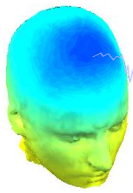
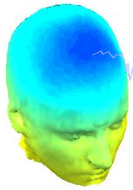
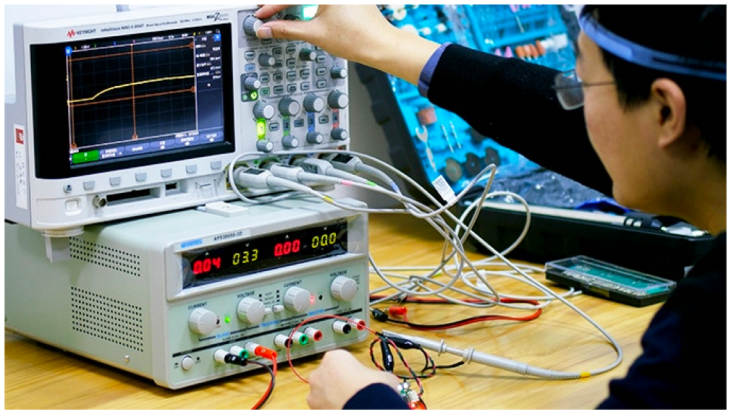


EEG Preprocessing in EEGLAB

Why preprocess data?





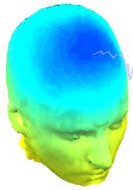
EEG data out of the recording device is a continuous unprocess signal. It is like measuring a difference of potential on an oscilloscope.

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

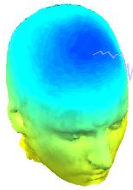
Identify/reject bad channels

Reject large artifact time points

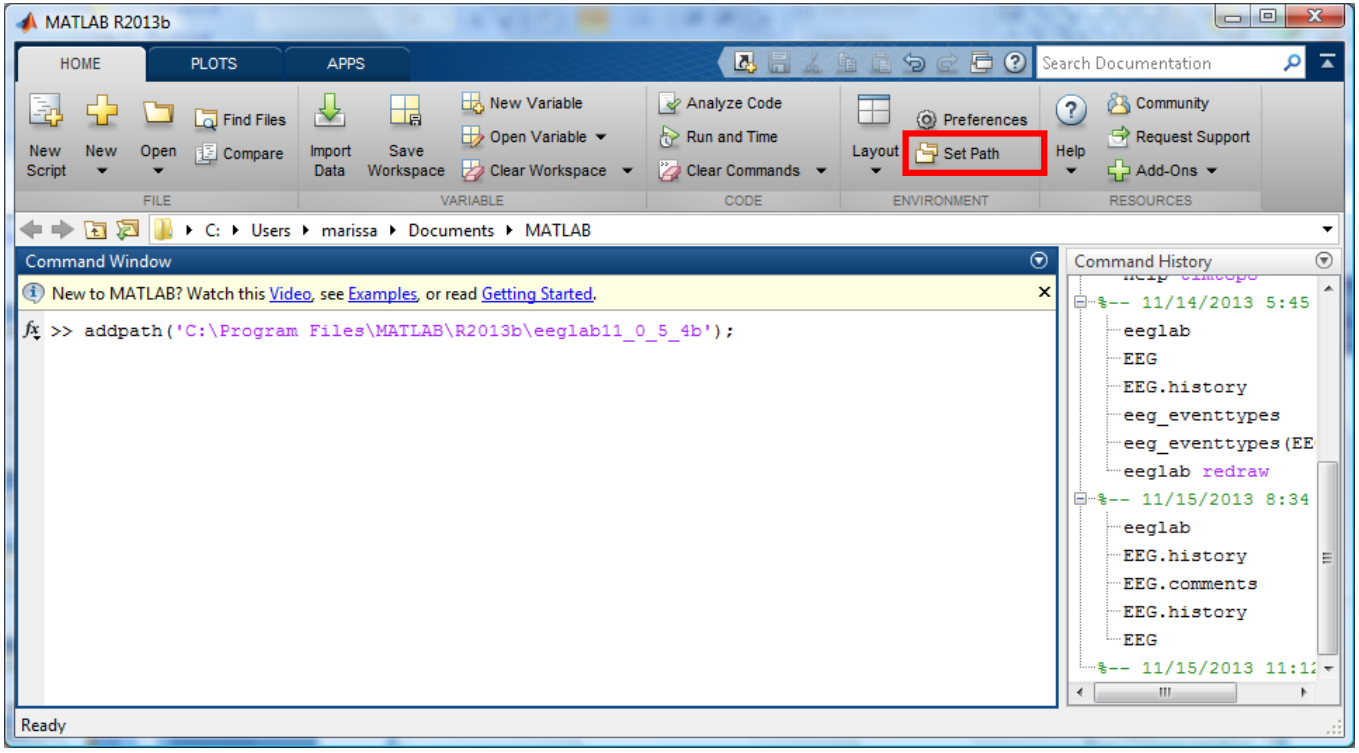
Run ICA and reject components

Done

Installing EEGLAB and data folder

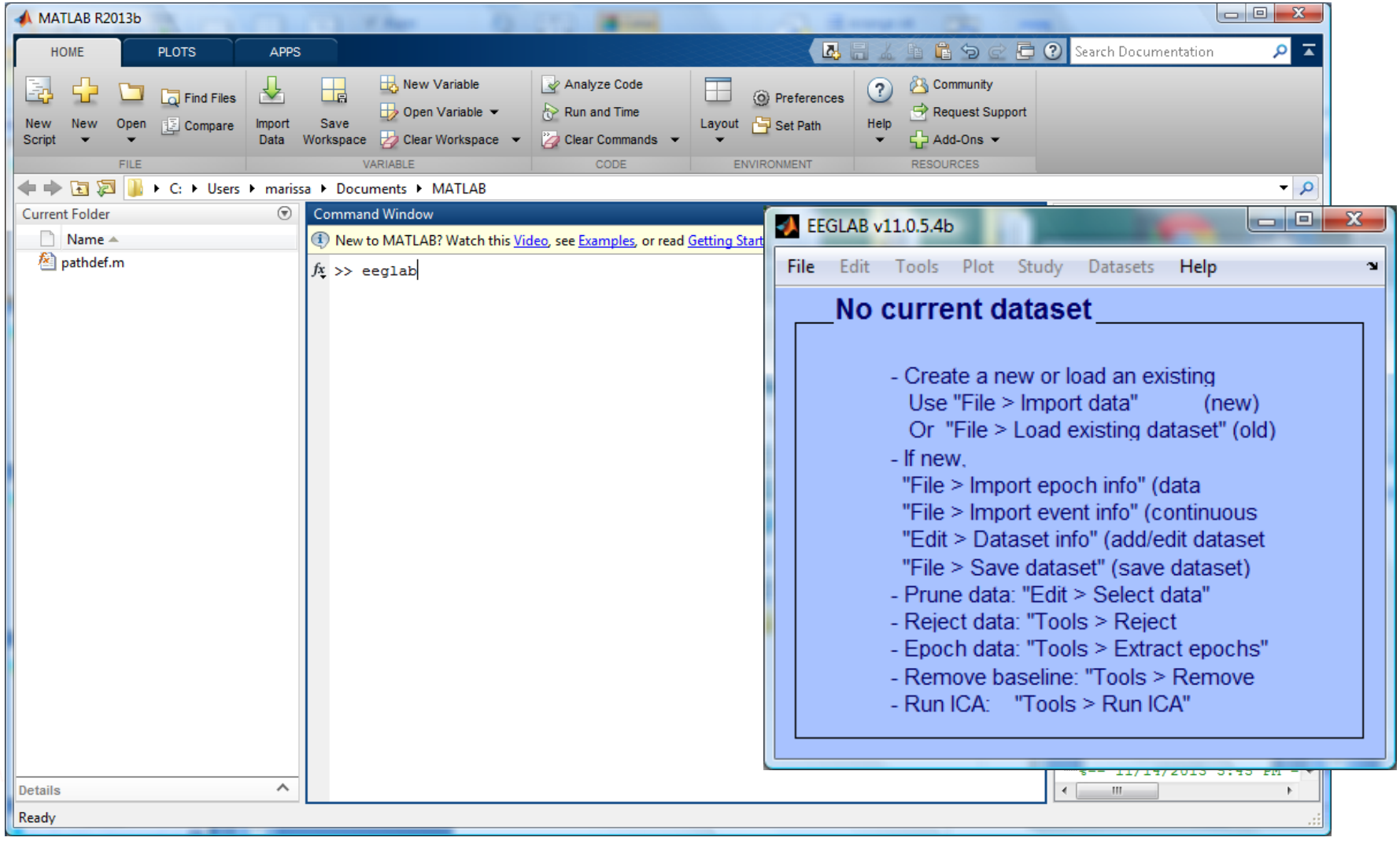


- Download and install Matlab (2008b or later)
- Download EEGLAB (http://www.sccn.ucsd.edu/eeglab)
- Unzip EEGLAB
- Add the EEGLAB folder to your Matlab path:

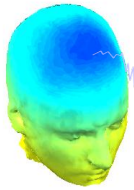


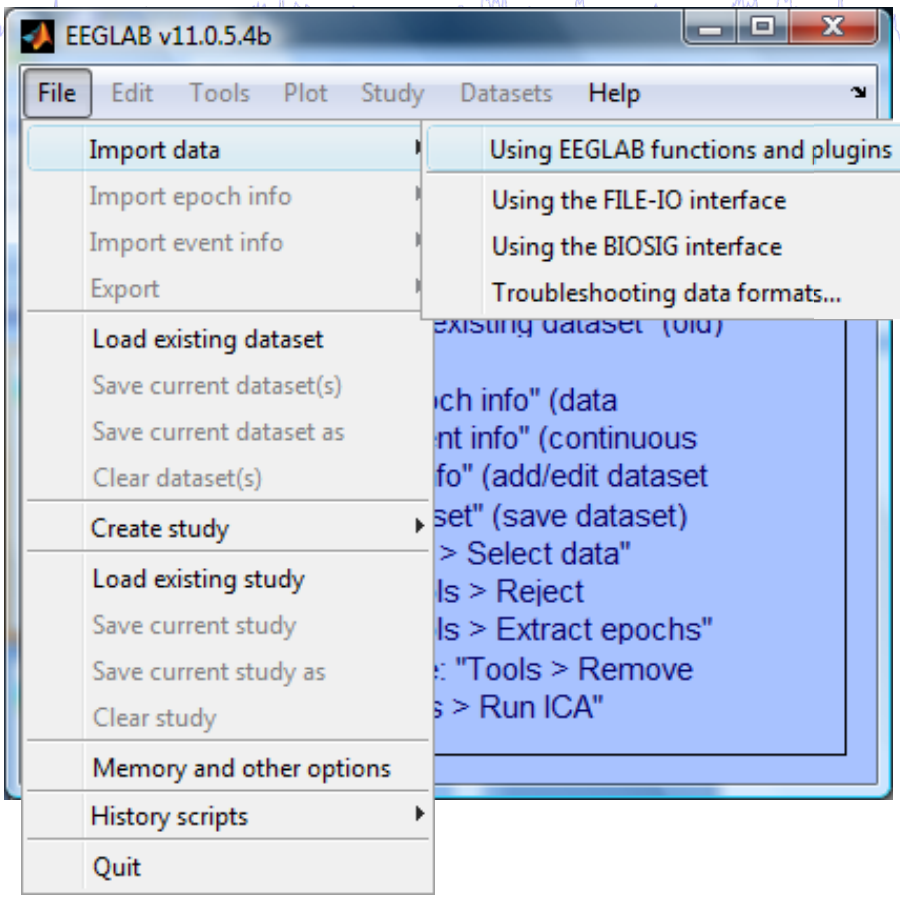
The EEGLAB Matlab software

main graphic interface

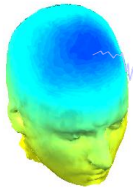


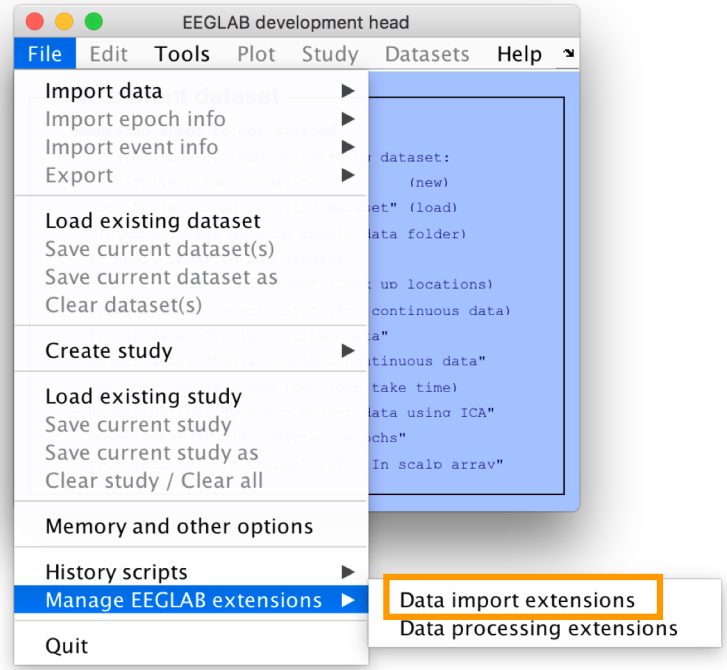
Importing a dataset

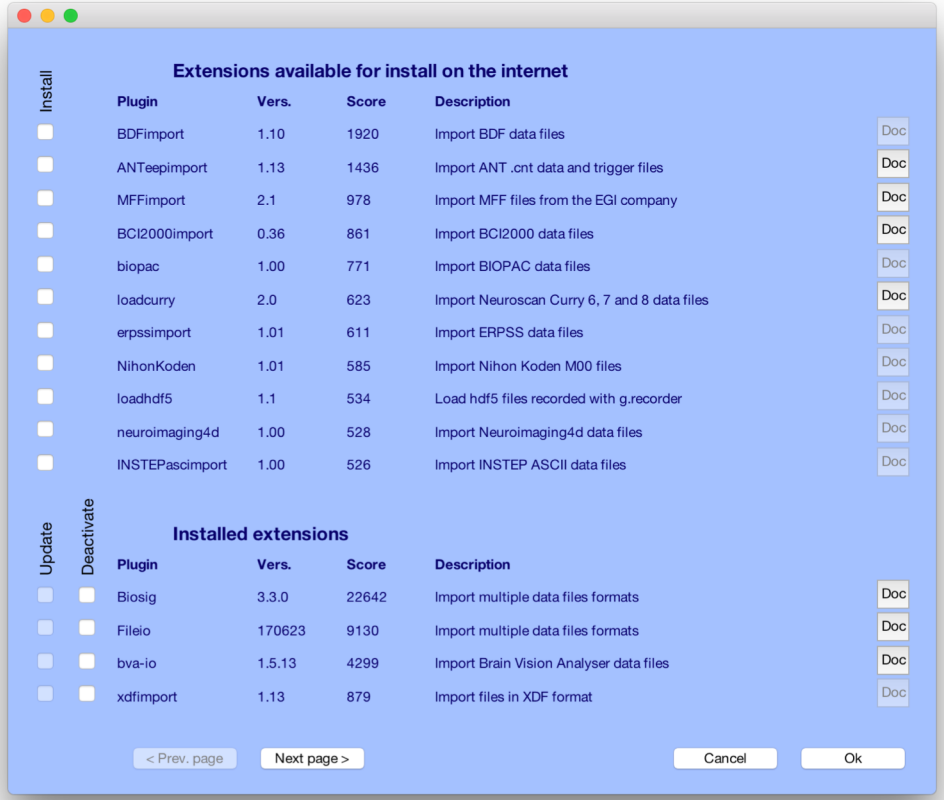




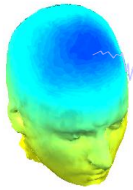
Install extension for importing data files







Supported data formats



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

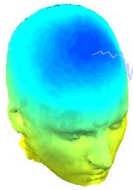
Supported Data Formats

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

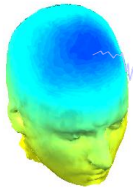
Data

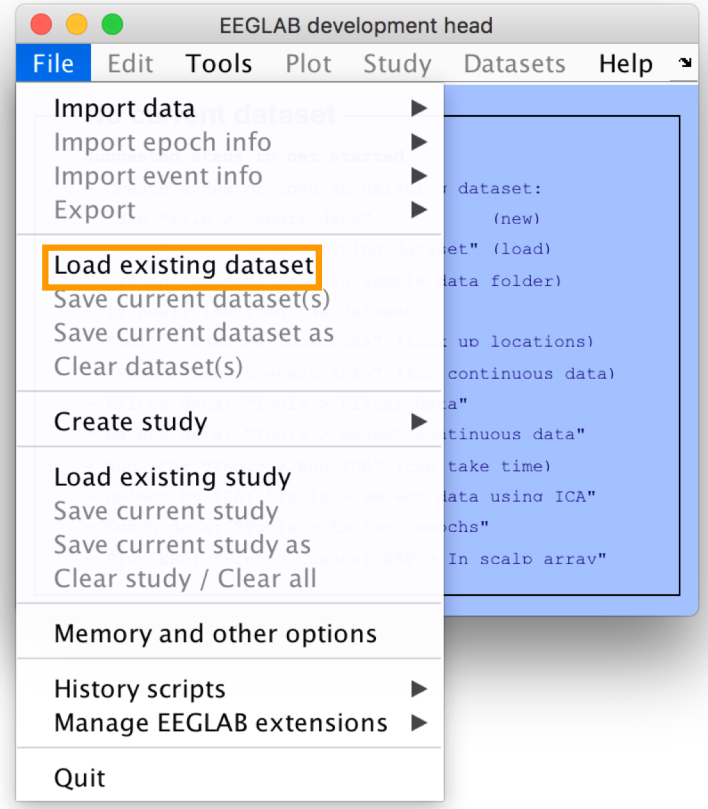
68 channel EEG, 256 Hz sampling rate, Biosemi system, re-referenced during import to averaged left and right mastoid electrodes

