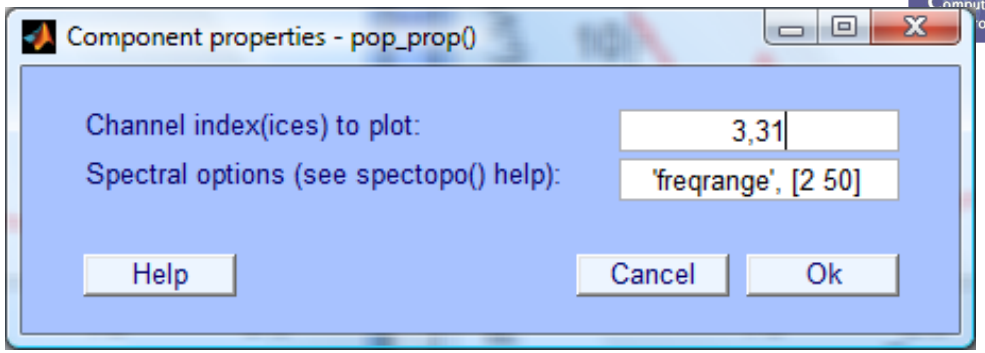


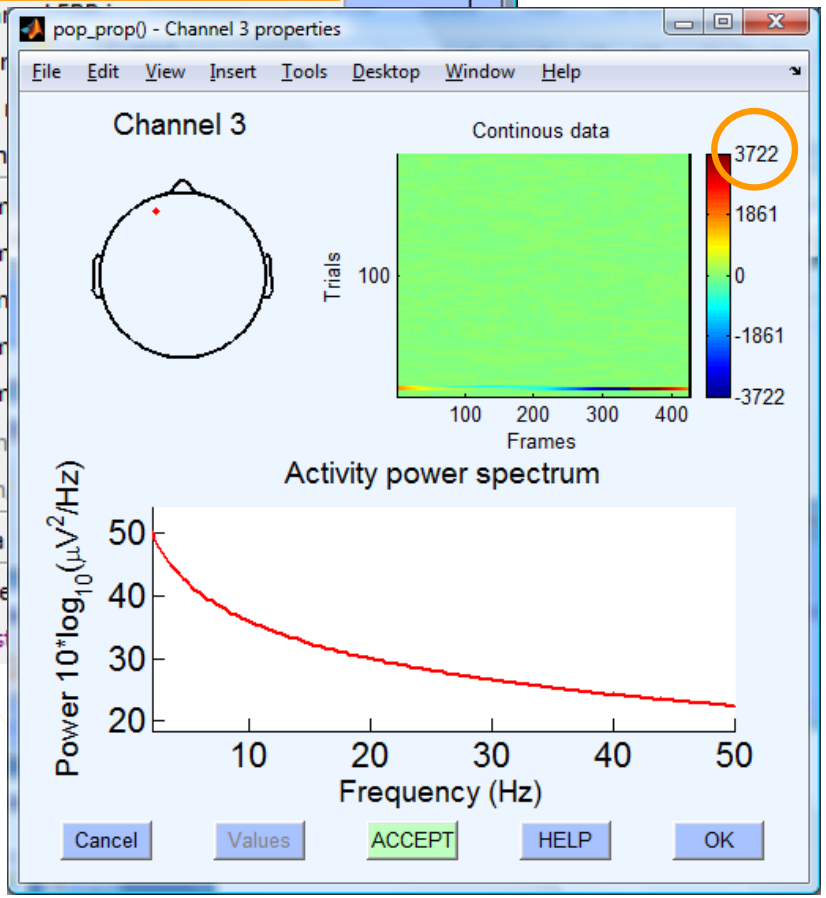


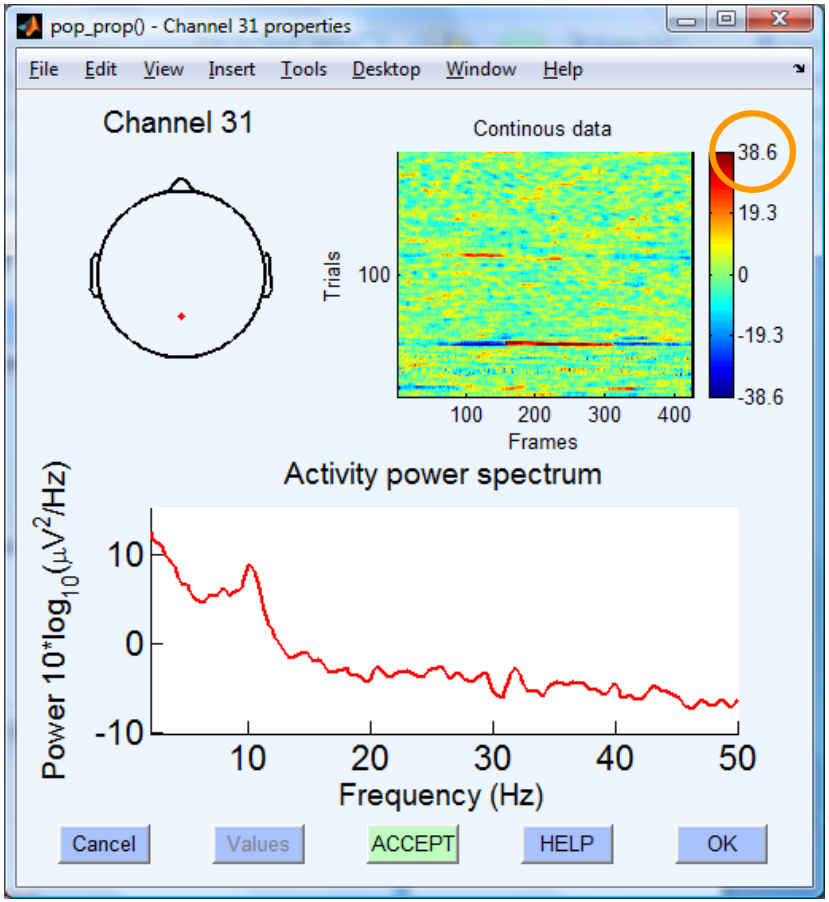
Manually identifying bad channels



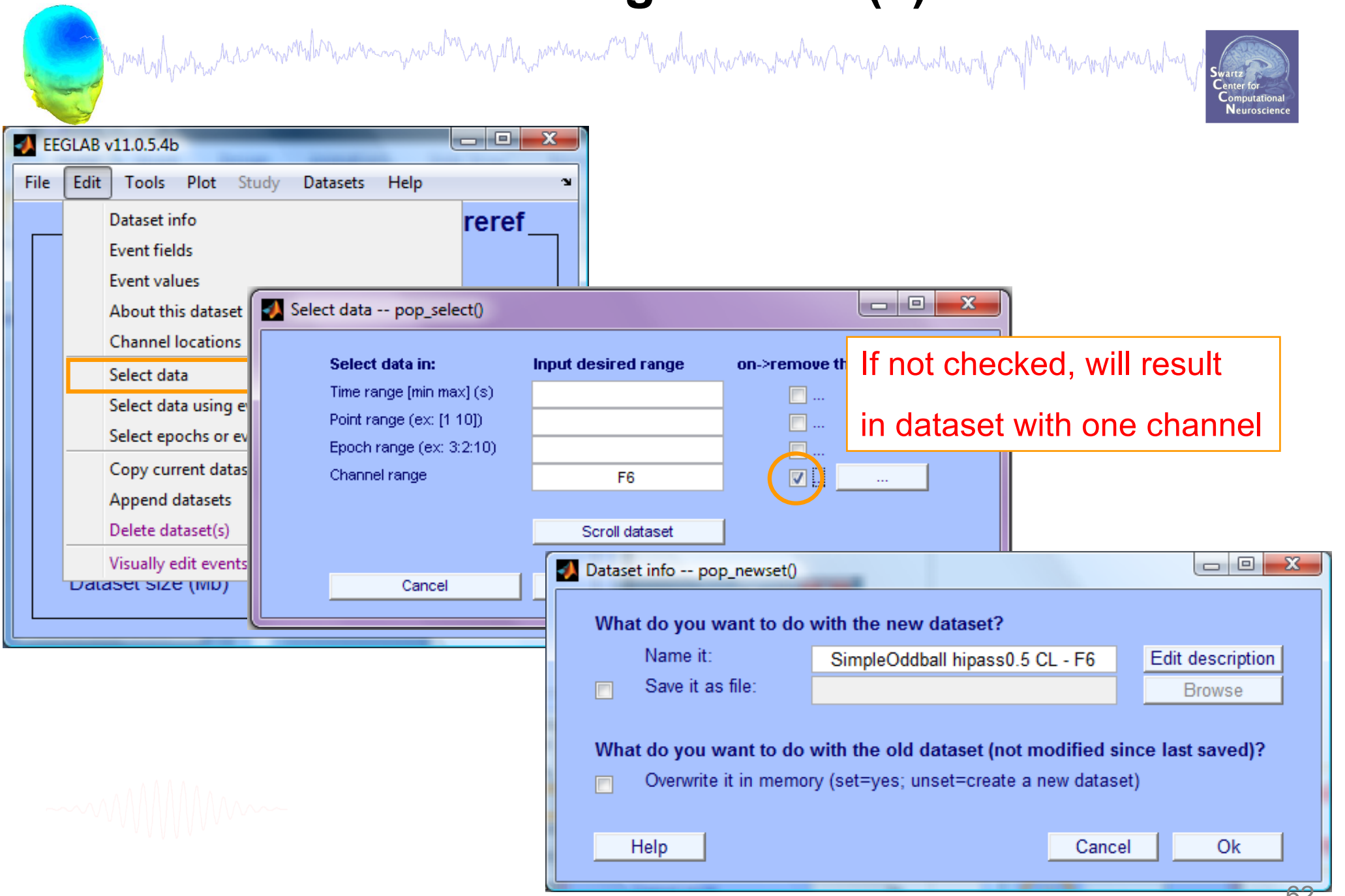




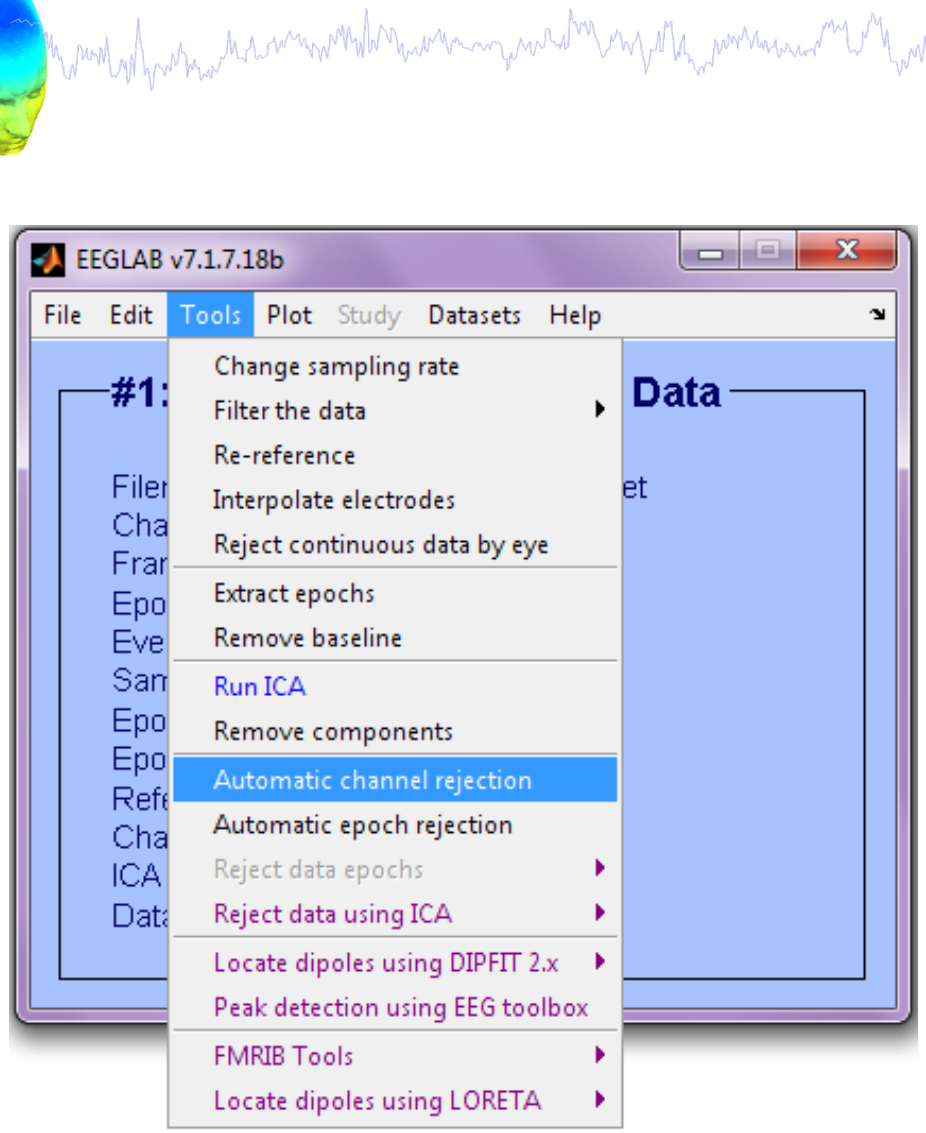


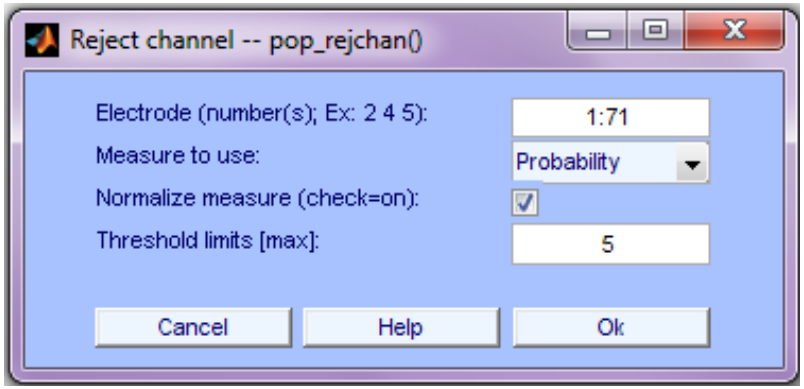


Removing channel(s)



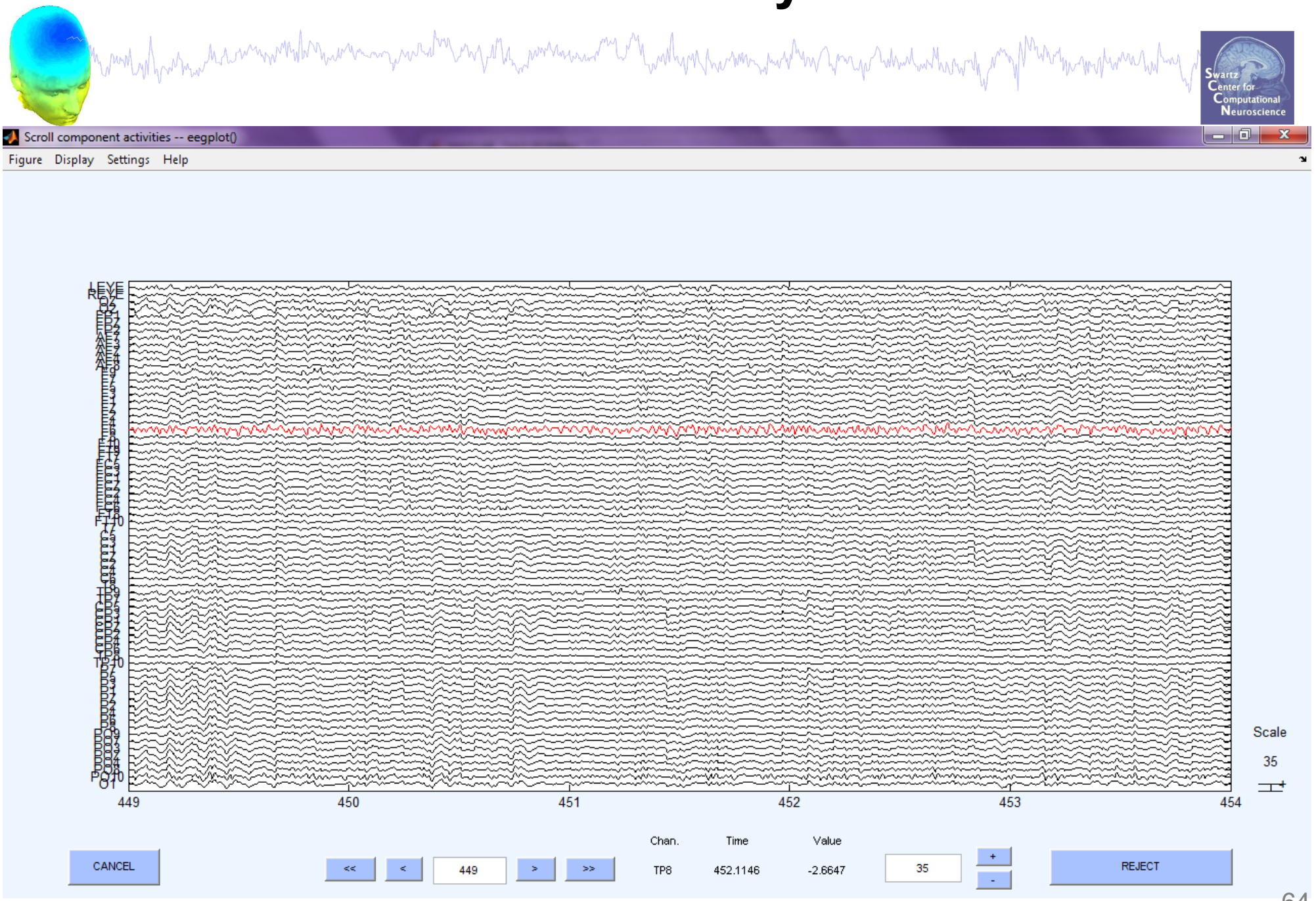
Auto-detection of noisy channels