Task

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

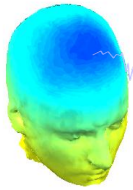
Load a dataset

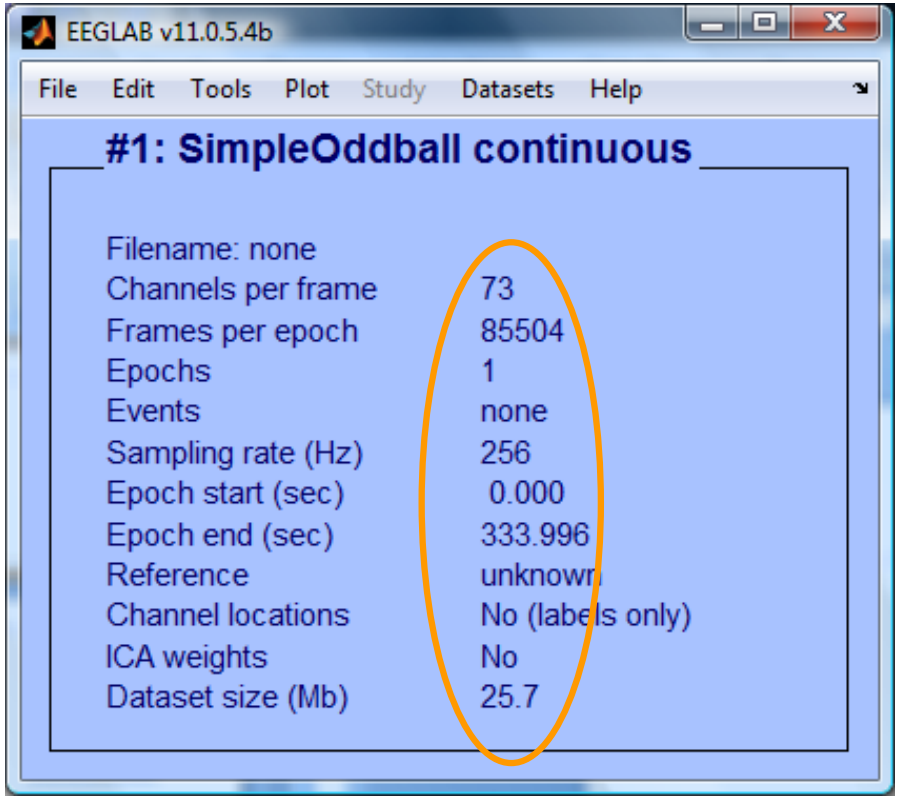




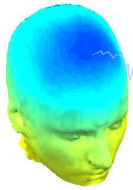
Load "SimpleOddball.set"

Imported EEG data





Pre-processing pipeline



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

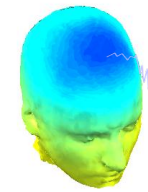
Identify/reject bad channels

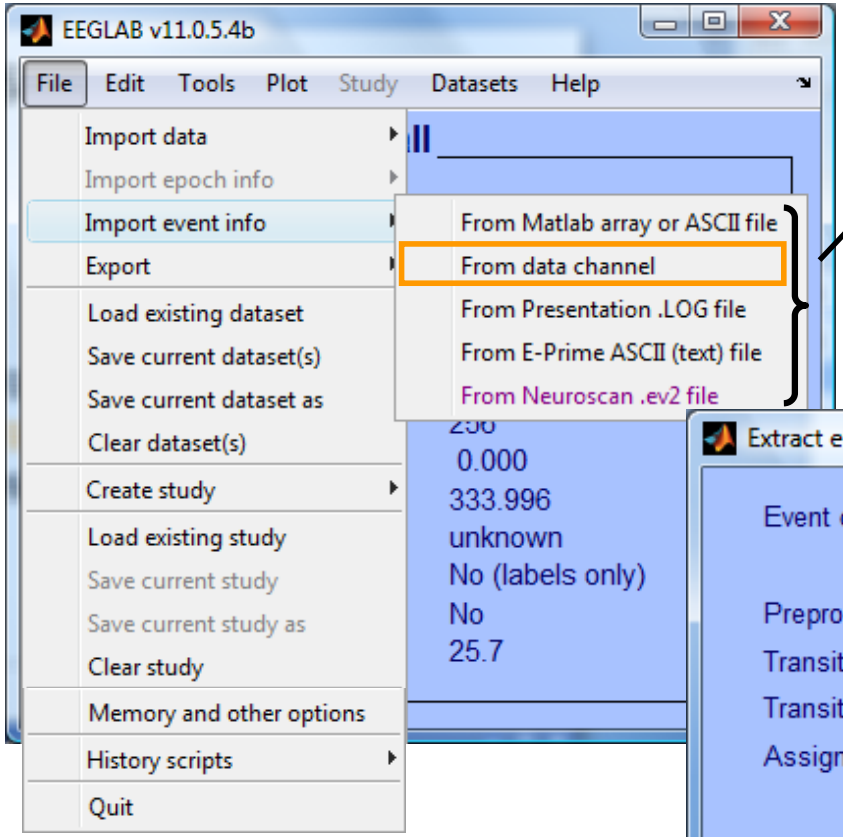
Reject large artifact time points

Run ICA and reject components

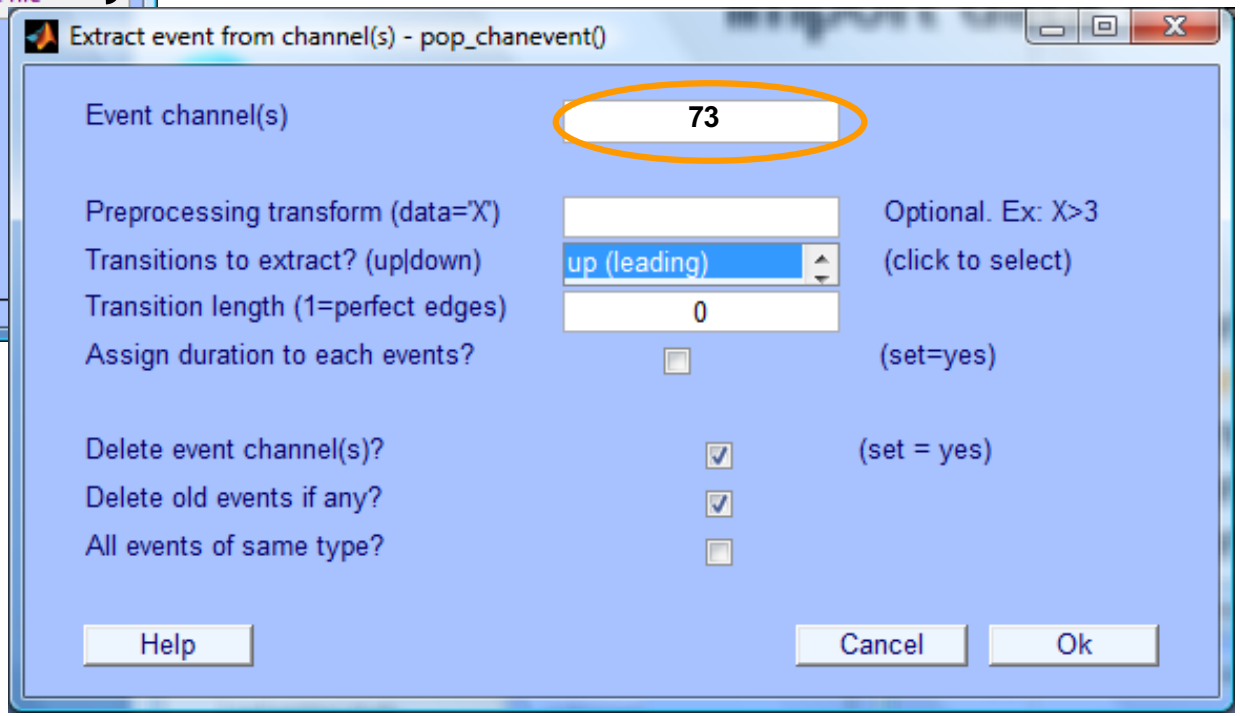
Done

Import data events



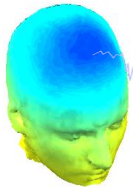


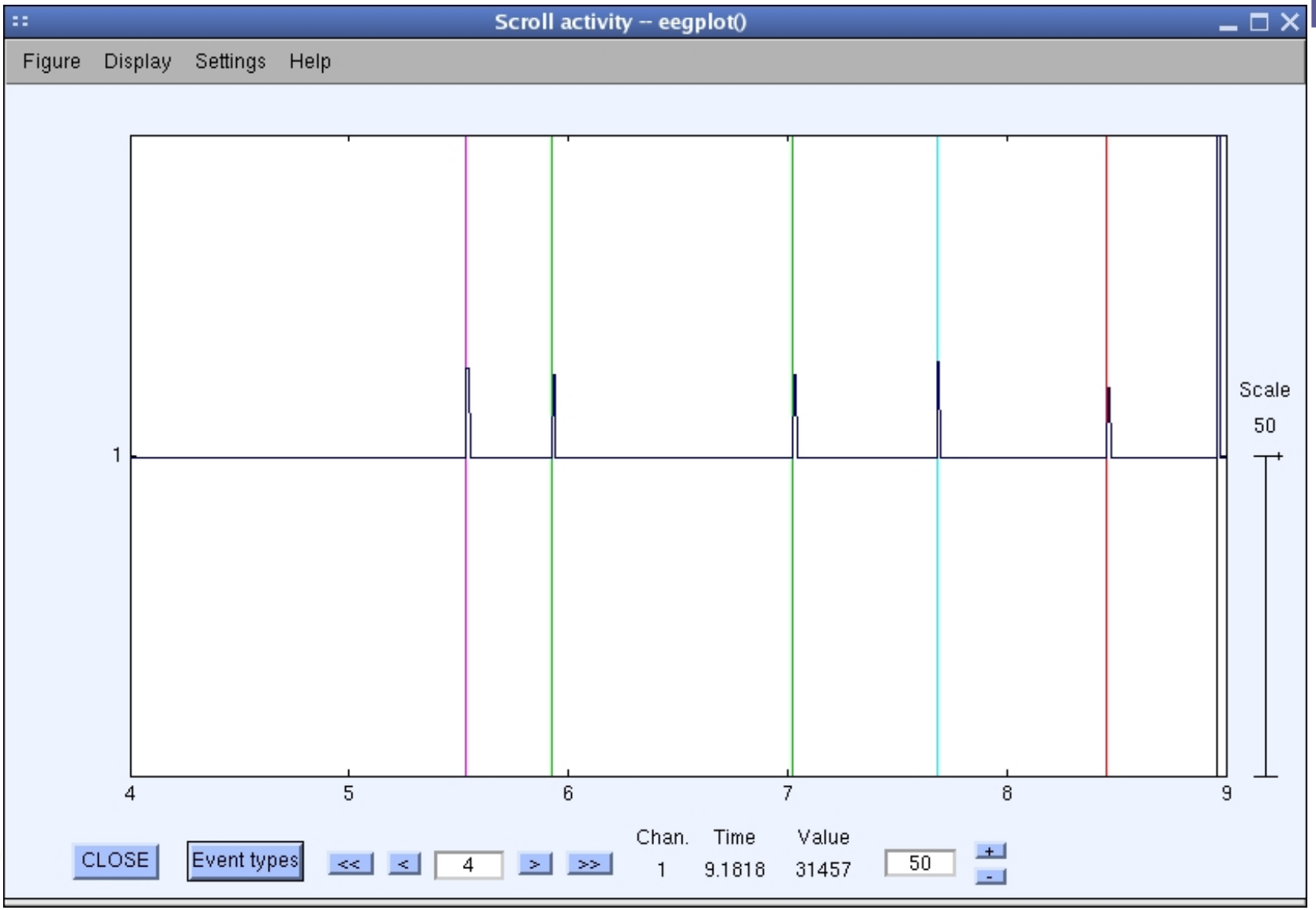
- Import events from Matlab array or ASCII file
- Import events from data channel
- Import from Presentation event file
- Import events from E-Prime event file
- Import events from Neuroscan event file



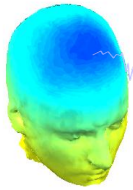
(Often imported automatically during data import)

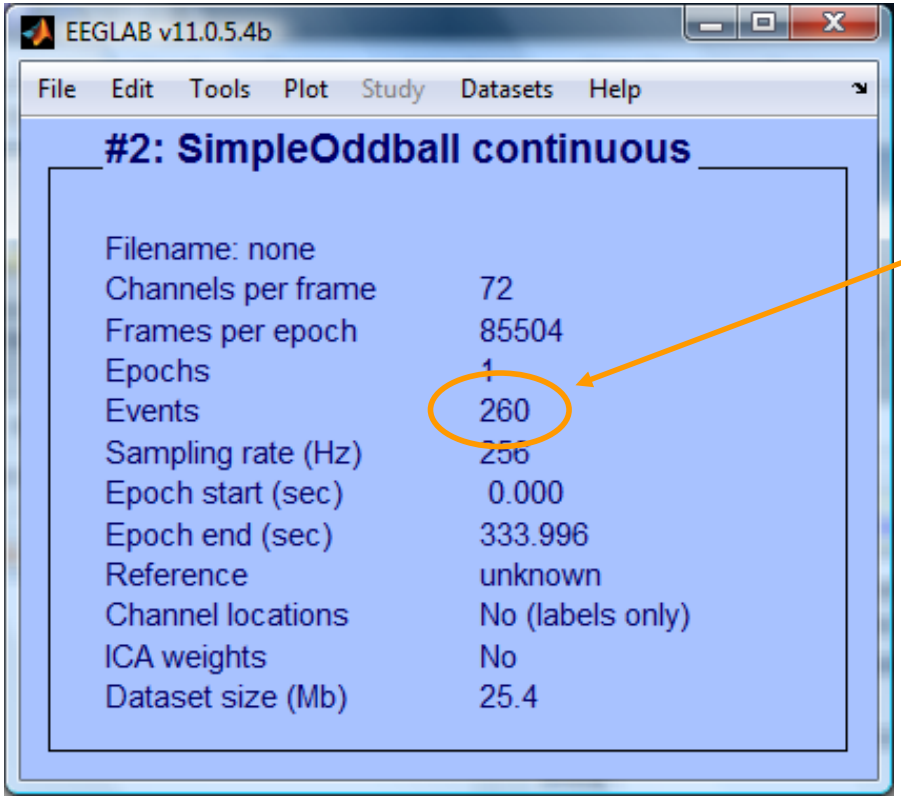
Appearance of an event channel in raw data





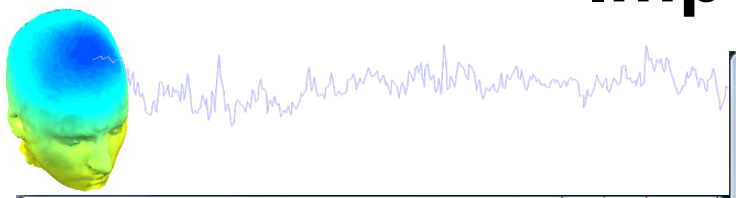
Imported data events

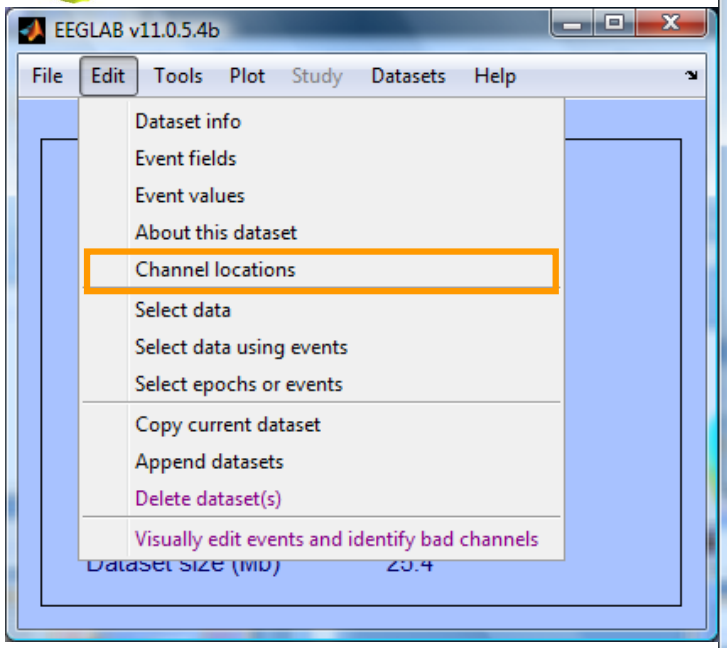


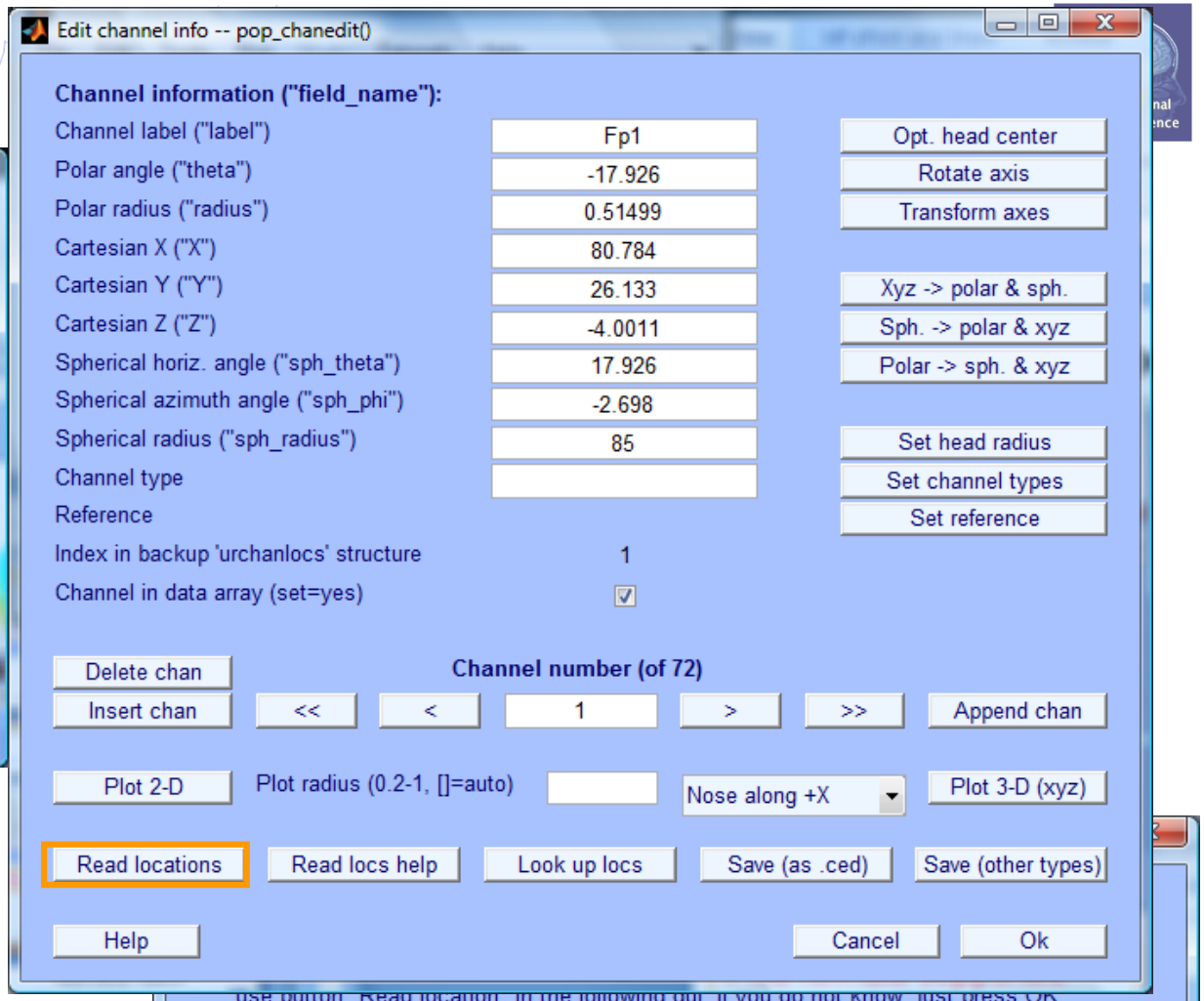


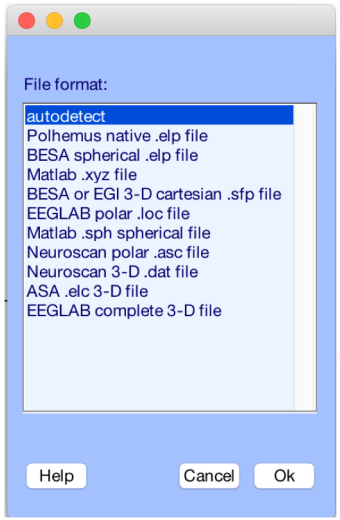
If event import was successful, you will see an appropriate number here

Import channel locations

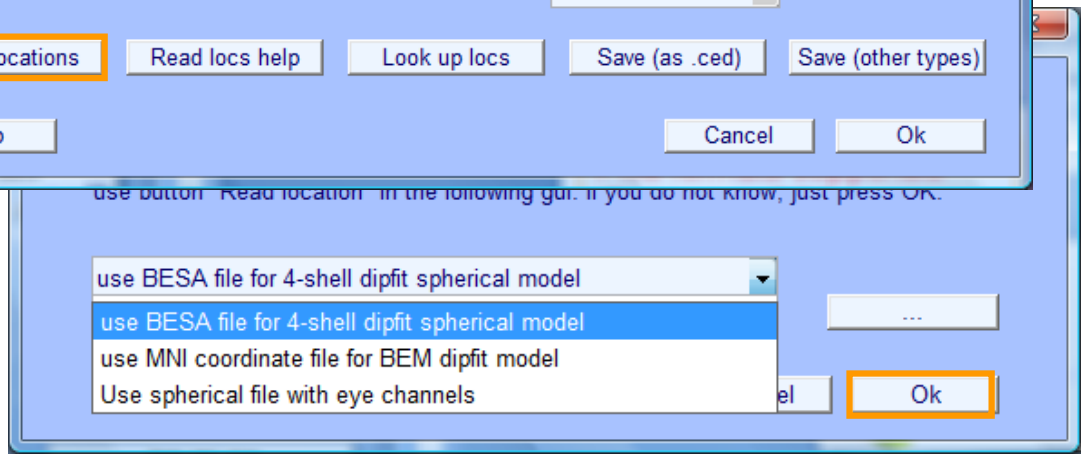


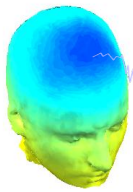






10 file formats supported (Polhemus, BESA, …)





Edit channel info -- pop_chanedit()

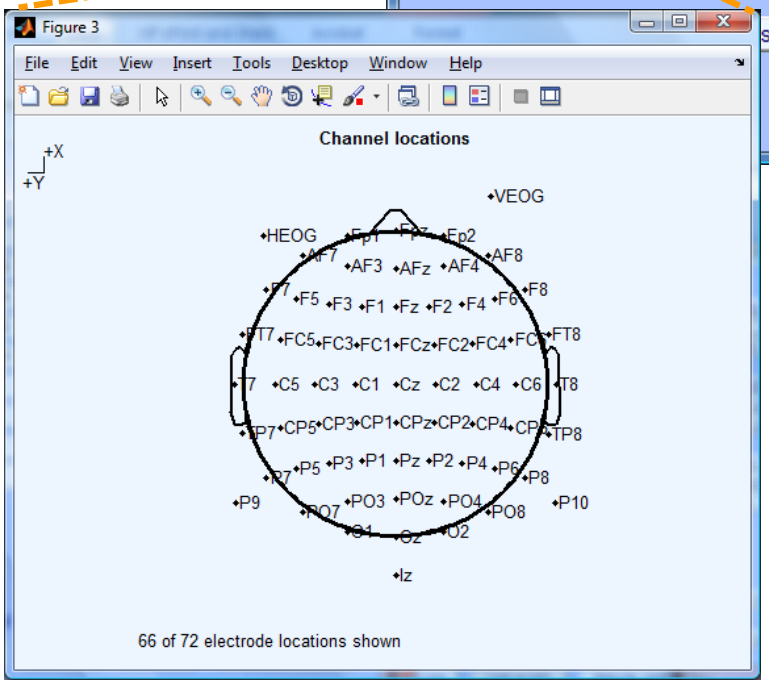
Channel information ("field_name"):

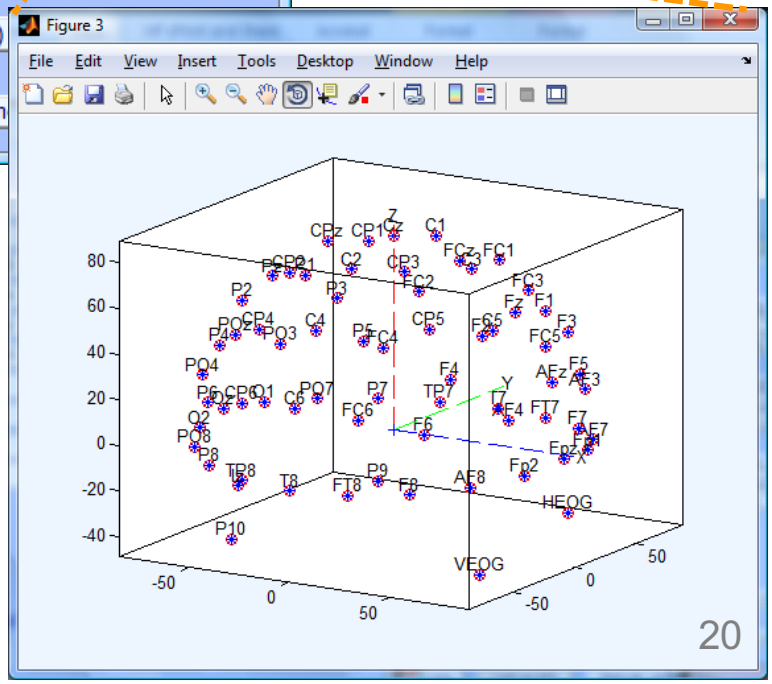
Channel label ("label")	HEOG	Opt. head center
Polar angle ("theta")	-42	Rotate axis
Polar radius ("radius")	0.65556	Transform axes
Cartesian X ("X")	55.7734	
Cartesian Y ("Y")	50.2186	Xyz -> polar & sph.
Cartesian Z ("Z")	-39.9051	Sph. -> polar & xyz
Spherical horiz. angle ("sph_theta")	42	Polar -> sph. & 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

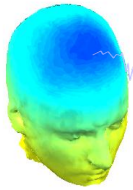
Plot 2-D | Plot radius (0.2-1, []=auto) | Nose along +X | Plot 3-D (xyz)

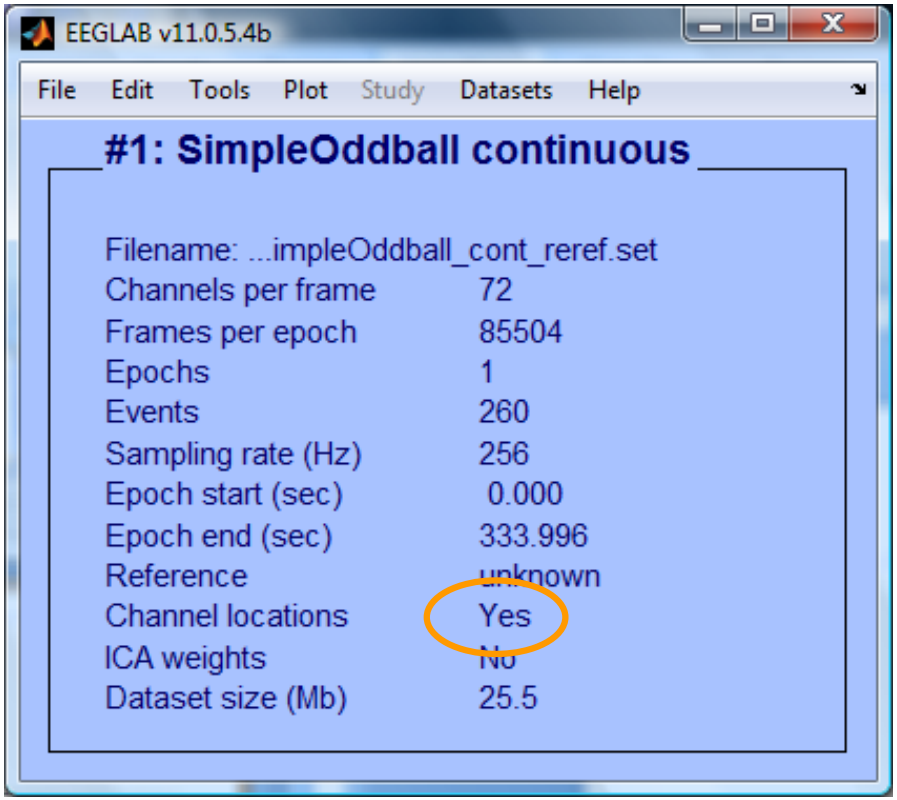
s help | Look up locs | Save (as .ced) | Can



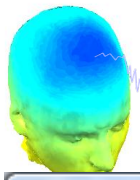


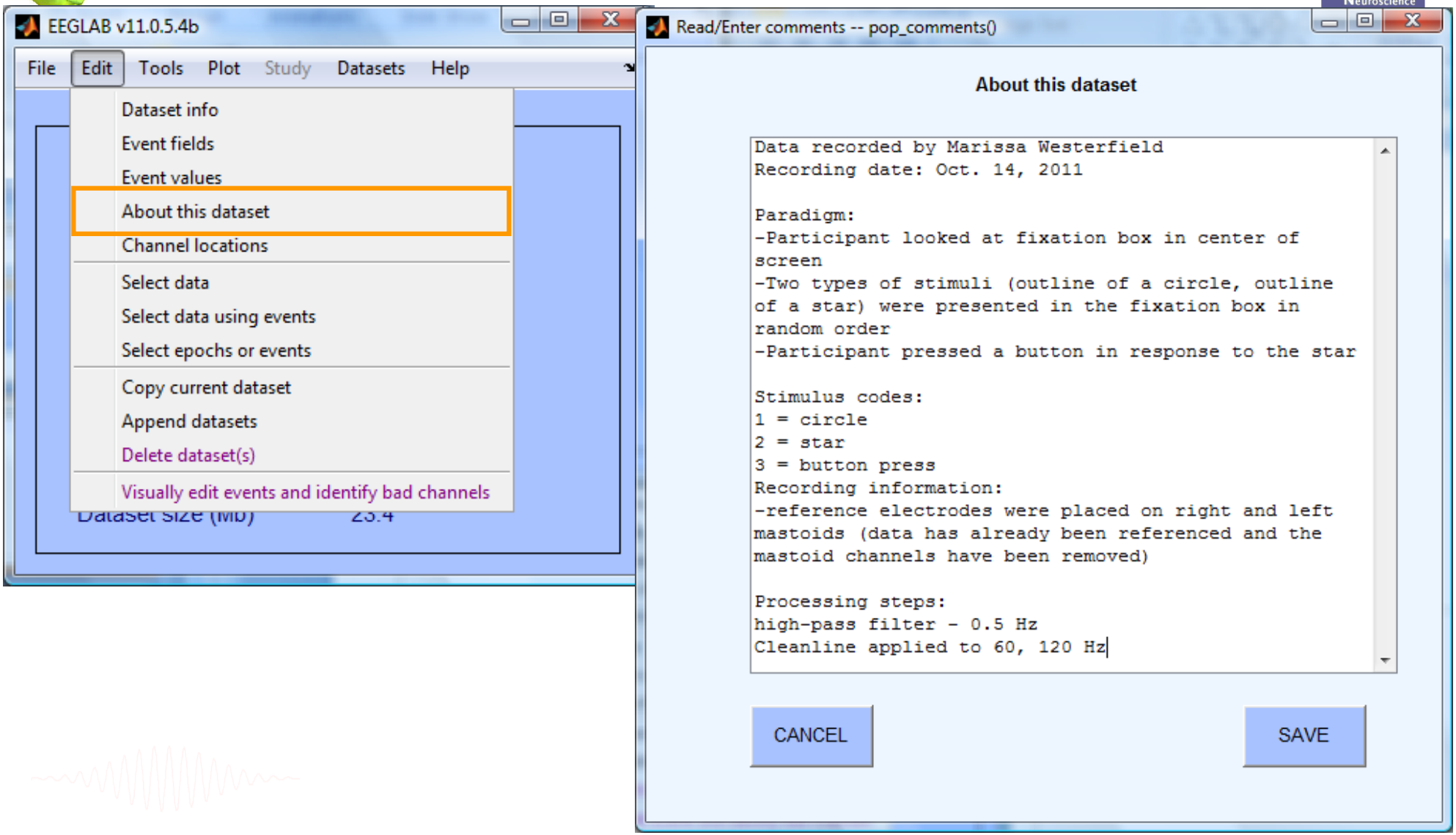
Imported channel locations



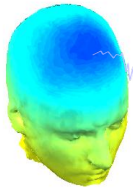


Comments and dataset history





Pre-processing pipeline



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

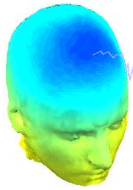
Identify/reject bad channels

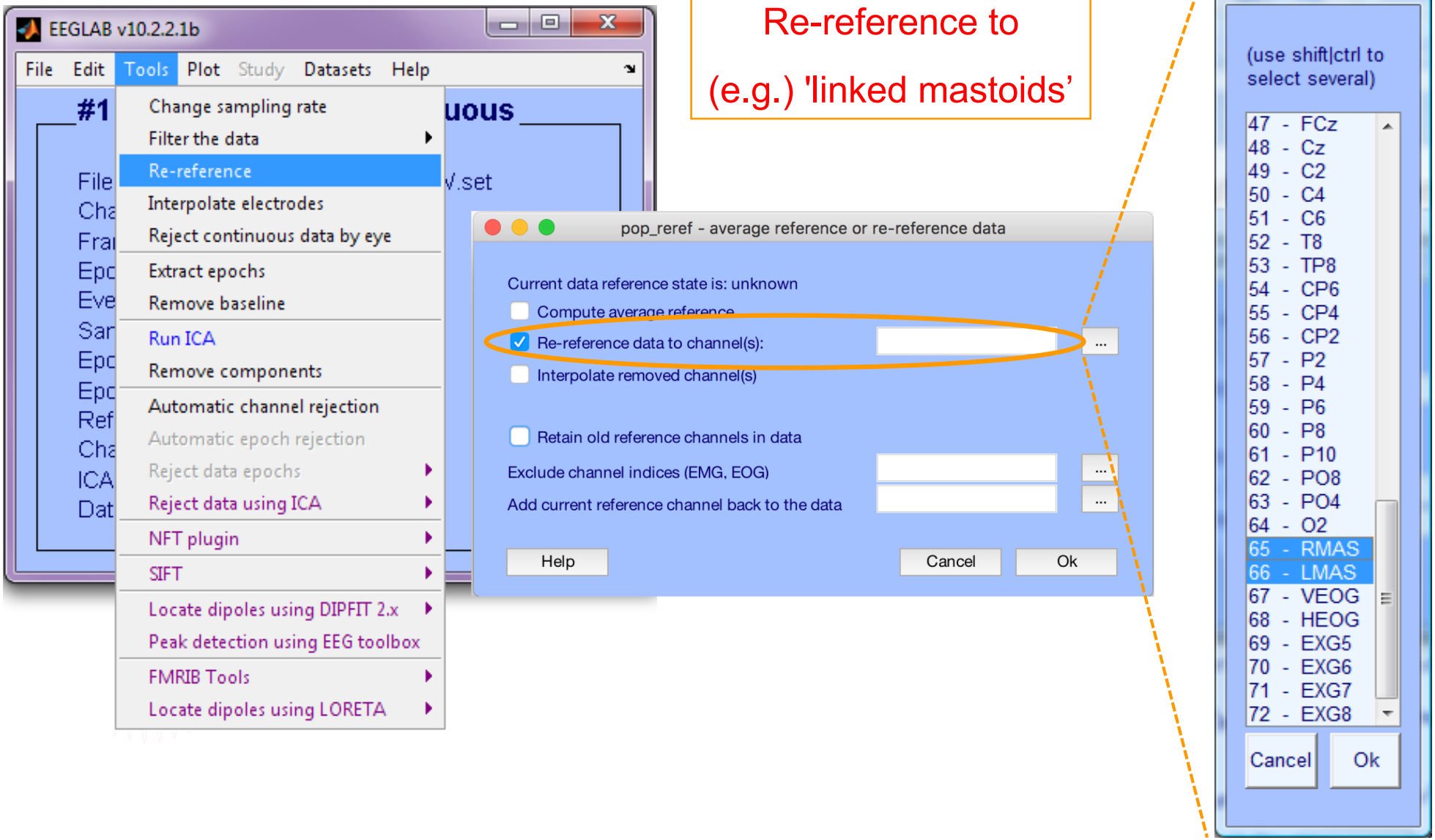
Reject large artifact time points

Run ICA and reject components

Done

Re-reference data (if necessary/desired)

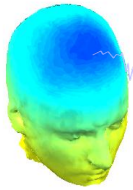




Re-reference to

(e.g.) 'linked mastoids'

Save new dataset, keep old one



Dataset info -- pop_newset()

What do you want to do with the new dataset?