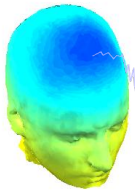


See also clean_rawdata plugin of EEGLAB

Auto-detected noisy channel

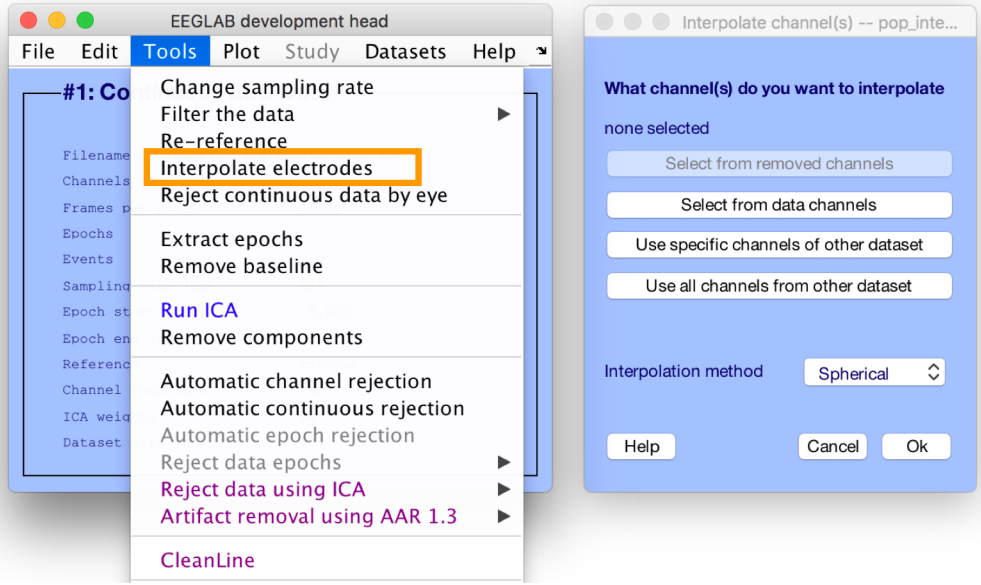


Removed channel(s)

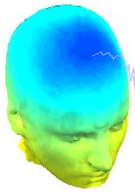


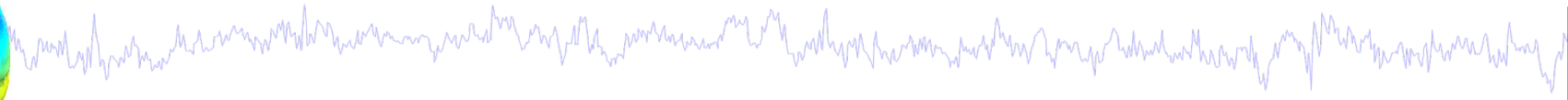
- In EEGLAB, removed channels are not only labeled for rejection, they are actually removed from the data.