Name it: SimpleOddball continuous reref — 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: C:\Users\marissa\Desktop\EEGLABwork — Browse

Help | Cancel | Ok

Enter filename

Save in: MATLAB

Recent Places, Desktop, Libraries, Computer, Network

Name	Date modified	Type
external	11/10/2009 5:54 AM	File folder
functions	11/10/2009 5:50 AM	File folder
plugins	11/10/2009 5:52 AM	File folder
sample_data	11/10/2009 5:52 AM	File folder
sample_locs	11/10/2009 5:52 AM	File folder

File name: | Save

Save as type: (*.set) | Cancel

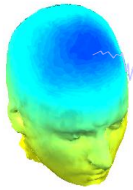
EEGLAB v11.0.5.4b

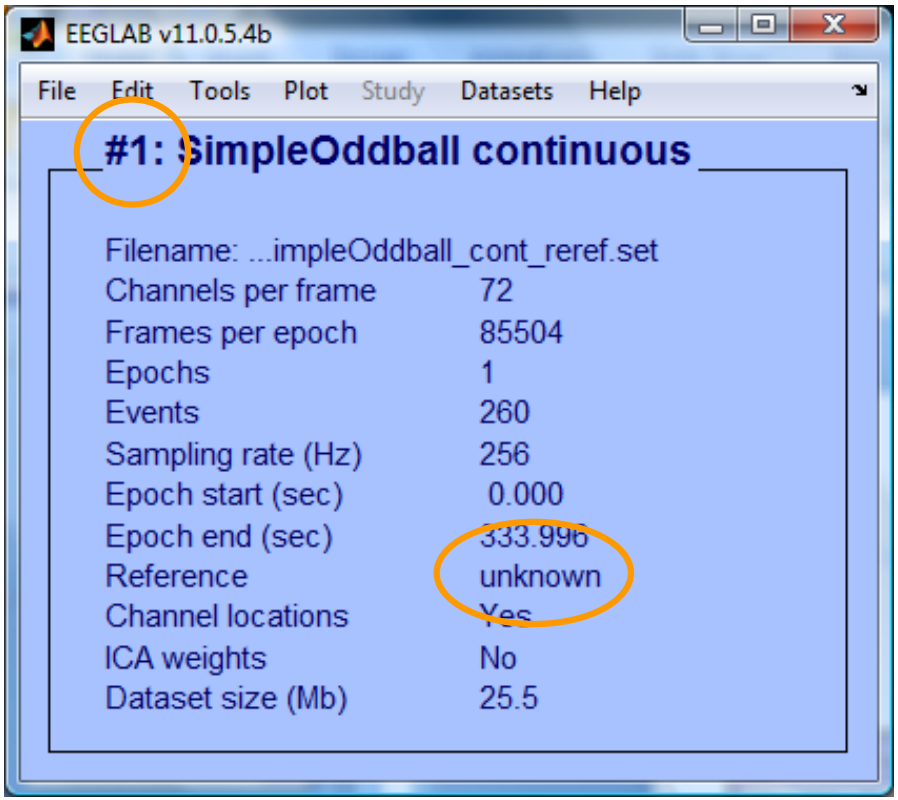
File Edit Tools Plot Study Datasets Help

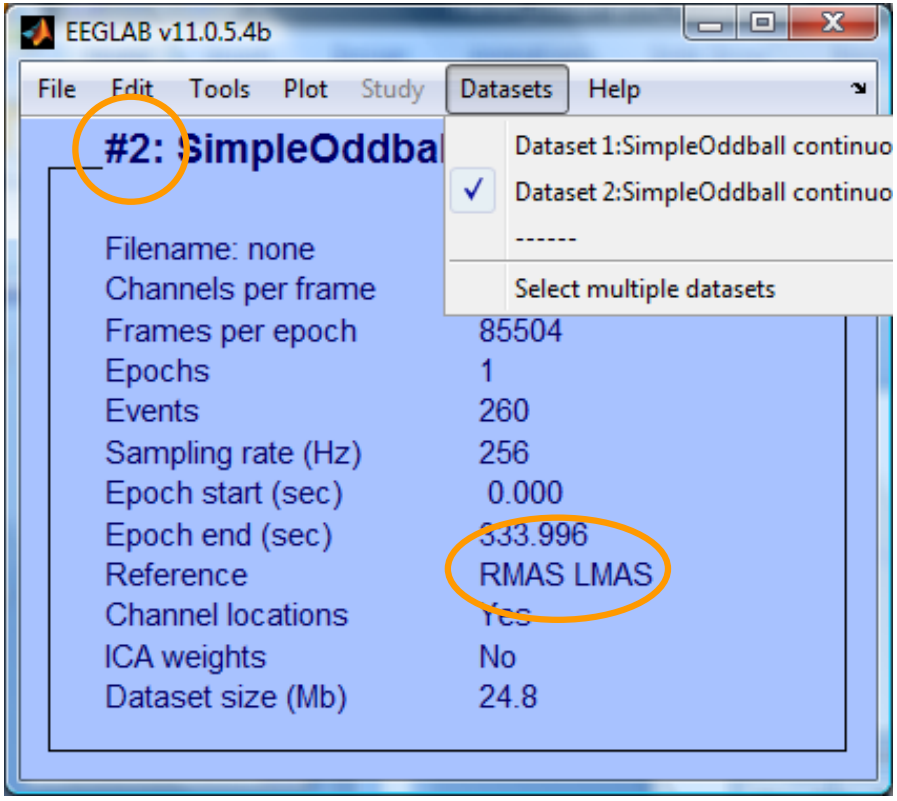
#2: SimpleOddball continuous reref

Filename: none	
Channels per frame	70
Frames per epoch	85504
Epochs	1
Events	260
Sampling rate (Hz)	256
Epoch start (sec)	0.000
Epoch end (sec)	333.996
Reference	RMAS LMAS
Channel locations	Yes
ICA weights	No
Dataset size (Mb)	24.8

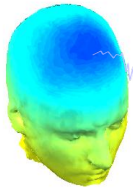
Multiple active datasets

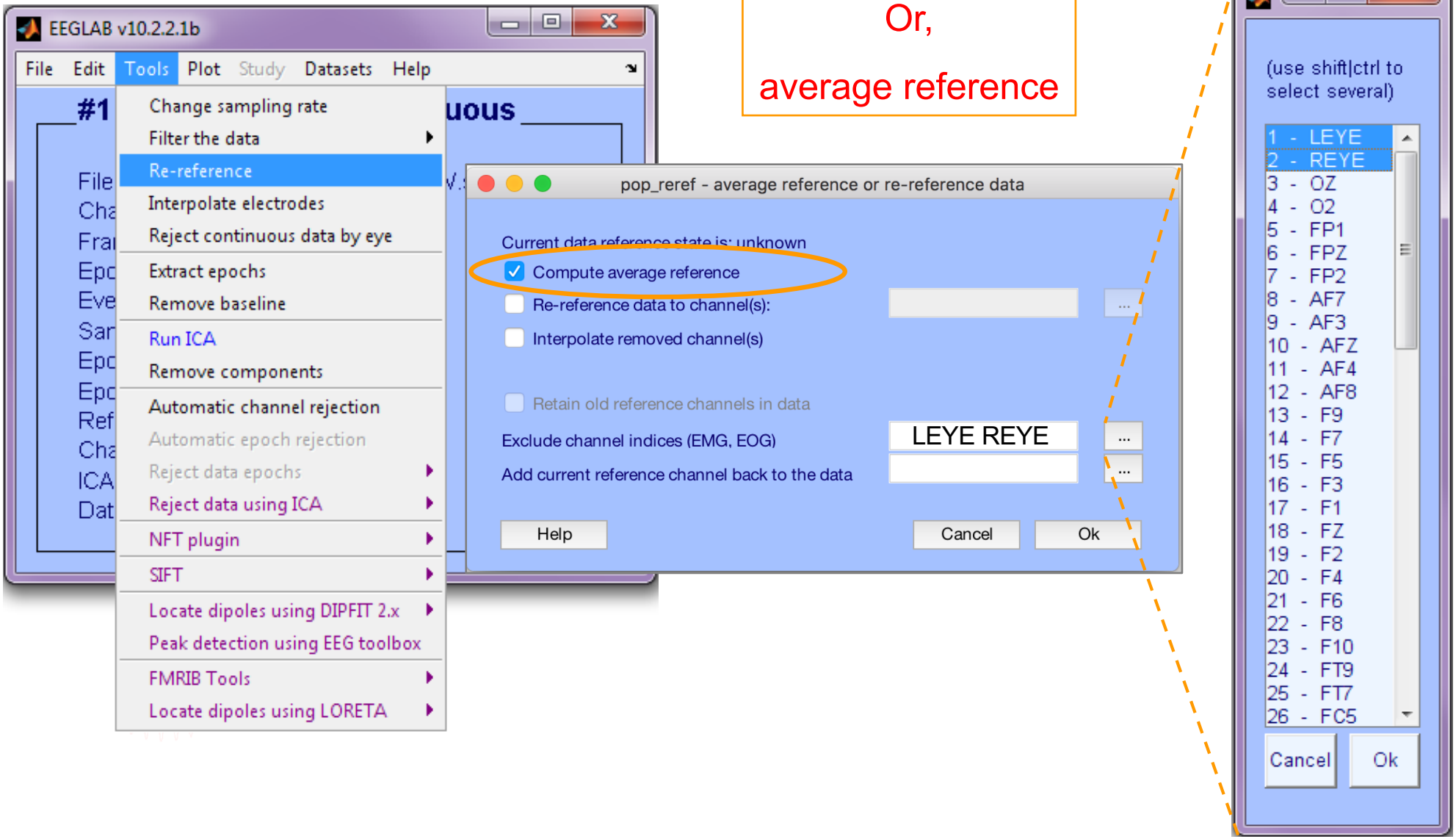




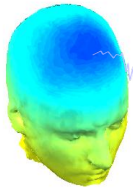


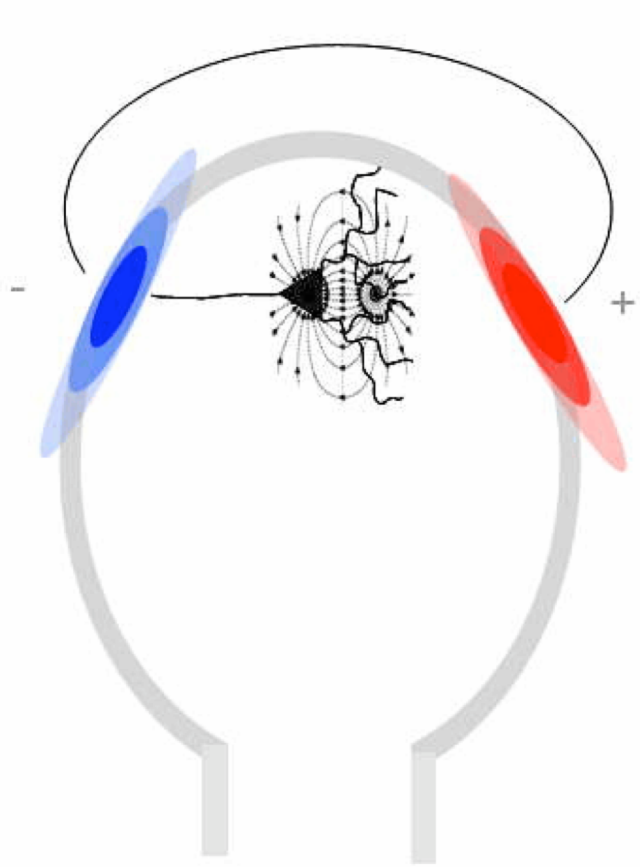
Re-reference data (if necessary/desired)





On Average Referencing

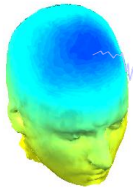


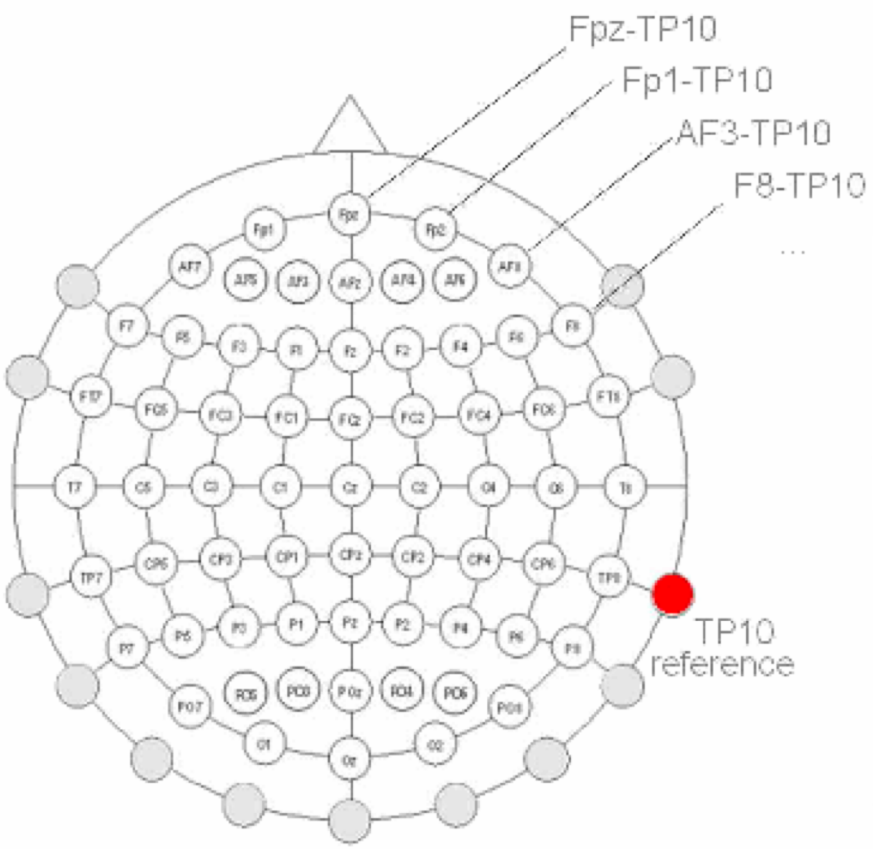


In theory, positive and negative current across entire head should balance—no net current source or sink: Average referencing enforces this.

In practice, depends on distribution of electrodes.

Average reference

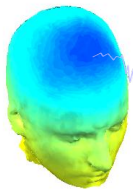


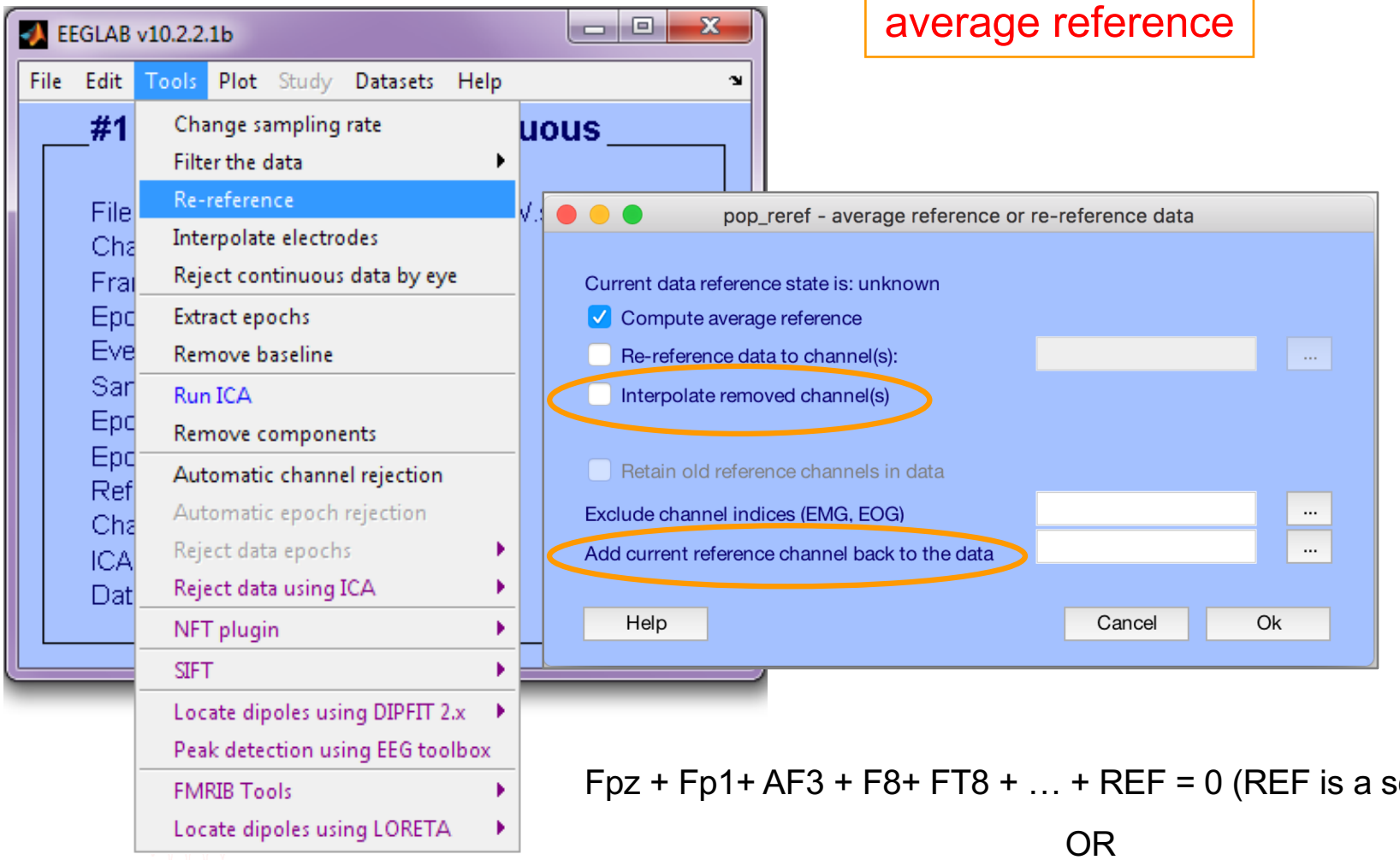


1. Average Reference assumption

$$Fpz + Fp1 + AF3 + F8 + FT8 + \ldots + TP10 = 0$$

Re-reference data (if necessary/desired)





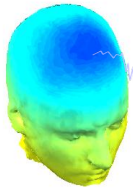
average reference

Fpz + Fp1+ AF3 + F8+ FT8 + … + REF = 0 (REF is a scalp channel)

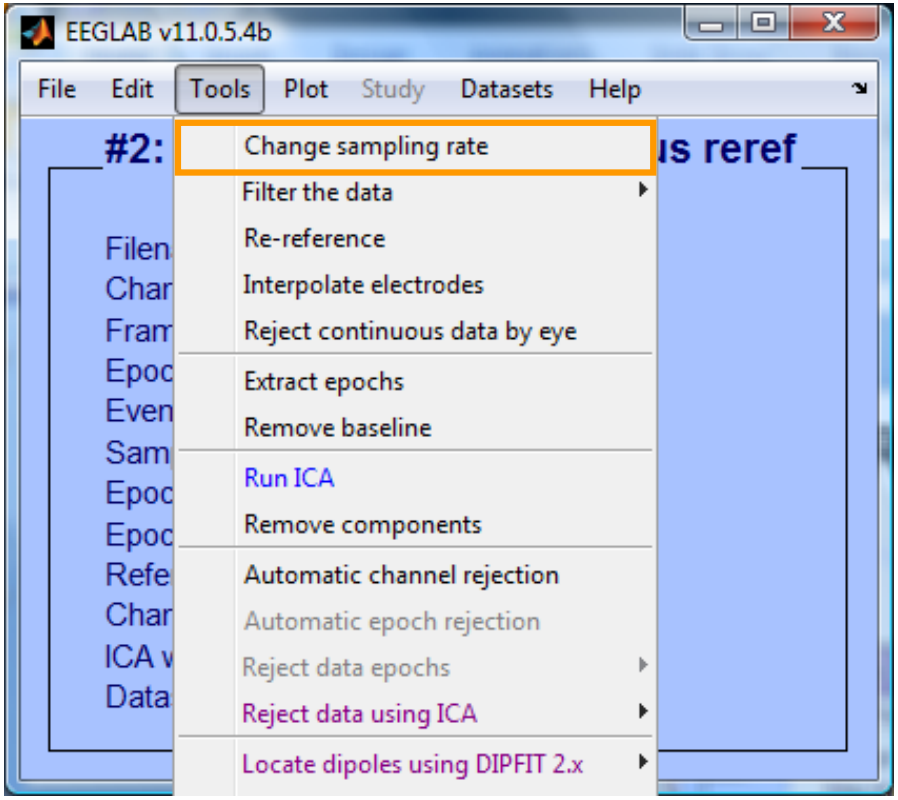
OR

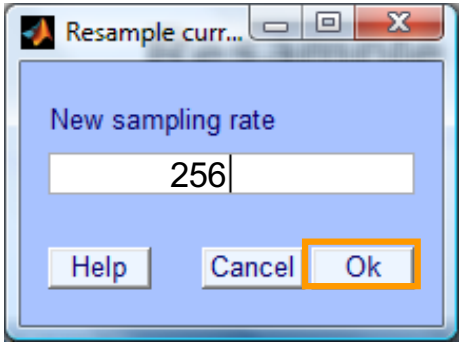
Fpz + Fp1+ AF3 + F8+ FT8 + … = 0 (REF is not on the scalp, ear reference, …)

Resample data (if desired)

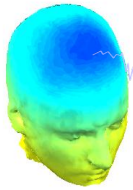


Reason: Reduce space, time.