- Interpolating channels instead of removing them?



Pre-processing pipeline





Swartz Center for Computational Neuroscience

Collect EEG data

Import into EEGLAB

Import event markers and channel locations

Re-reference/ down-sample (if necessary)

High pass filter (~.5 – 1 Hz)

Examine raw data

Identify/reject bad channels

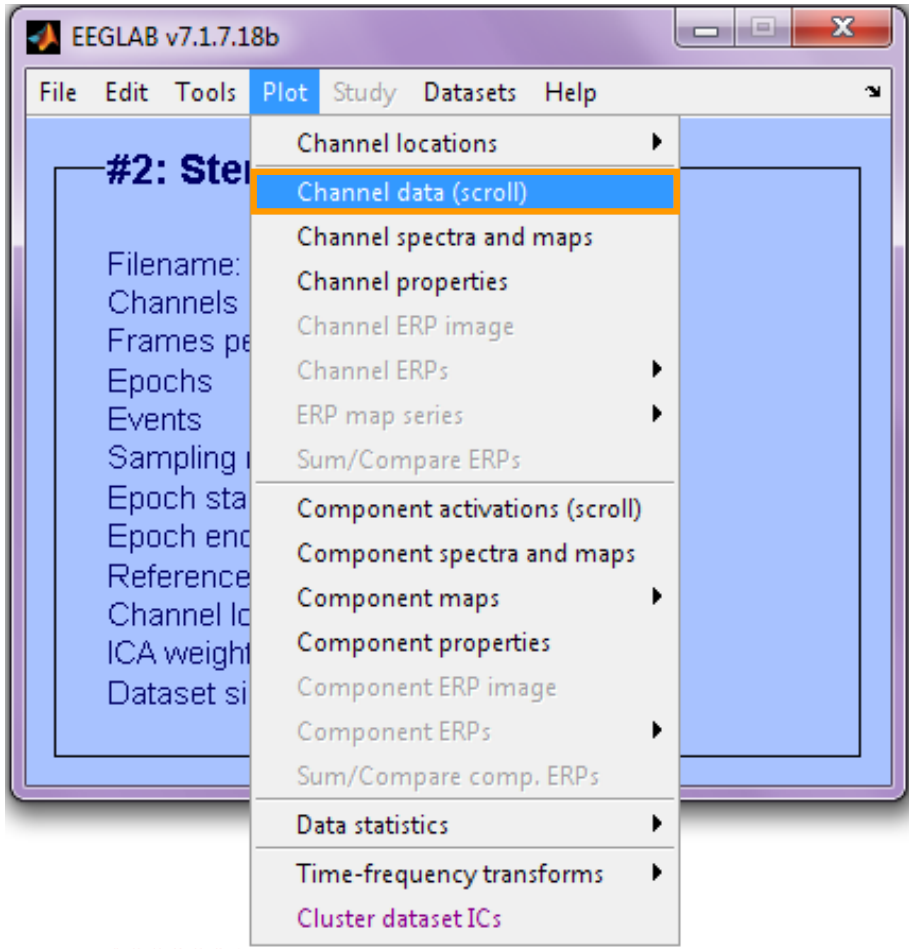
Reject large artifact time points

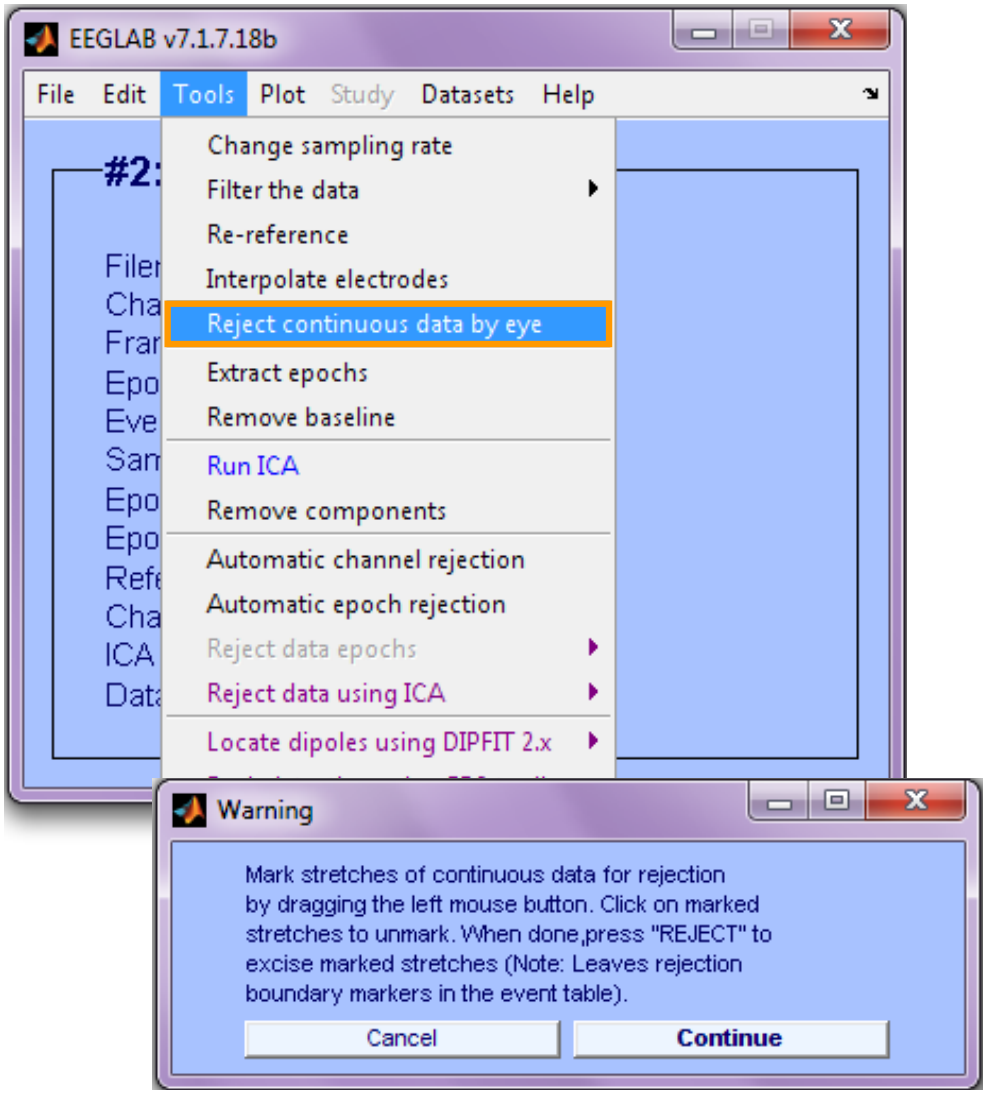