Pre-processing pipeline



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High pass filter (~.5 – 1 Hz)

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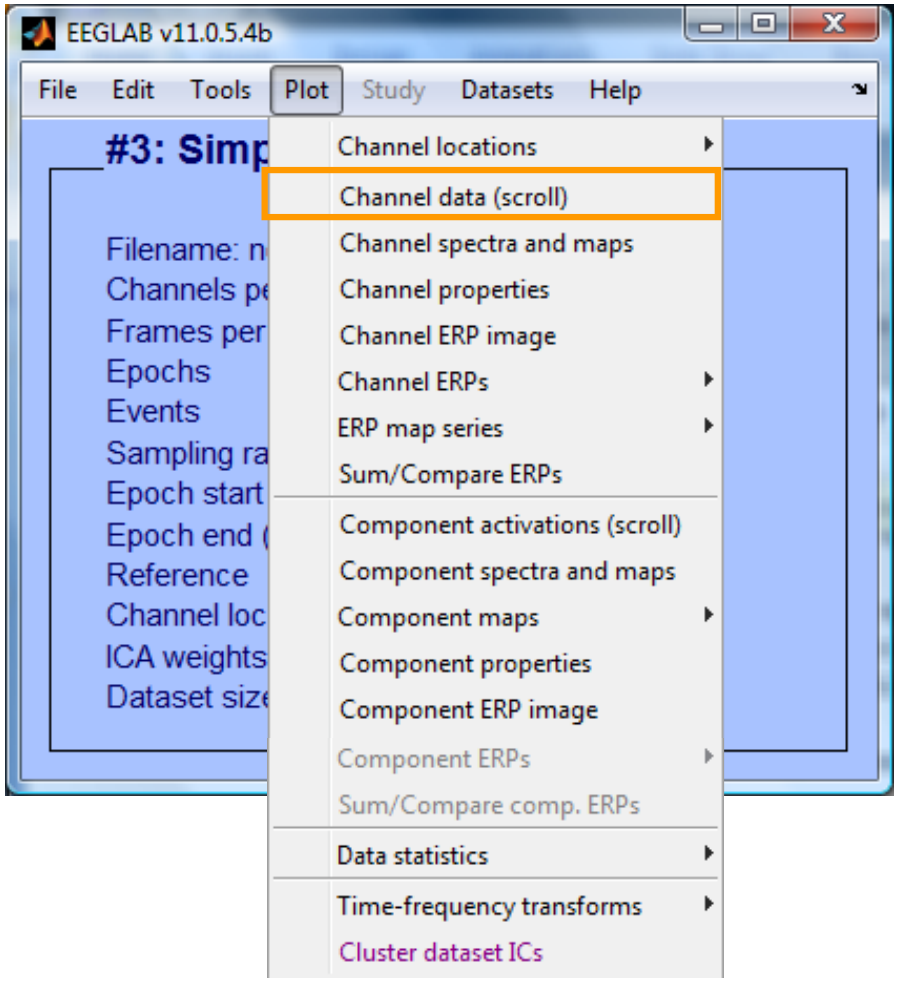
Identify/reject bad channels

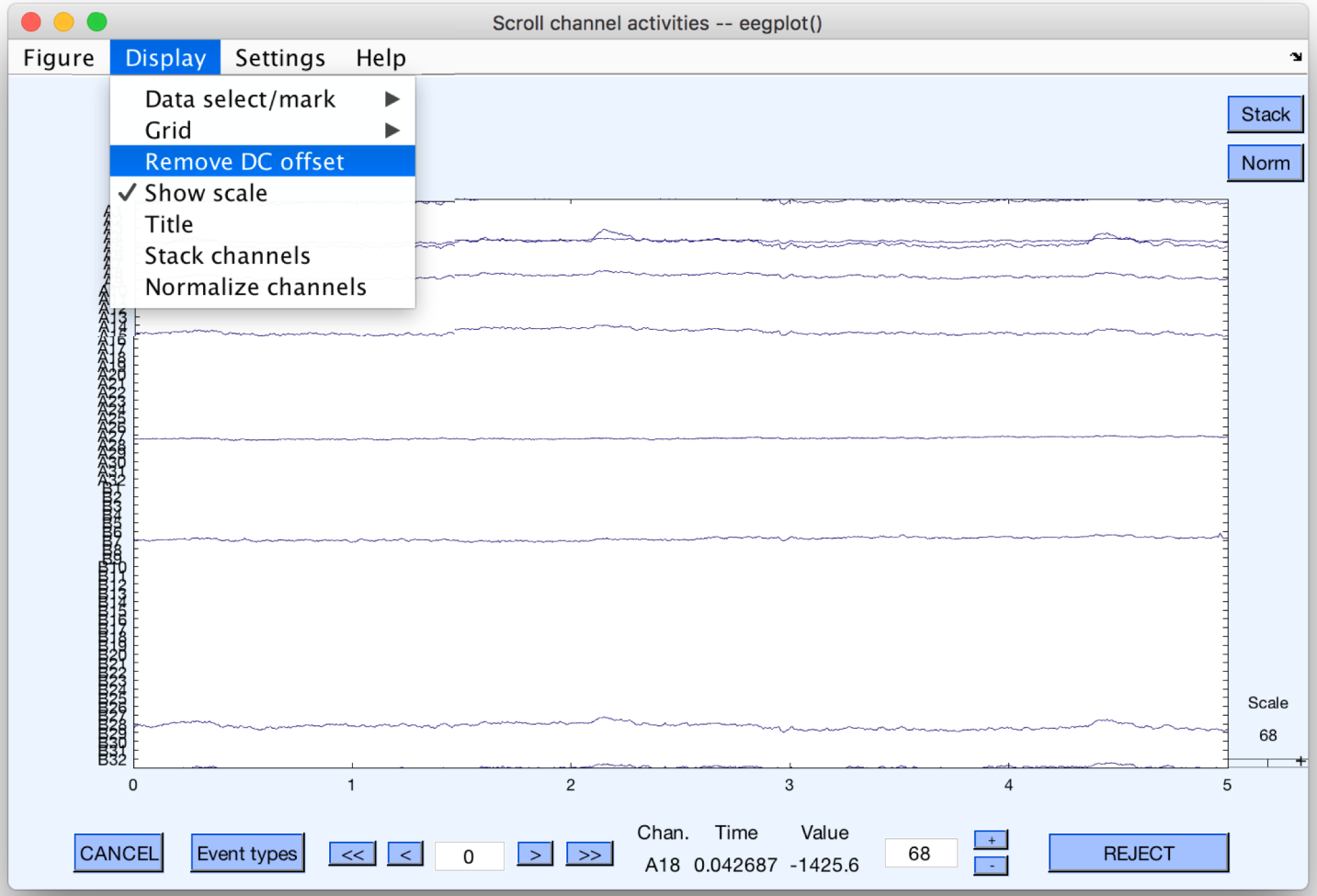
Reject large artifact time points

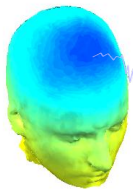
Run ICA and reject components

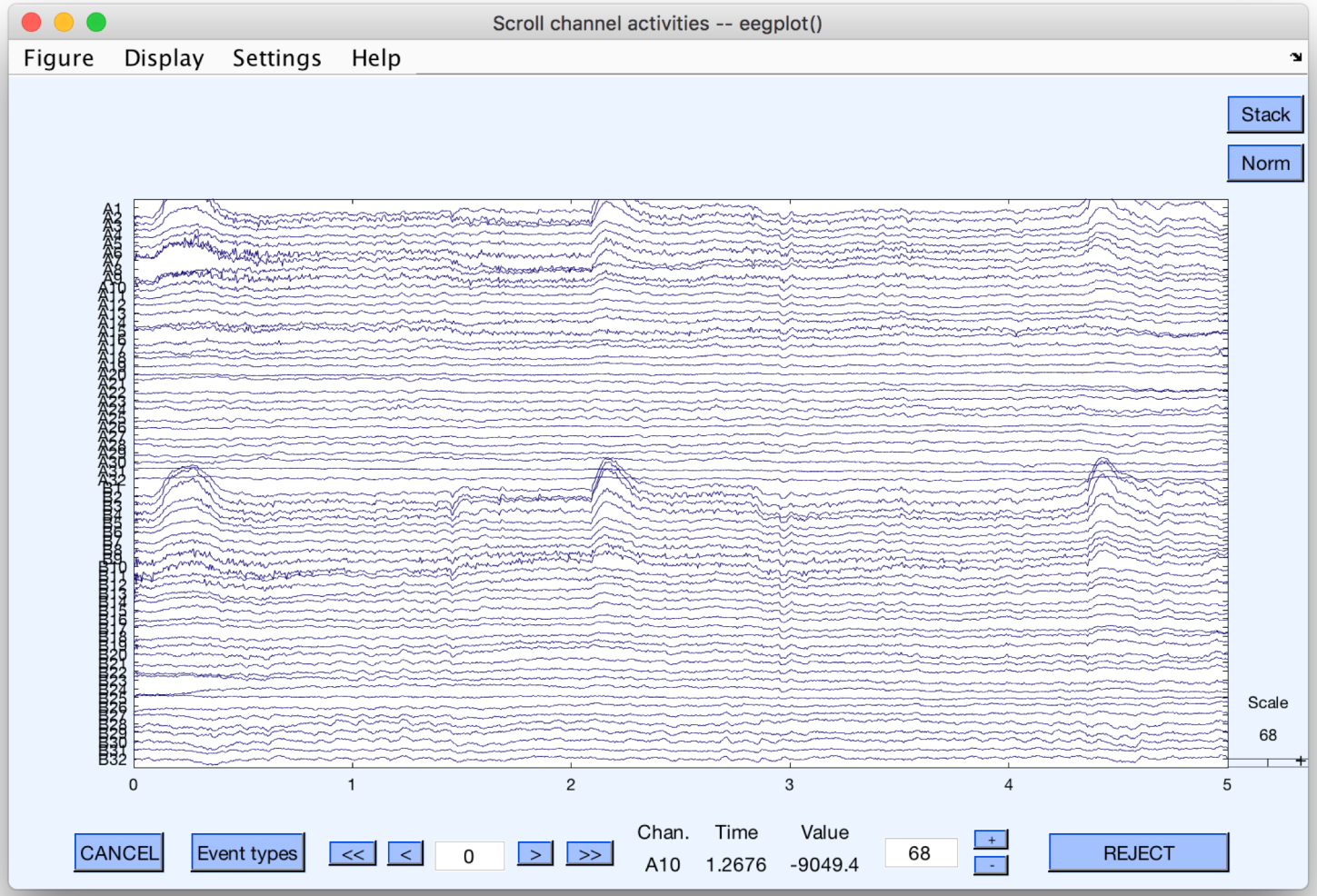
Done

Scroll channel data

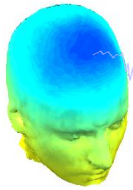


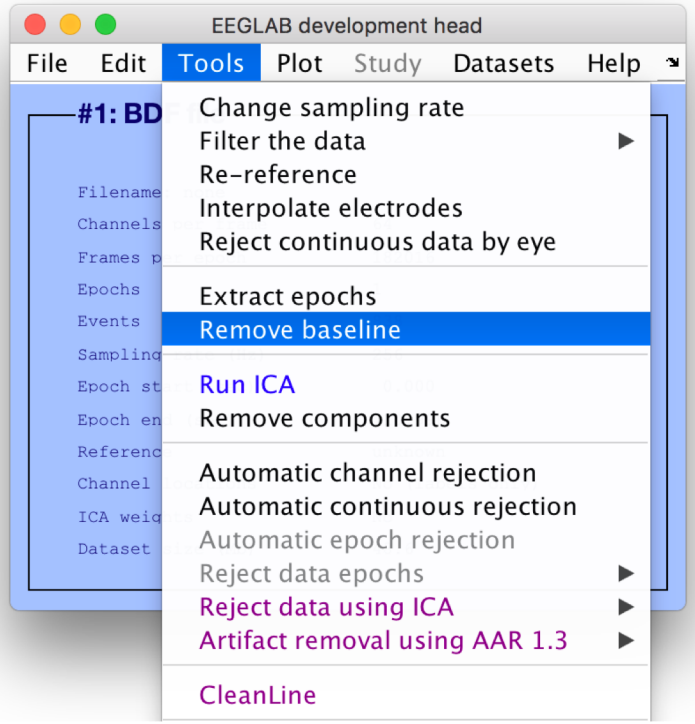

Scroll channel activities -- eegplot()
Figure
Display
Settings
Help
Data select/mark
Grid
Remove DC offset
Show scale
Title
Stack channels
Normalize channels
Stack
Norm
Scale
68
0
1
2
3
4
5
CANCEL
Event types
<<
<
0
>
>>
Chan. Time Value
A18 0.042687 -1425.6
68
+
-
REJECT

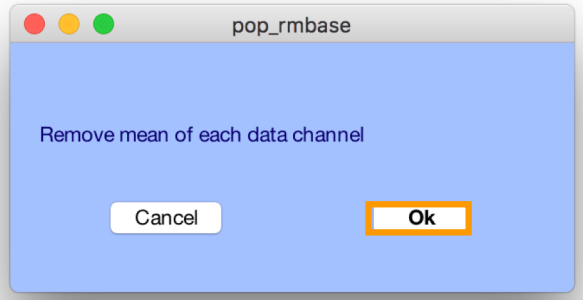


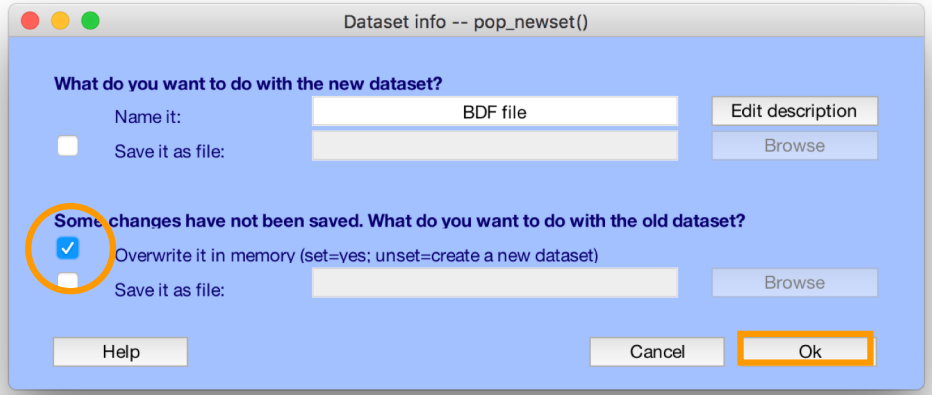

Scroll channel activities -- eegplot()
Figure
Display
Settings
Help
Stack
Norm
Scale
68
0
1
2
3
4
5
CANCEL
Event types
<<
<
0
>
>>
Chan.
Time
Value
A10
1.2676
-9049.4
68
+
-
REJECT

Remove DC offset



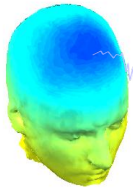




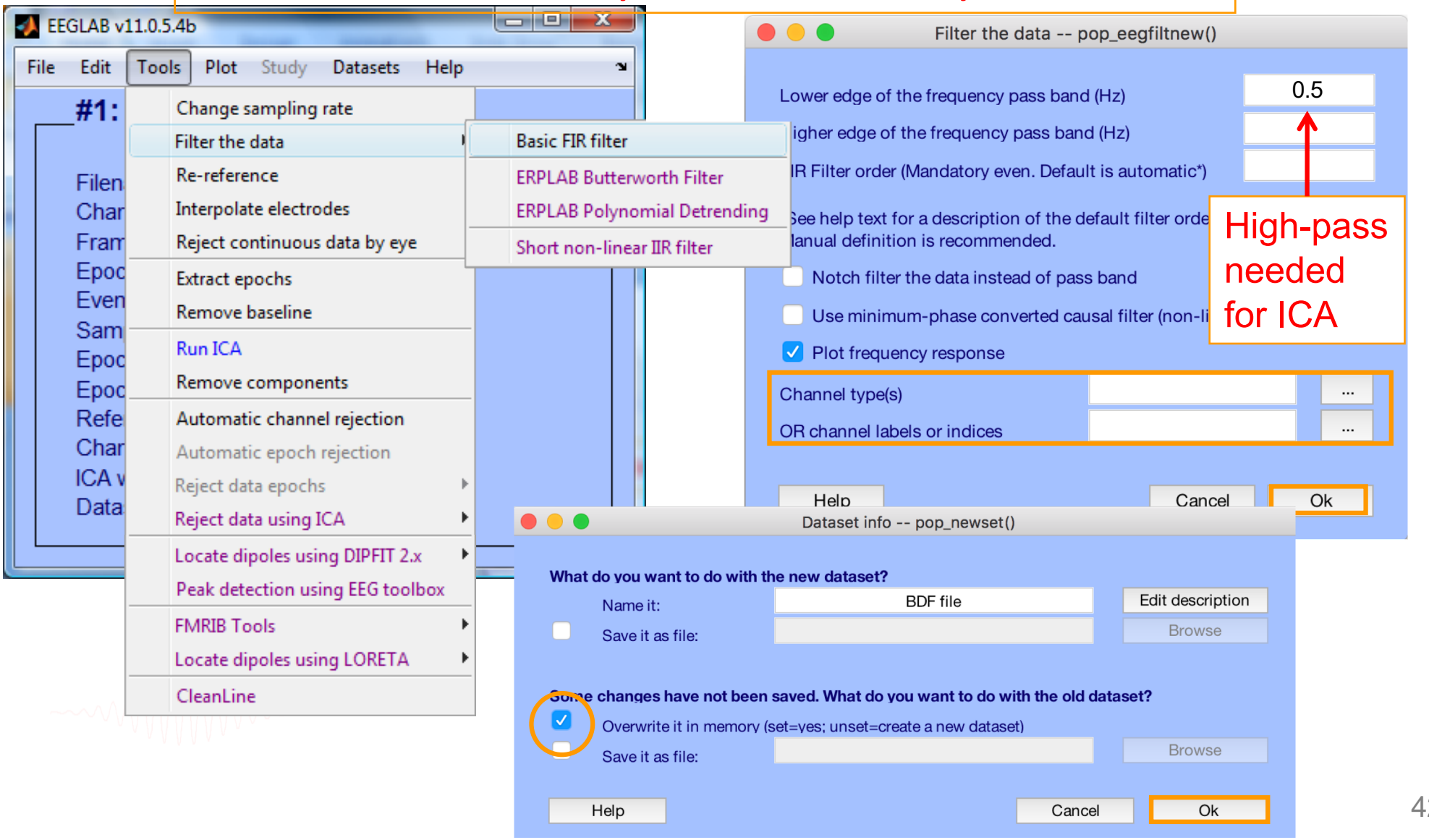


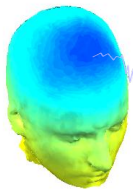
DC offsets introduce large filter artifact at signal boundaries, so it better to remove them prior to filter the signal.