Run ICA and reject components

Done

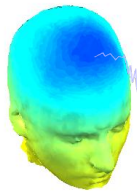
Reject continuous data

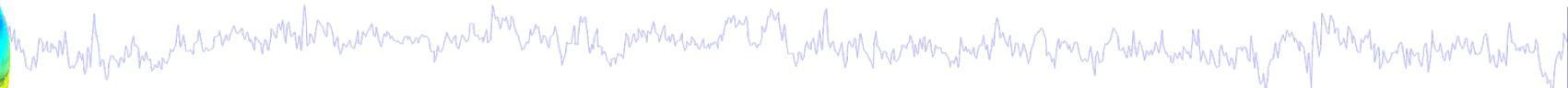
Equivalent

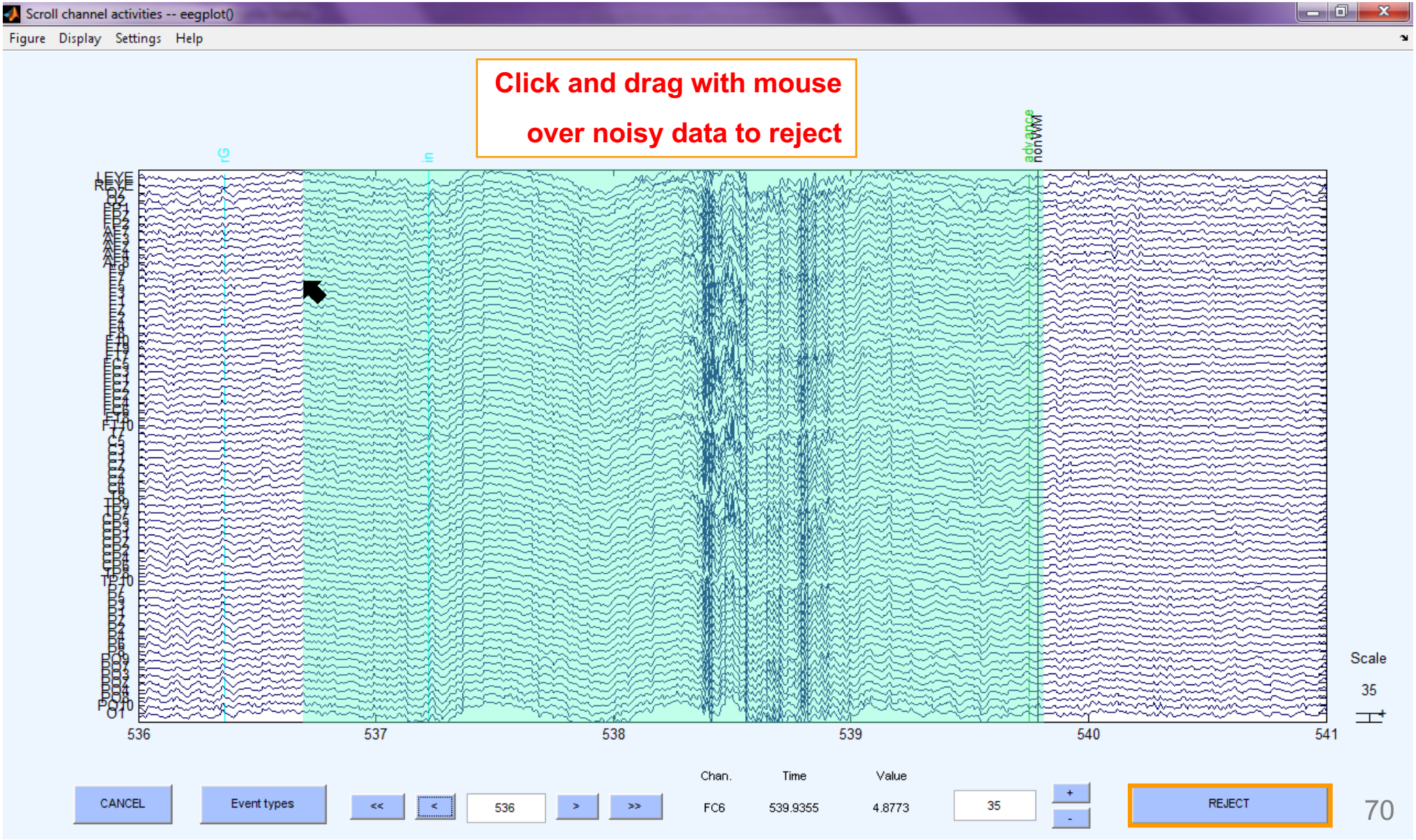




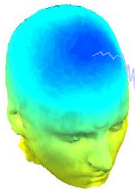
Reject continuous data







Rejecting data for ICA

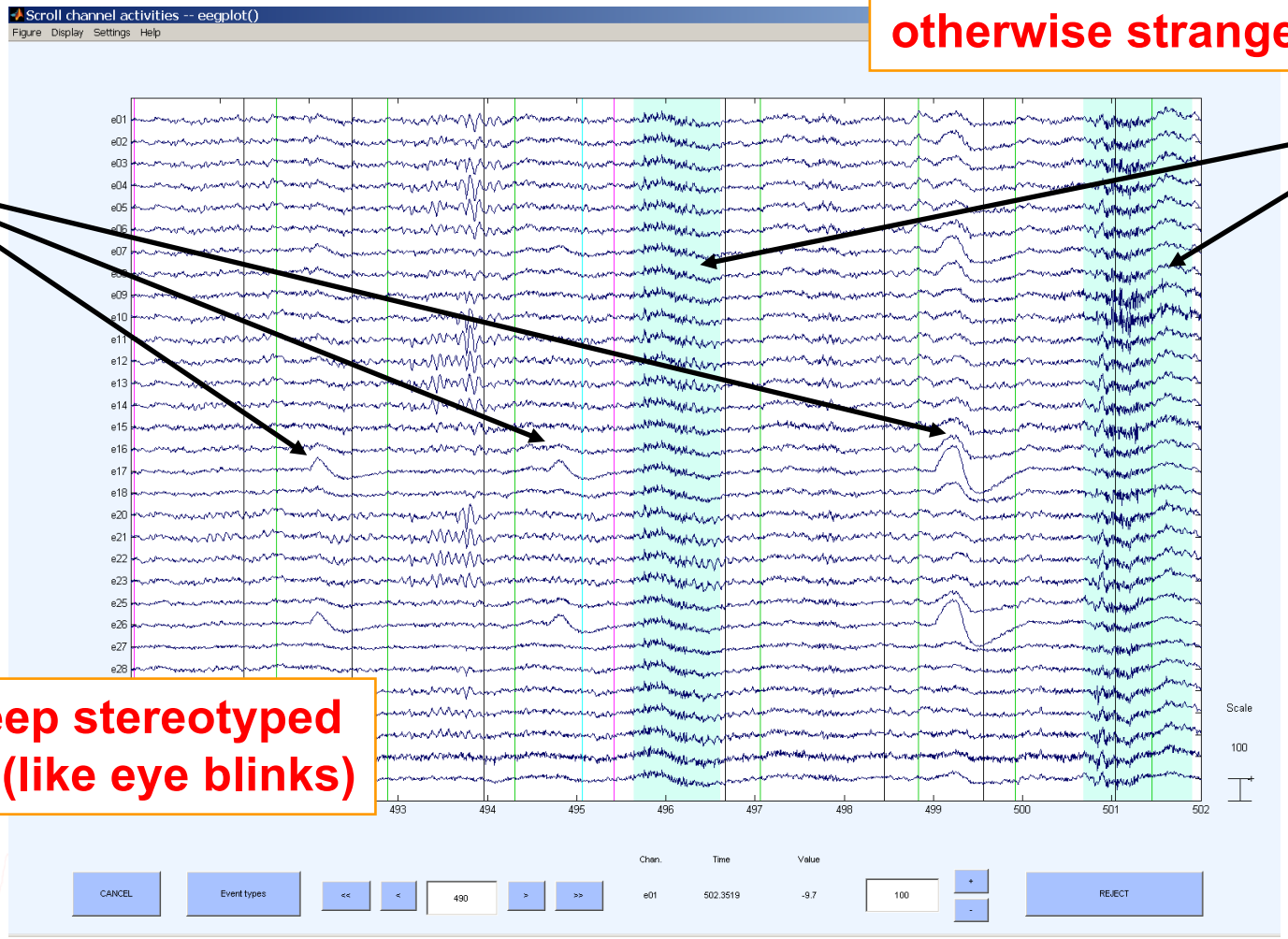


To prepare data for ICA:

Reject large muscle or otherwise strange events...

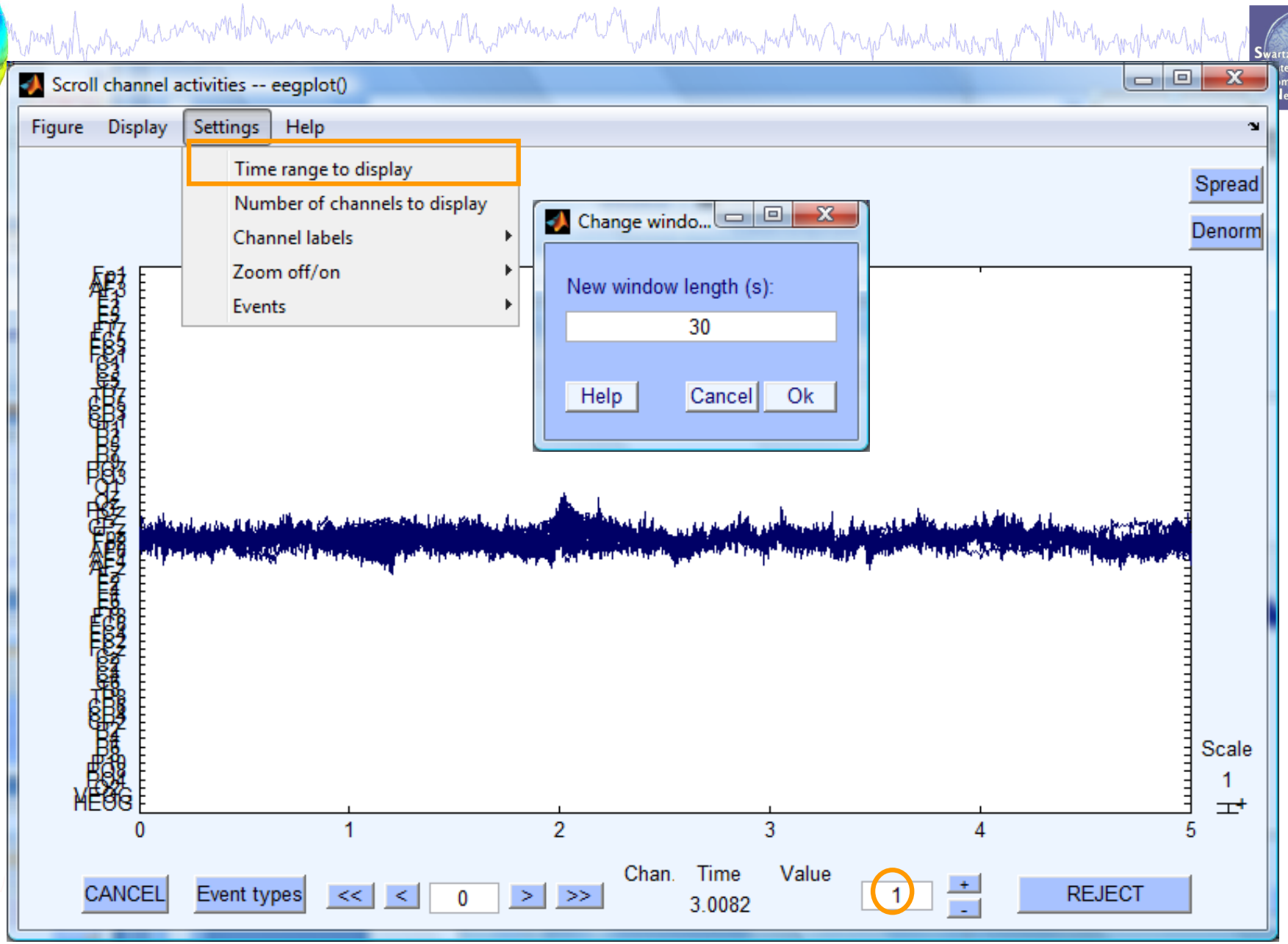
Keep

Reject

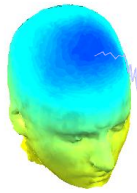


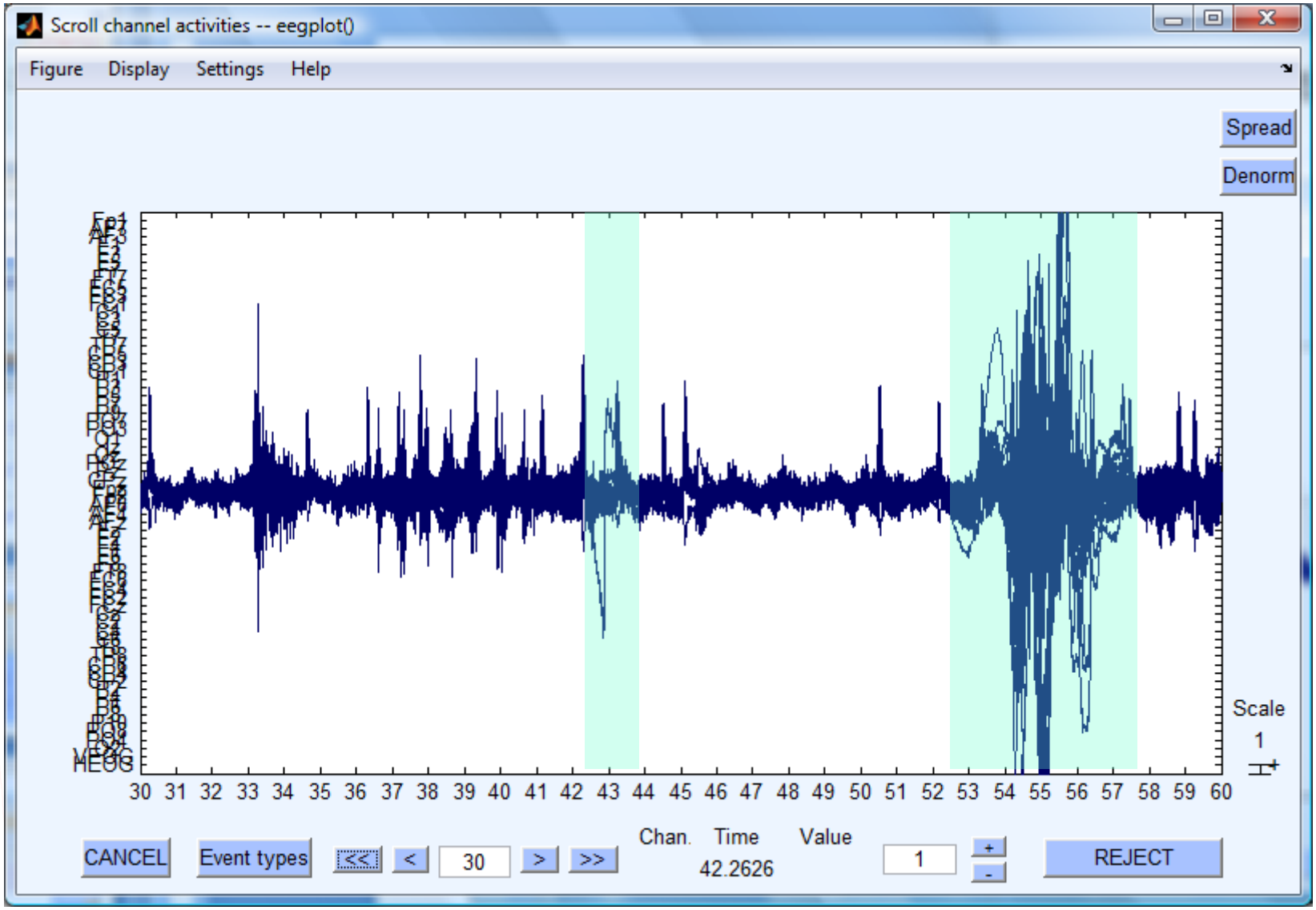
... but keep stereotyped artifacts (like eye blinks)