High-Pass Filter the data

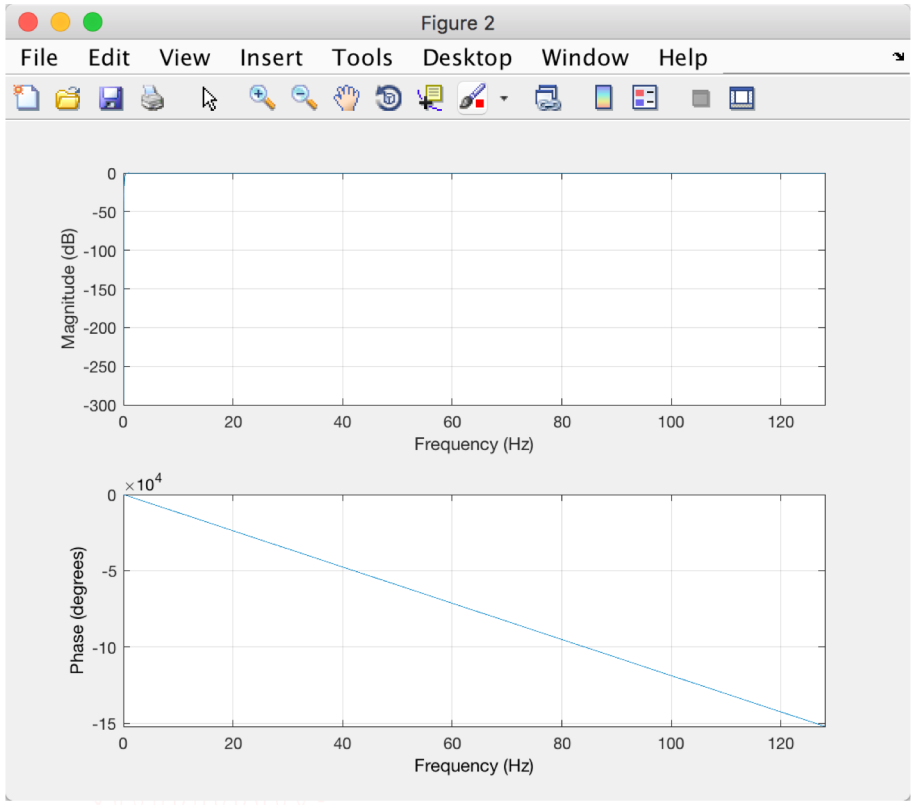


Reason: remove slow, possibly large amplitude, drift

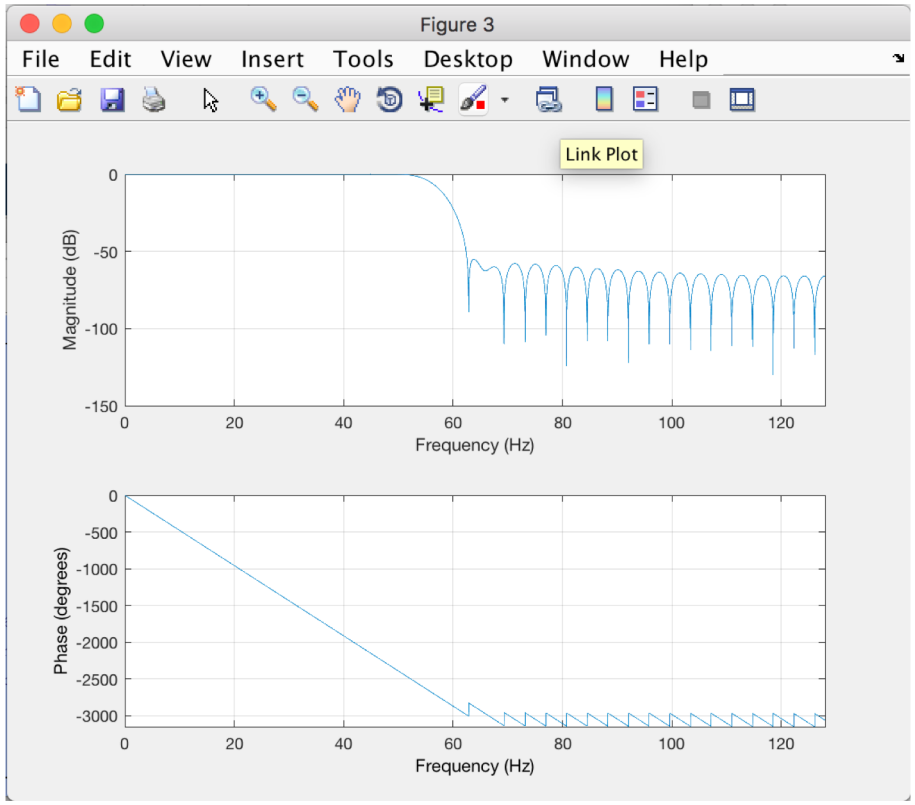


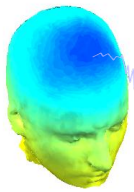


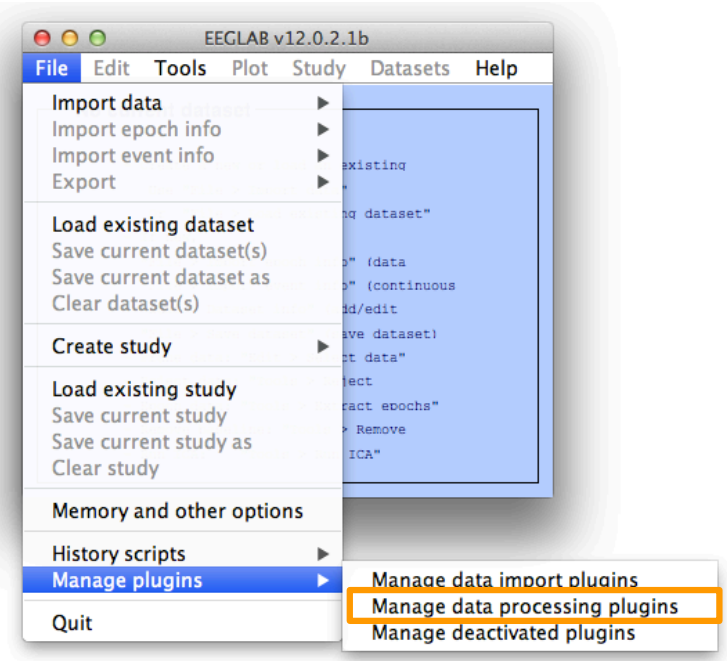
High pass (0.5 Hz)

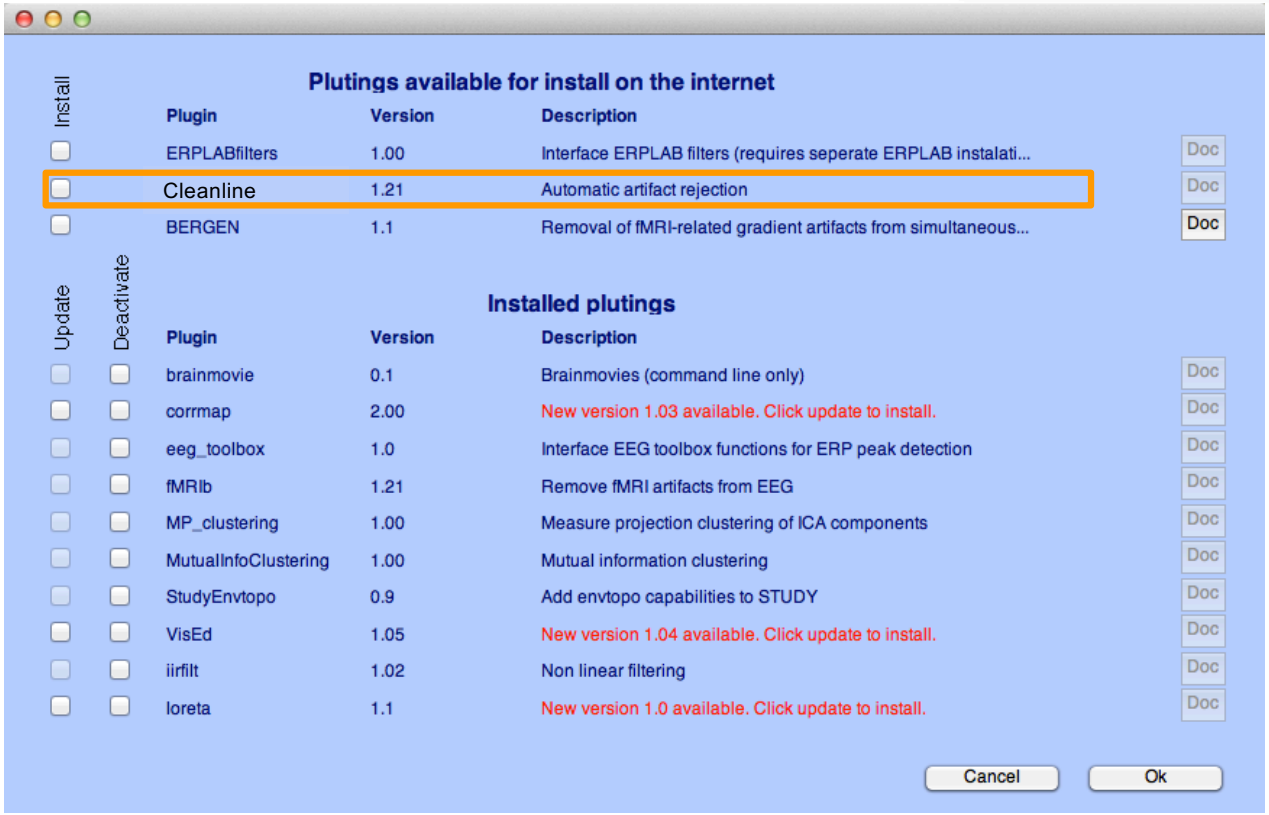


Low pass (50 Hz)





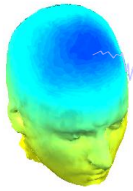


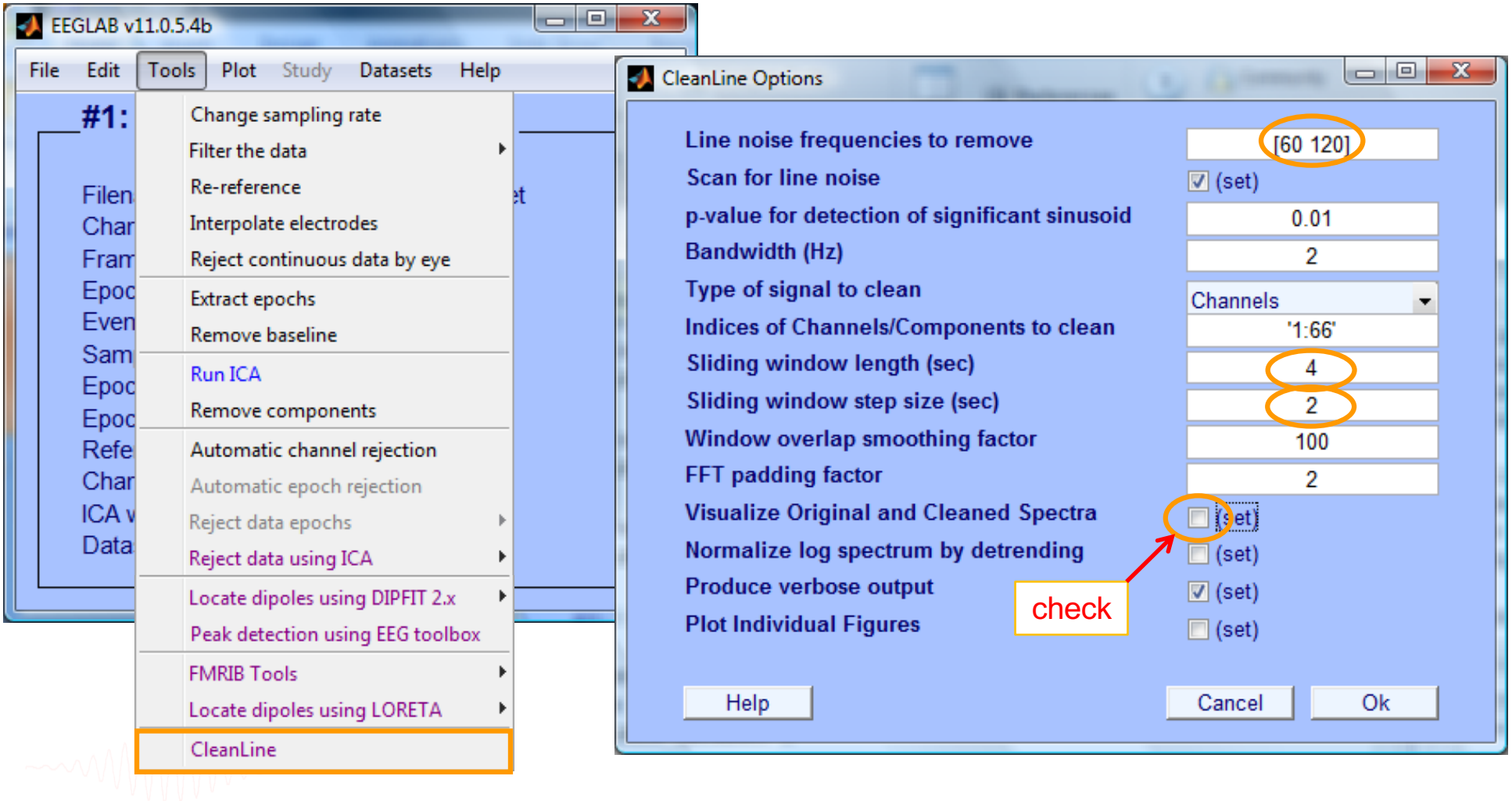


CleanLine uses an approach for line noise removal advocated by Partha Mitra and Hemant Bokil in

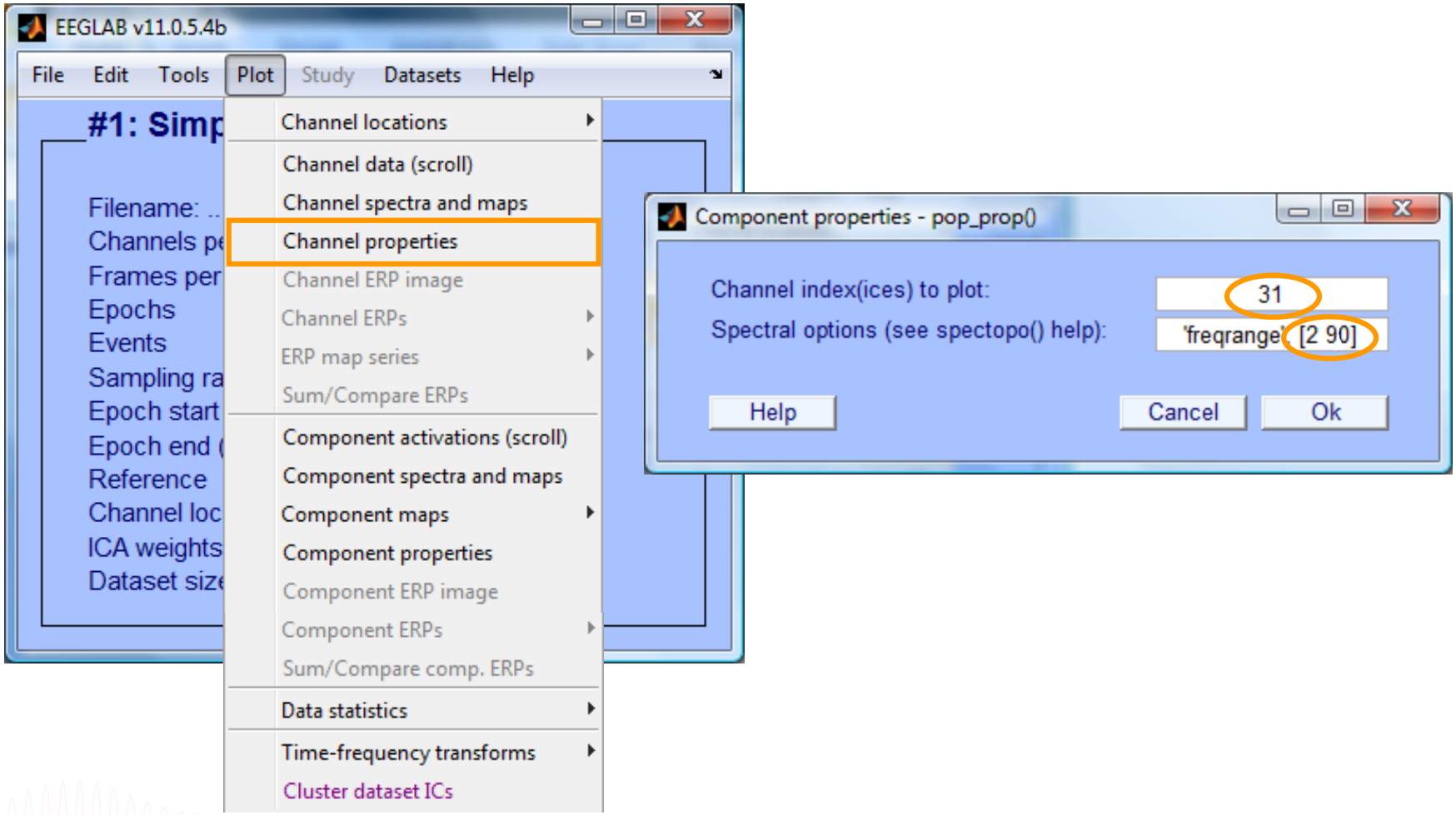
"Observed Brain Dynamics" (2007), Chapter 7.3.4.