Fast manual artifact rejection

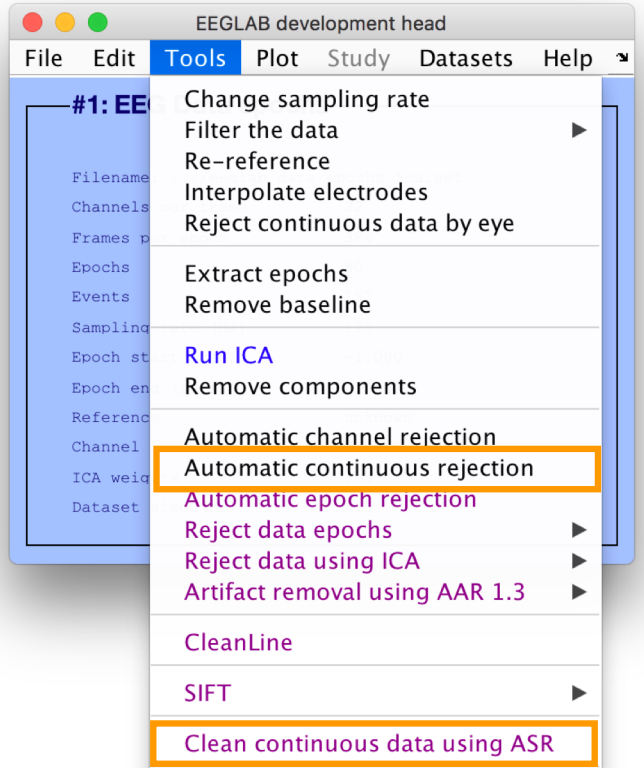


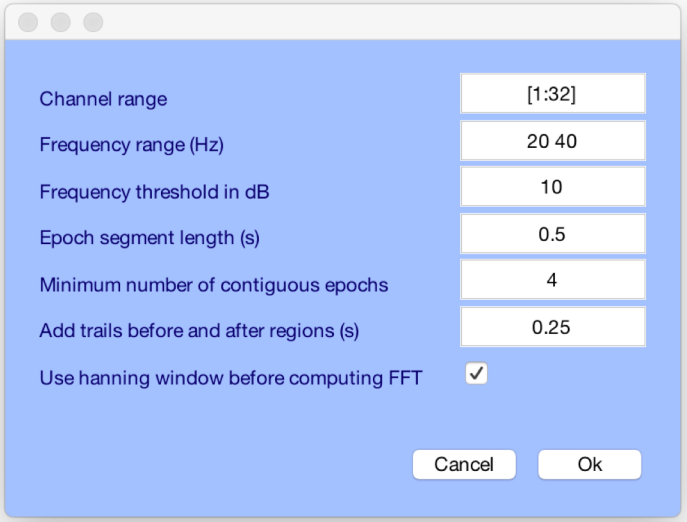
Fast manual artifact rejection



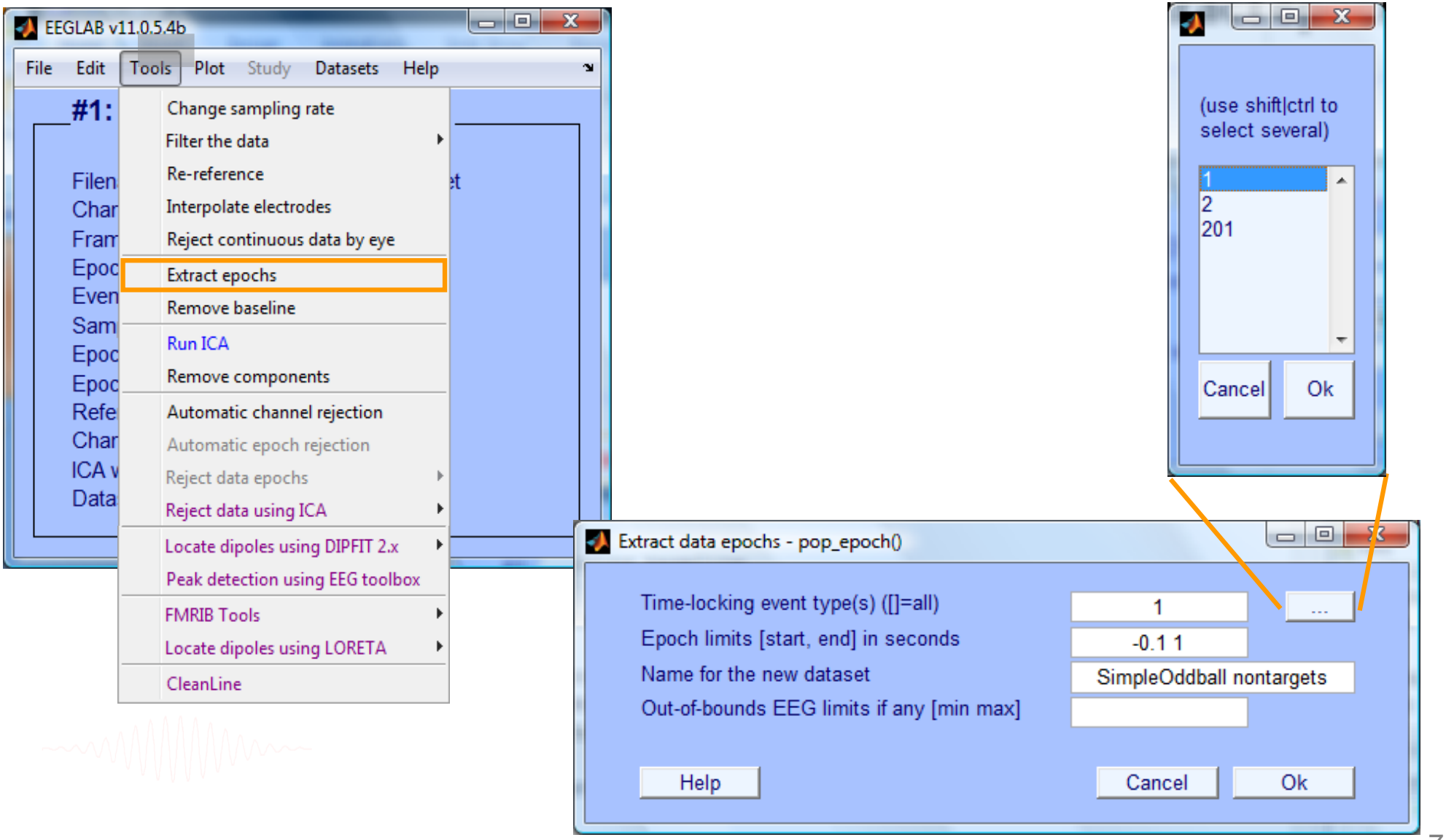


Automatic rejection of continuous data

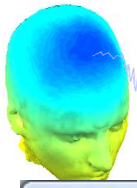


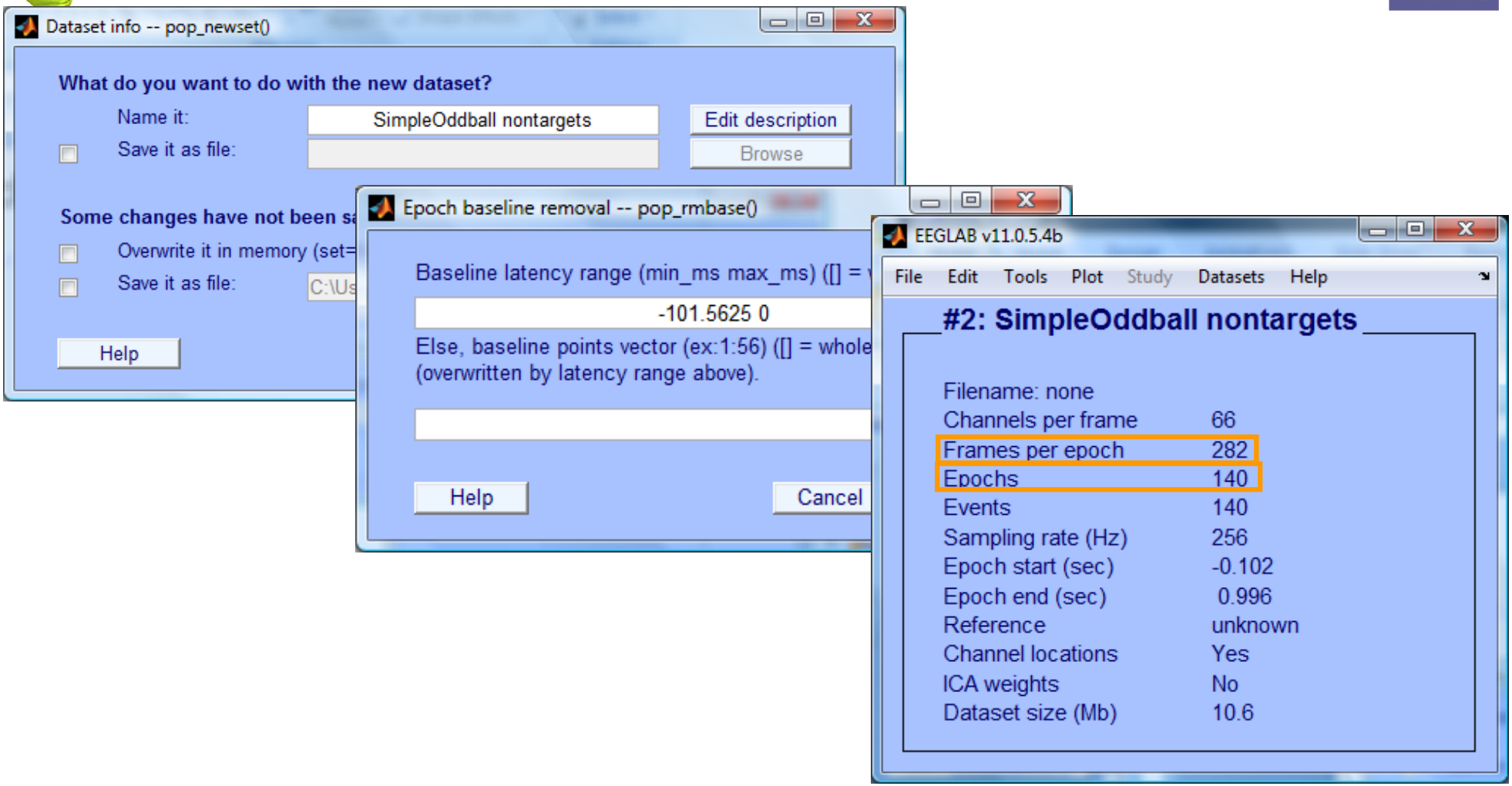


Extract epochs

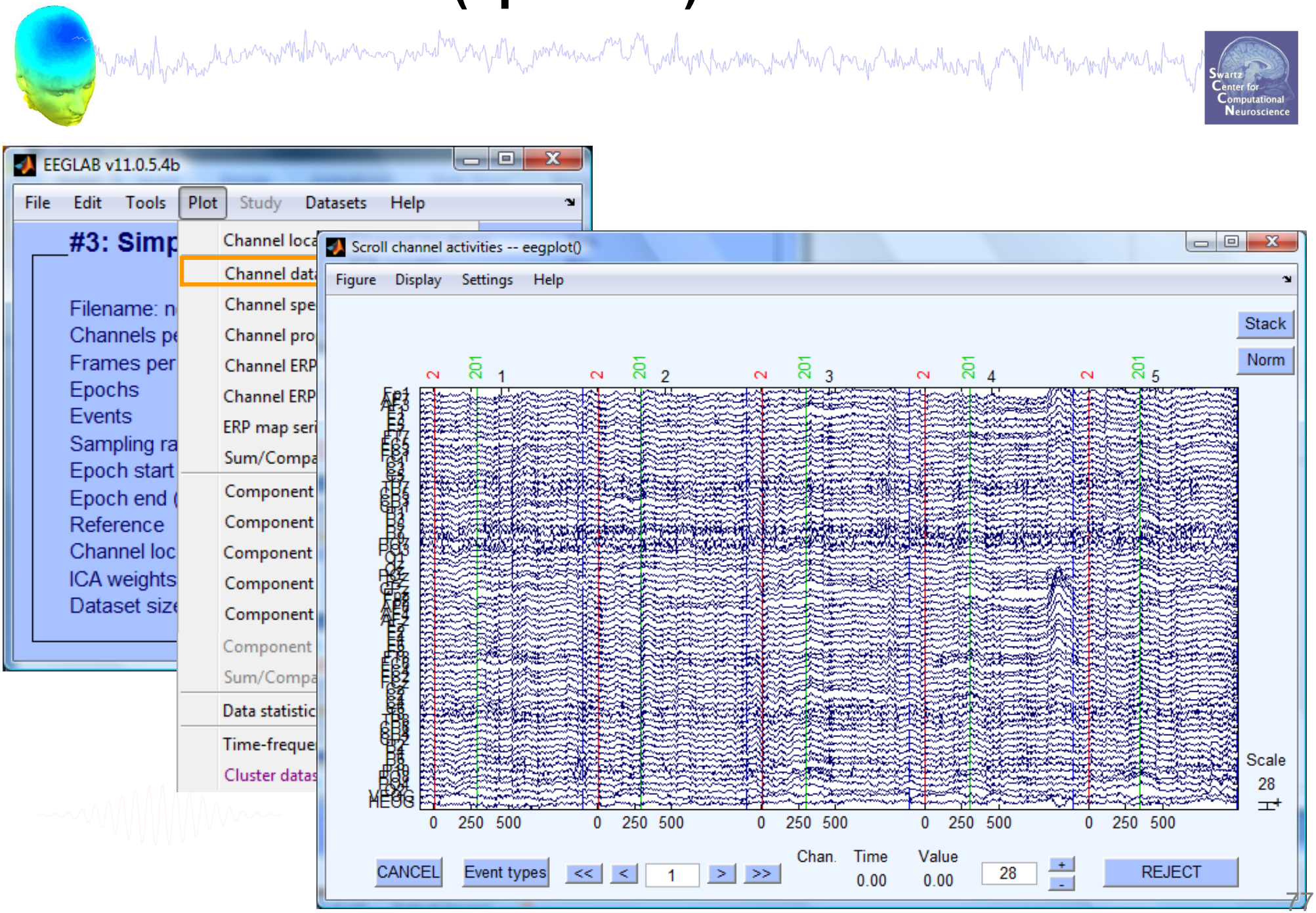


Extract epochs

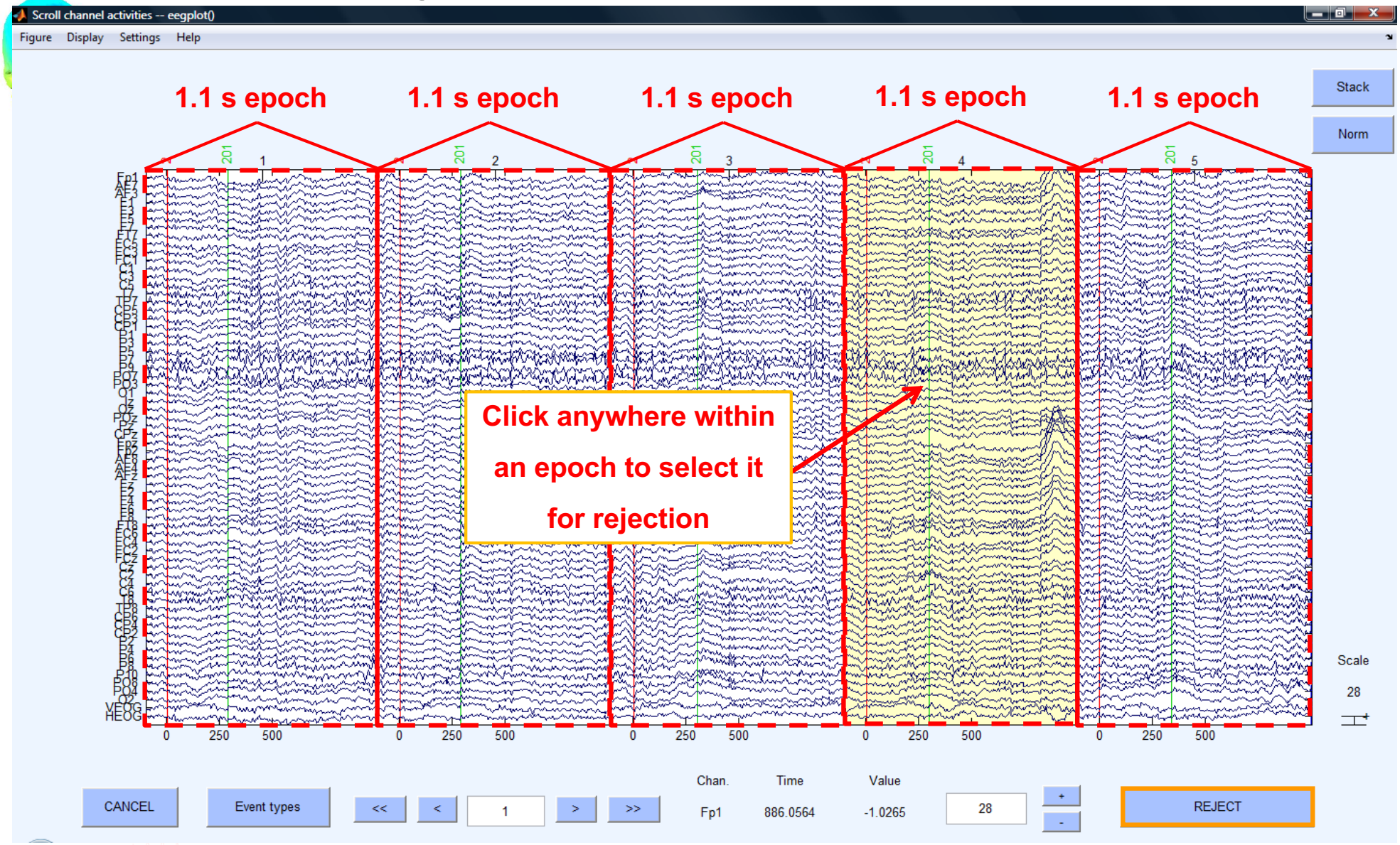




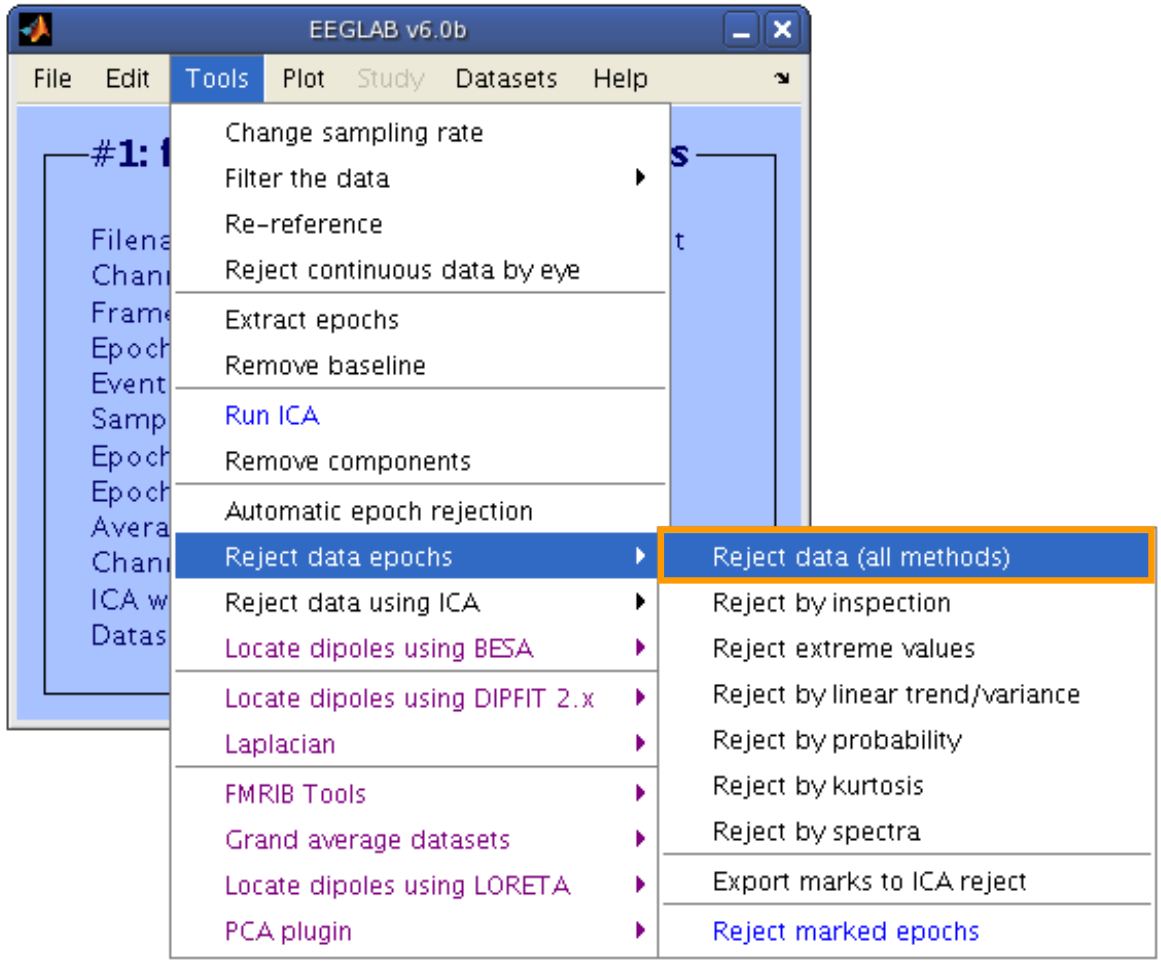
Scroll (epoched) channel data



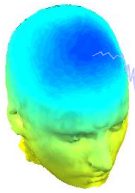
Reject epochs with artifact