Remove line noise (Cleanline)



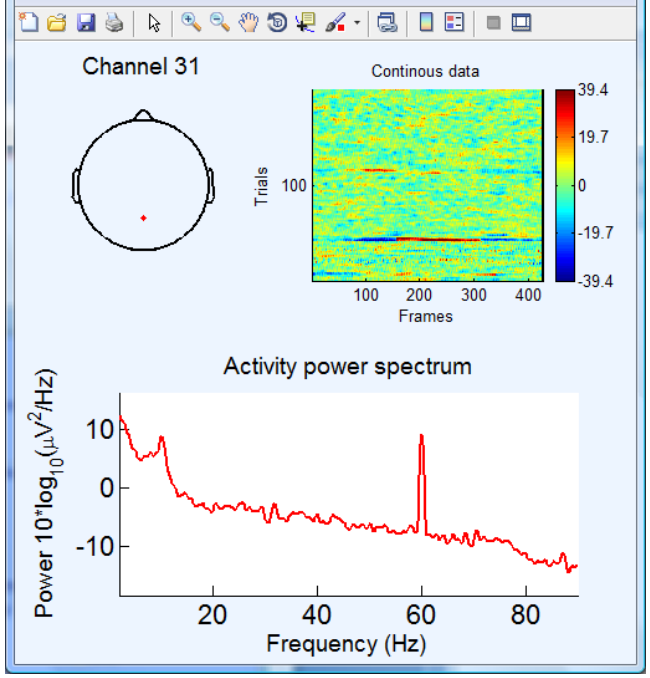


Plot channel properties

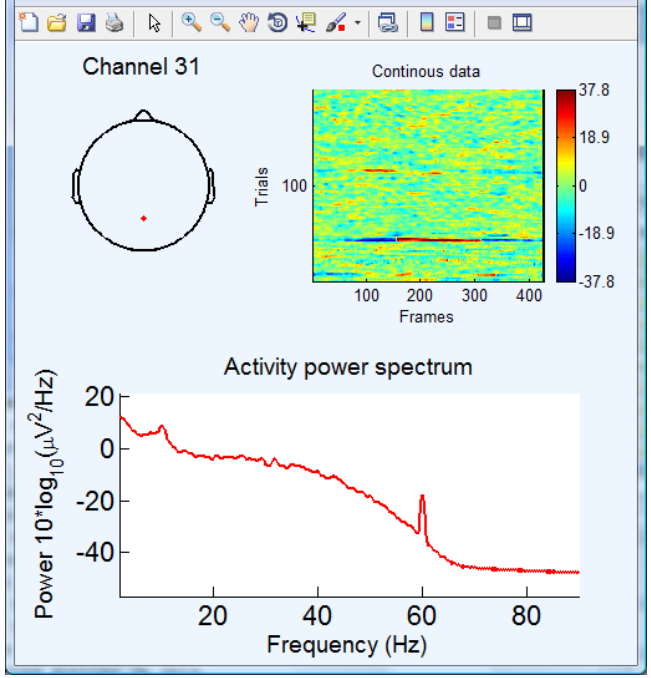


Filter comparisons

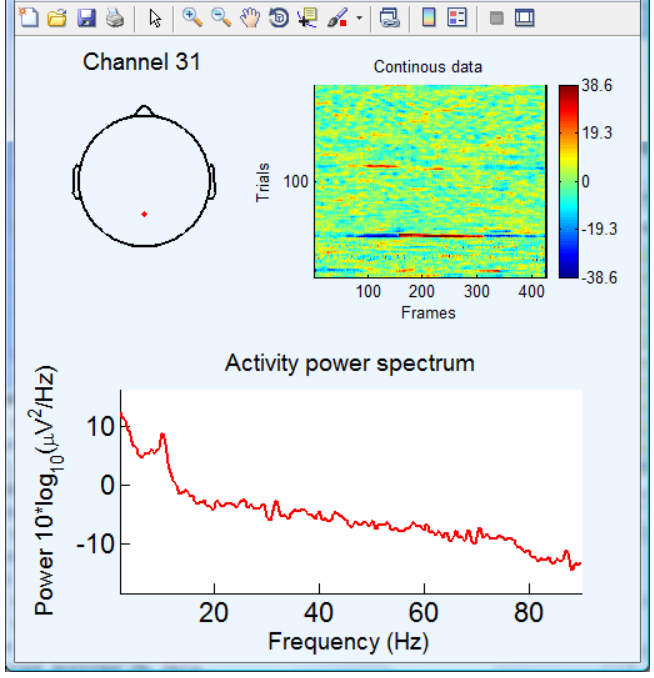
0.5 Hz high-pass filter



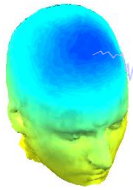
0.5 Hz high-pass filter
50 Hz low-pass filter



0.5 Hz high-pass filter
Cleanline



Pre-processing pipeline



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Identify/reject bad channels

Reject large artifact time points

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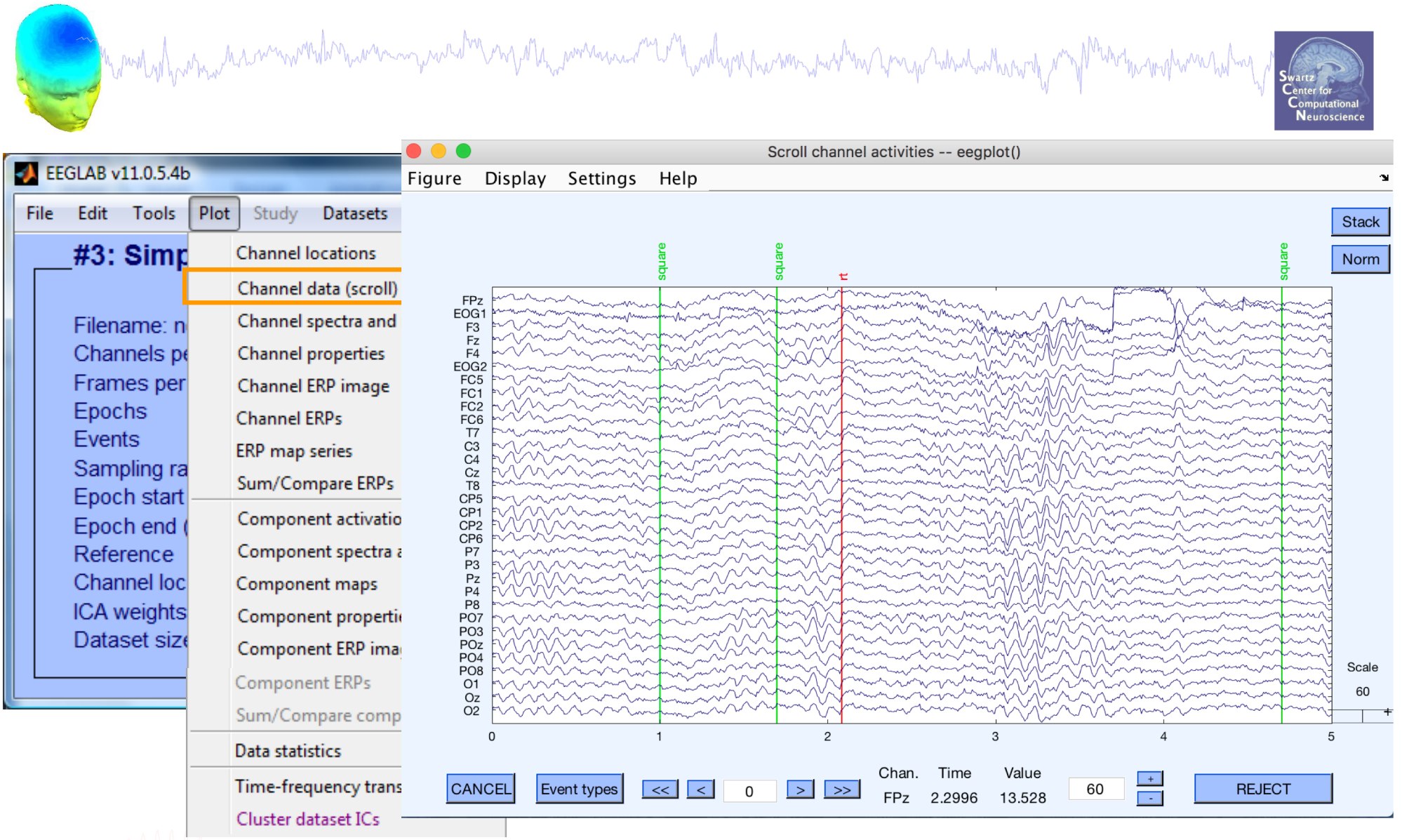
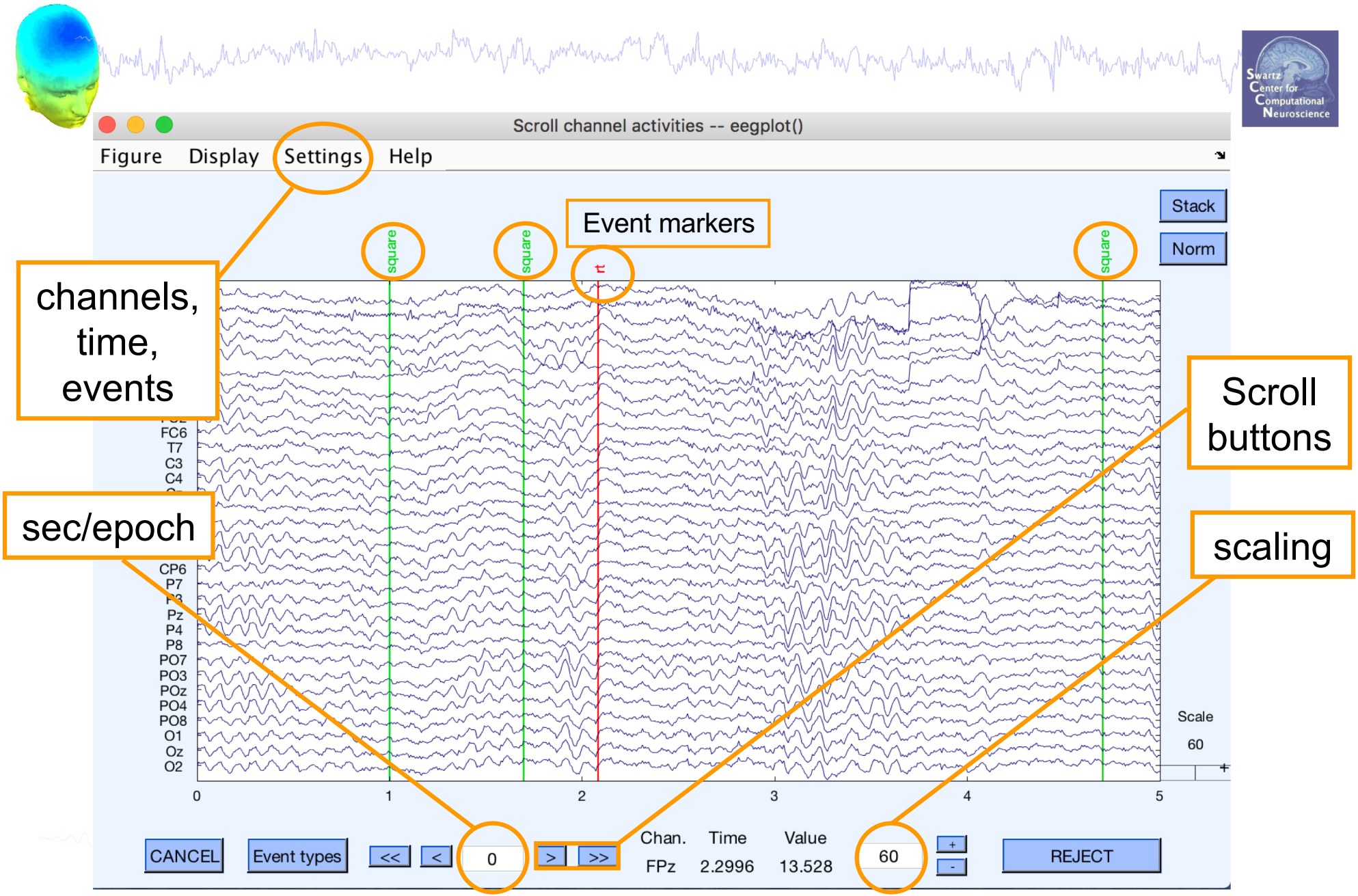
Done

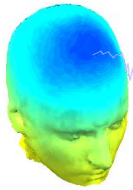
Scroll channel data



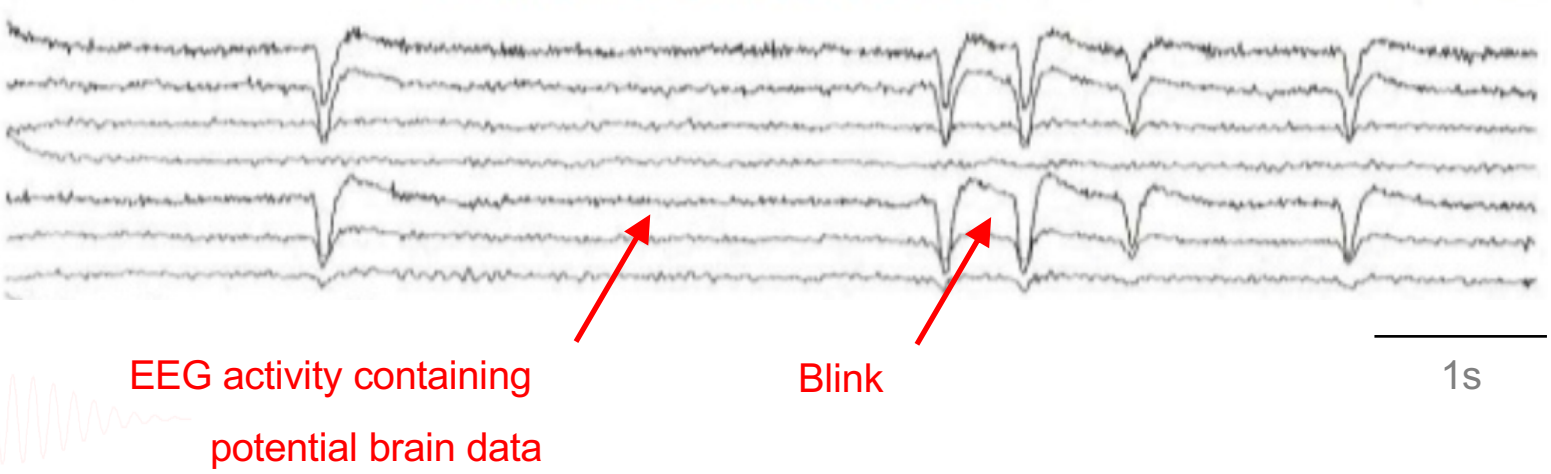
Scroll channel data



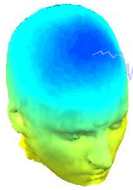
EEG artifacts

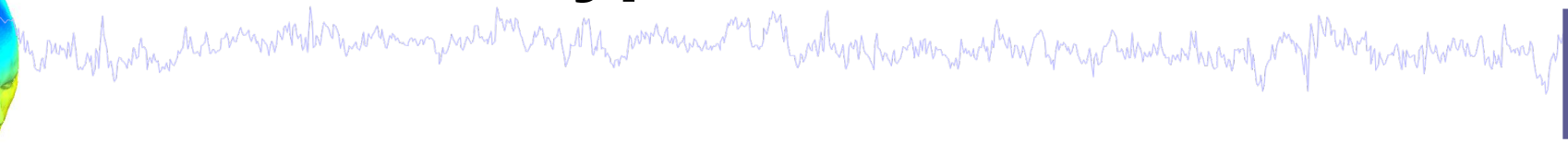


The amplitude of artifacts (such as eye movements) is often larger than the amplitude of brain data which potentially decrease signal/noise ratio, bias data analysis and potential results



Type of artifacts

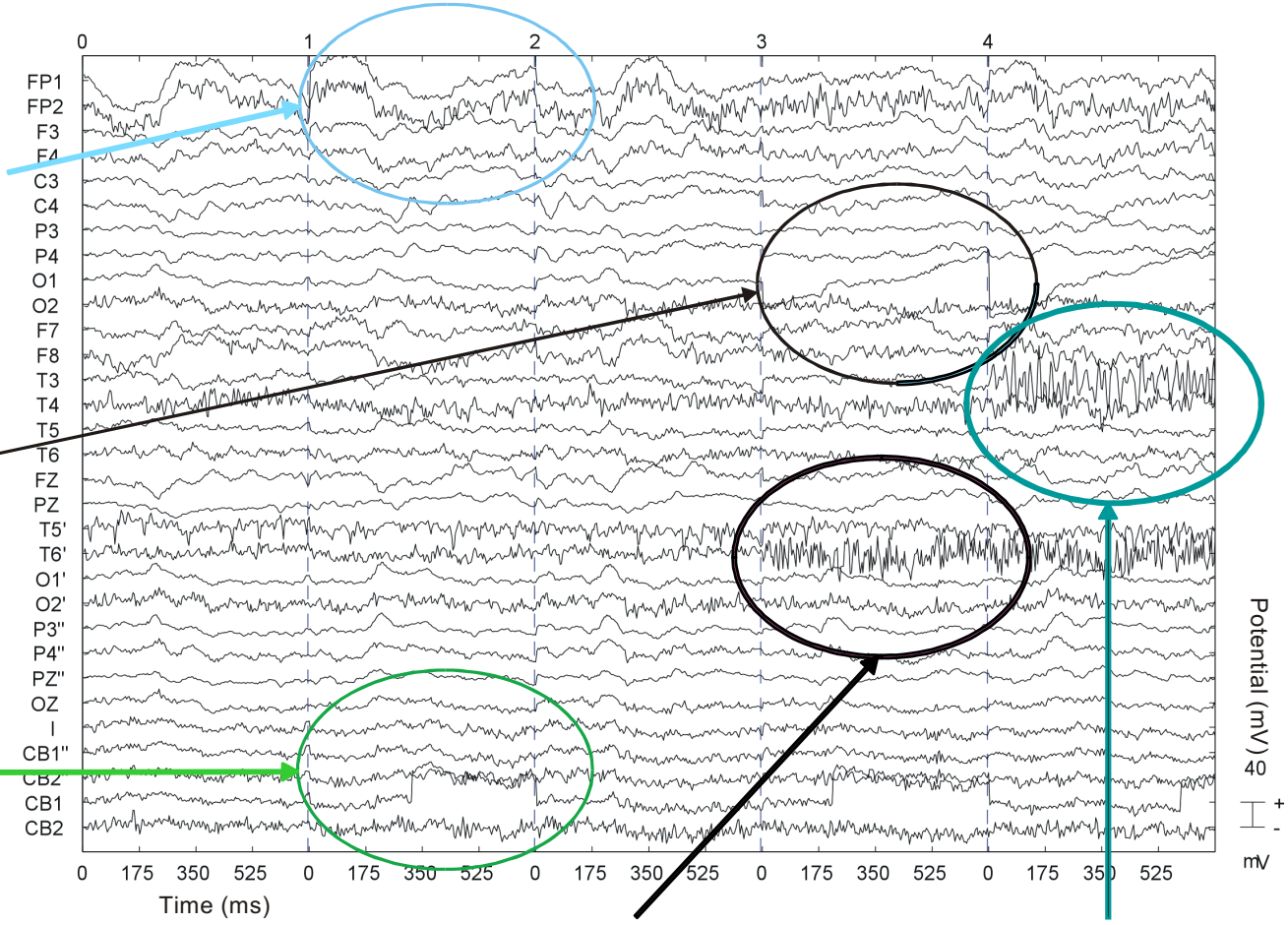




2 - Low frequency event (eye movements)