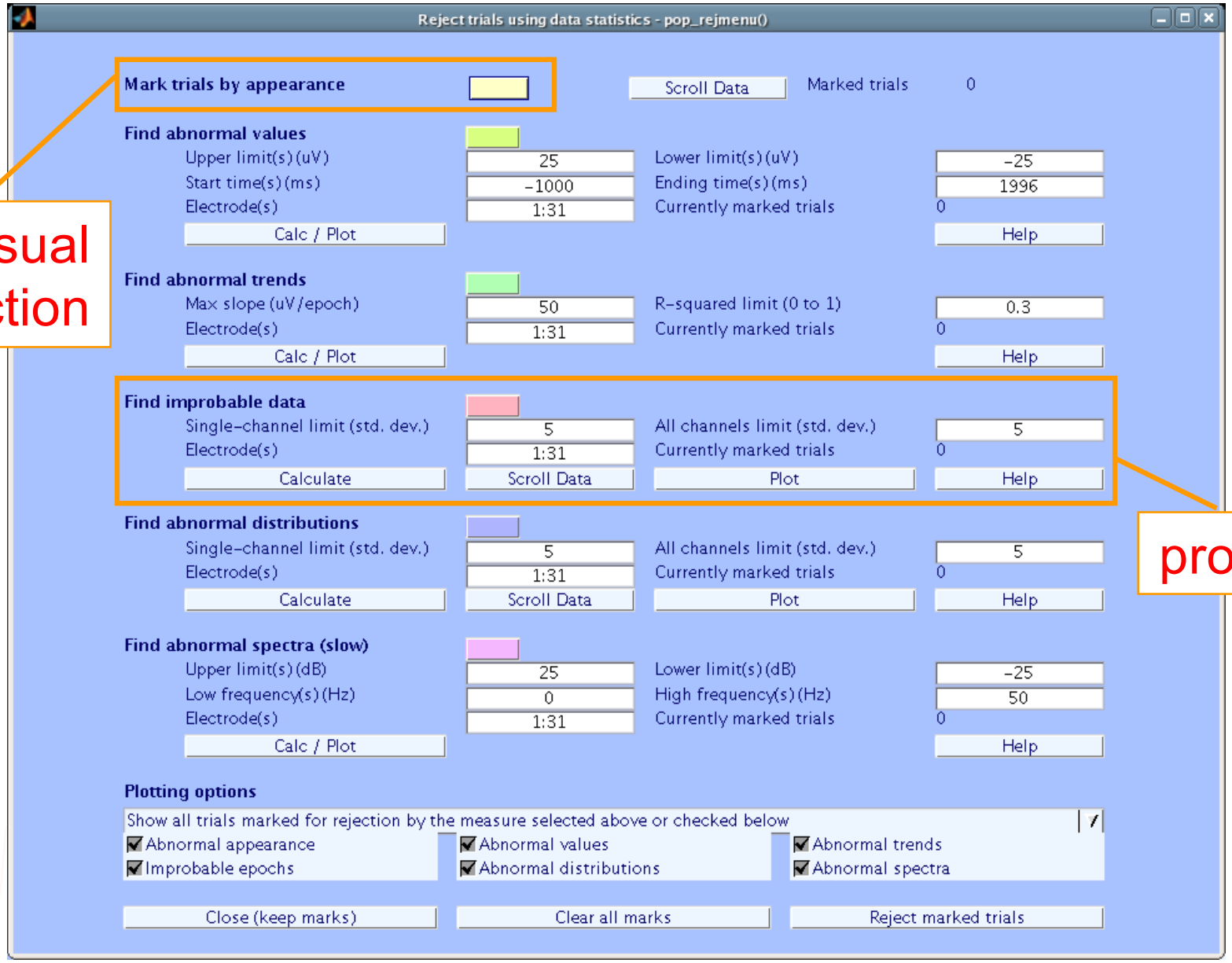


Reject data epochs



Reject data epochs

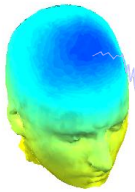


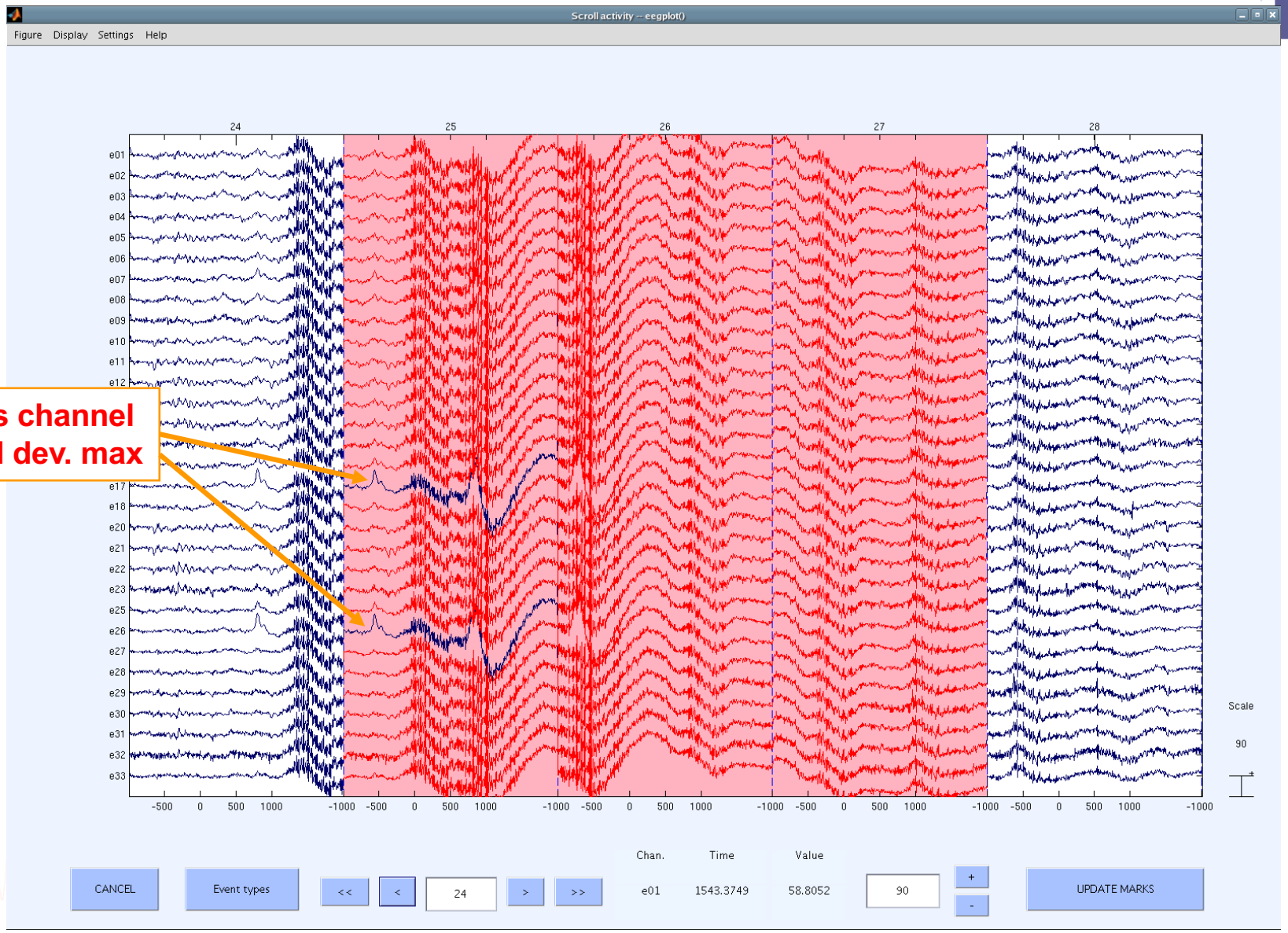


visual inspection

probability

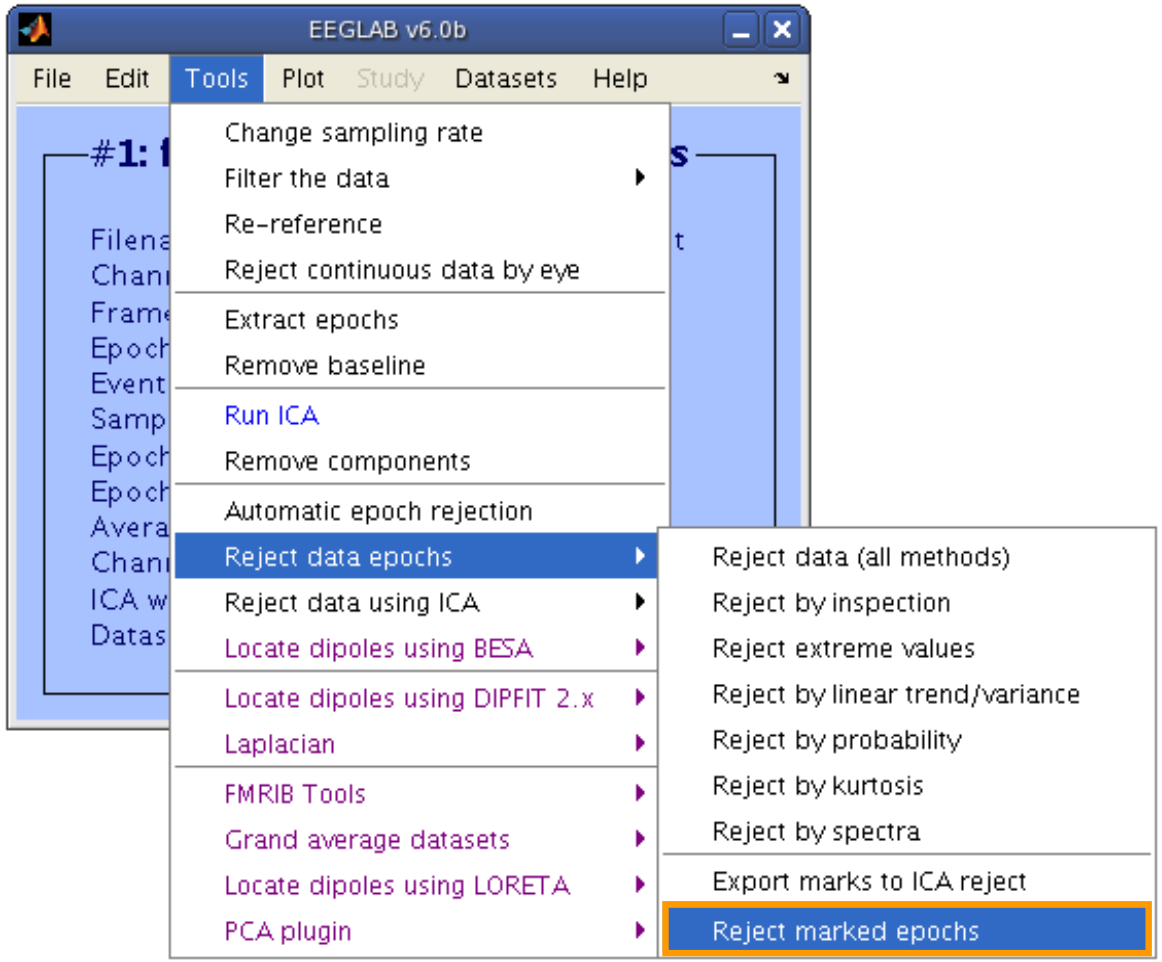
Reject data epochs



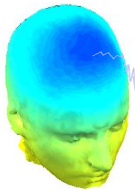


Exceeds channel standard dev. max

Reject data epochs



Pre-processing pipeline



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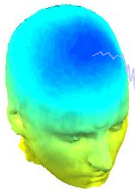
Acknowledgements



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Tim Mullen
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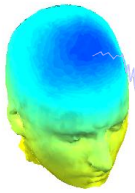
Zeynep Akalin
Cyril Pernet
Clement Lee
John Iversen
Johanna Wagner
Jason Palmer

Exercises



- Load time SimpleOddball.set dataset
- Identify bad channel(s) using auto-detection tool; plot channel properties of flagged channels
- Identify and remove non-task portions of continuous data; see if the previously flagged channels are still identified as bad
- Epoch on event of interest. Scroll the epoched data and perform visual rejection of epochs
- Explore the automated artifact rejection tools