5 - Linear trend

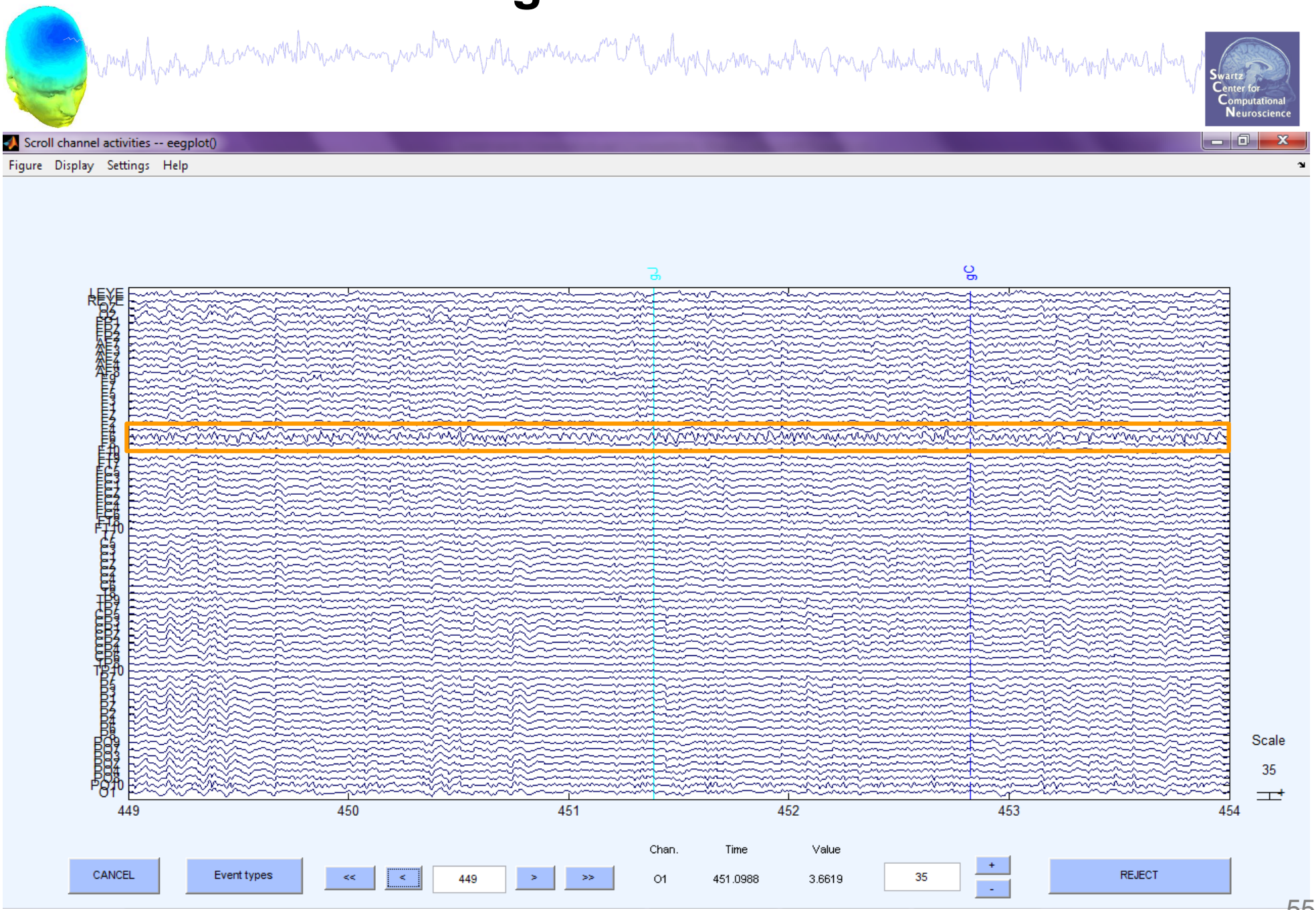
3 - Discontinuity



4 - High noise

1 - Transient high frequency event (muscle)

Looking for bad channels



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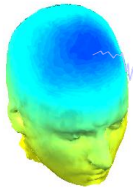

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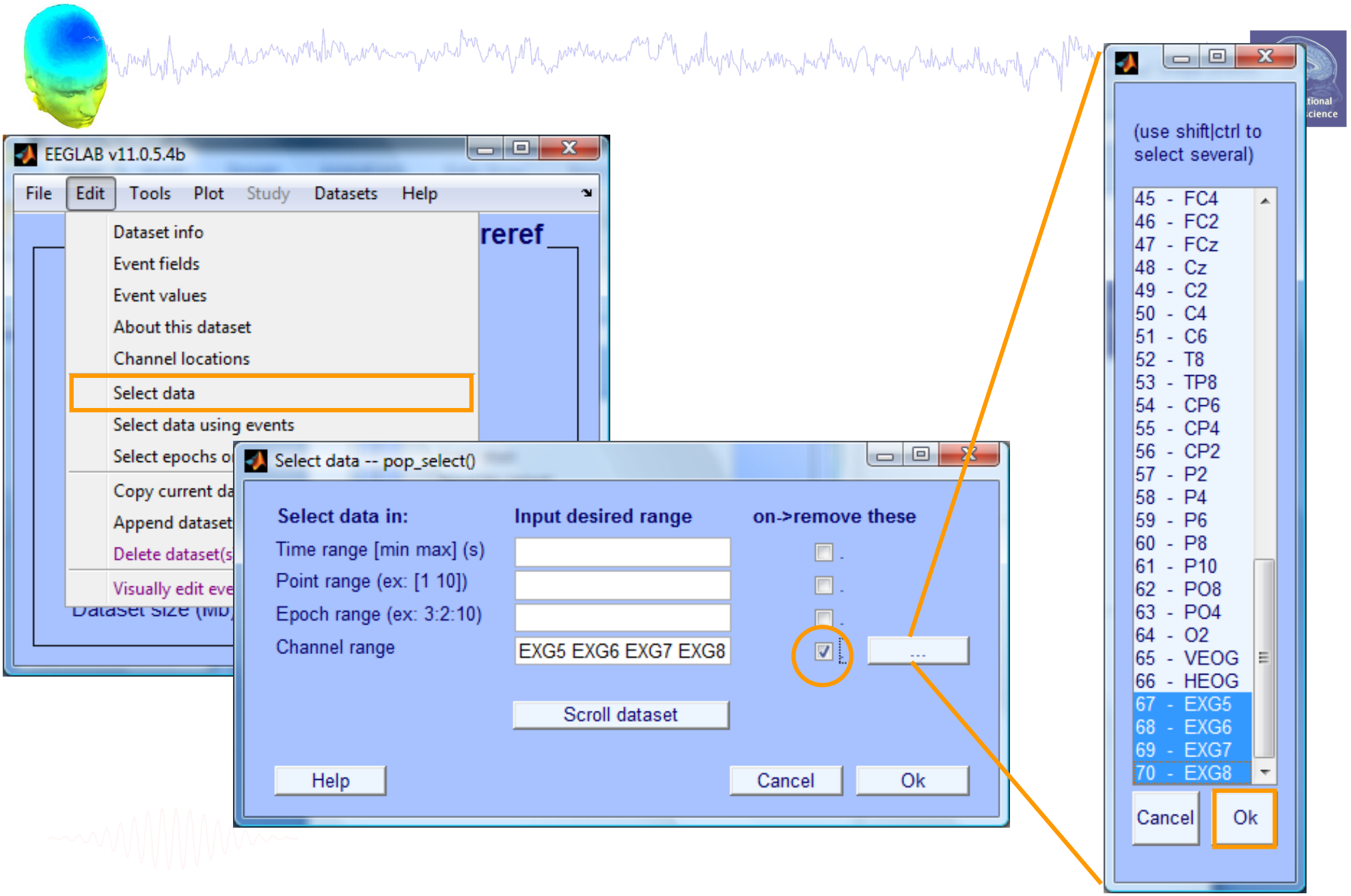
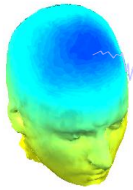
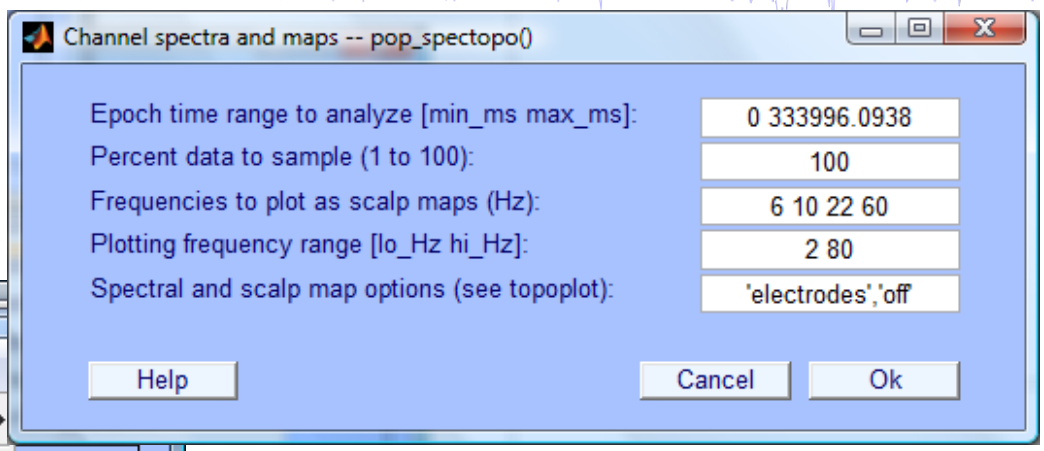
Done

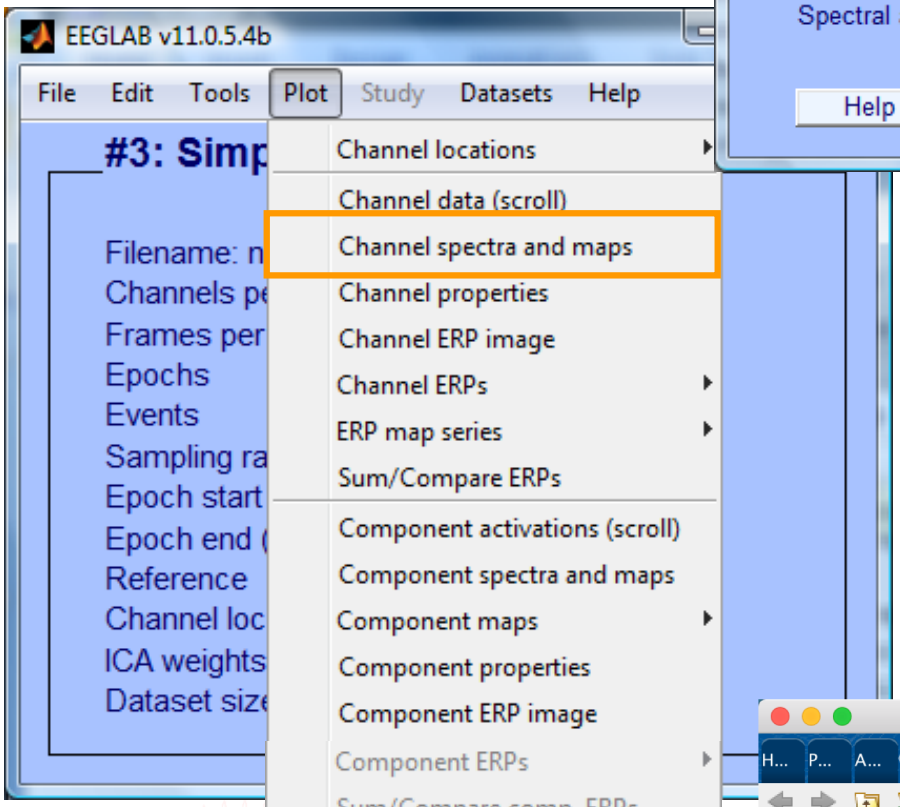
Remove unwanted channels

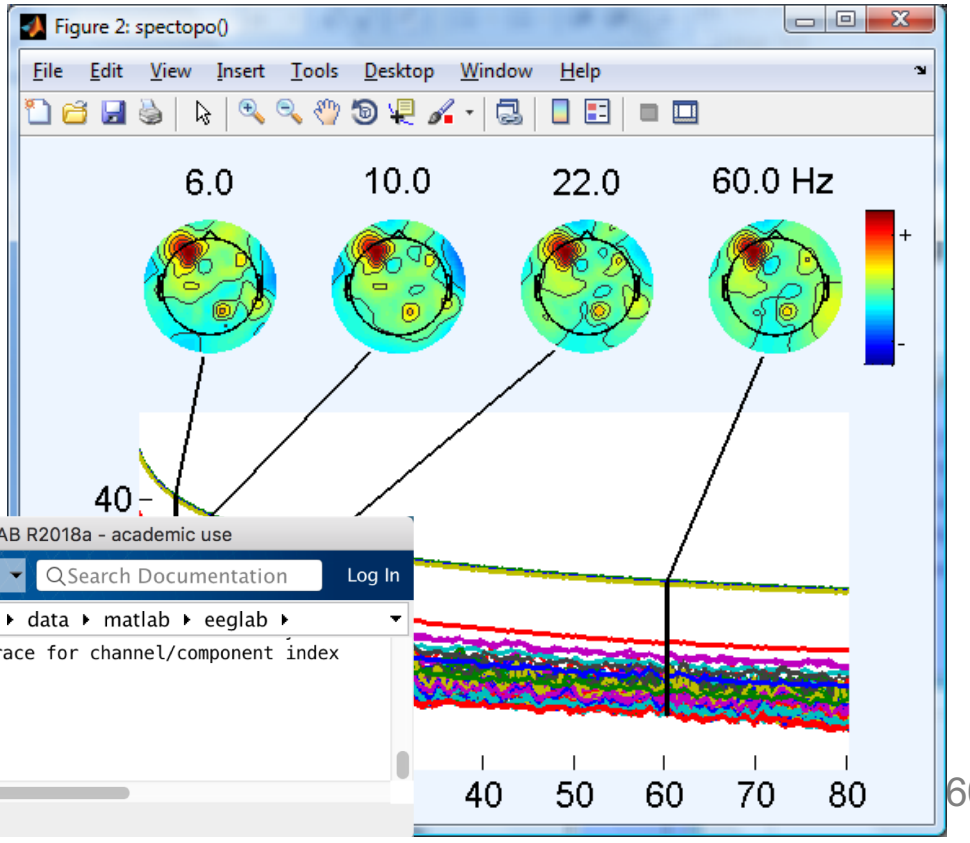


Manually identifying bad channels

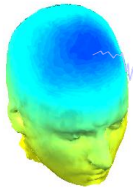


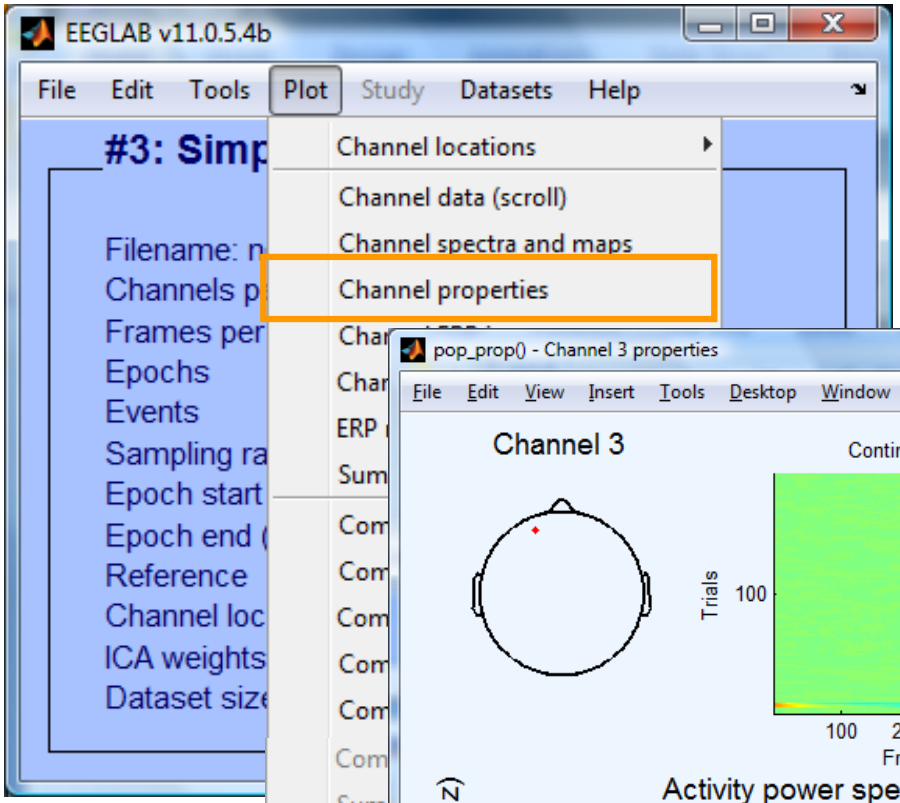


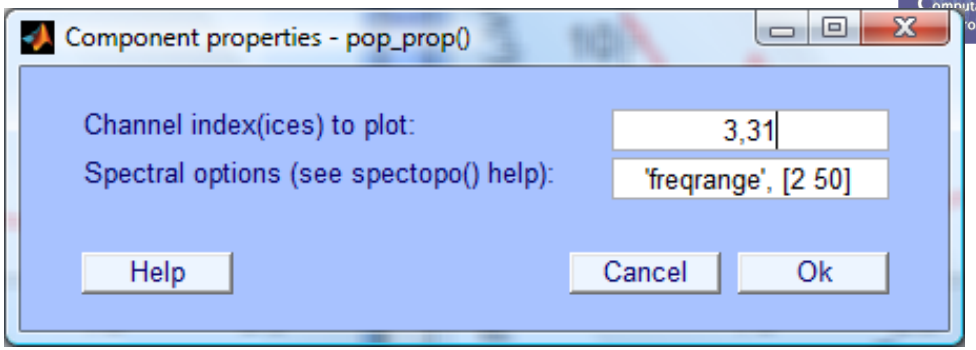


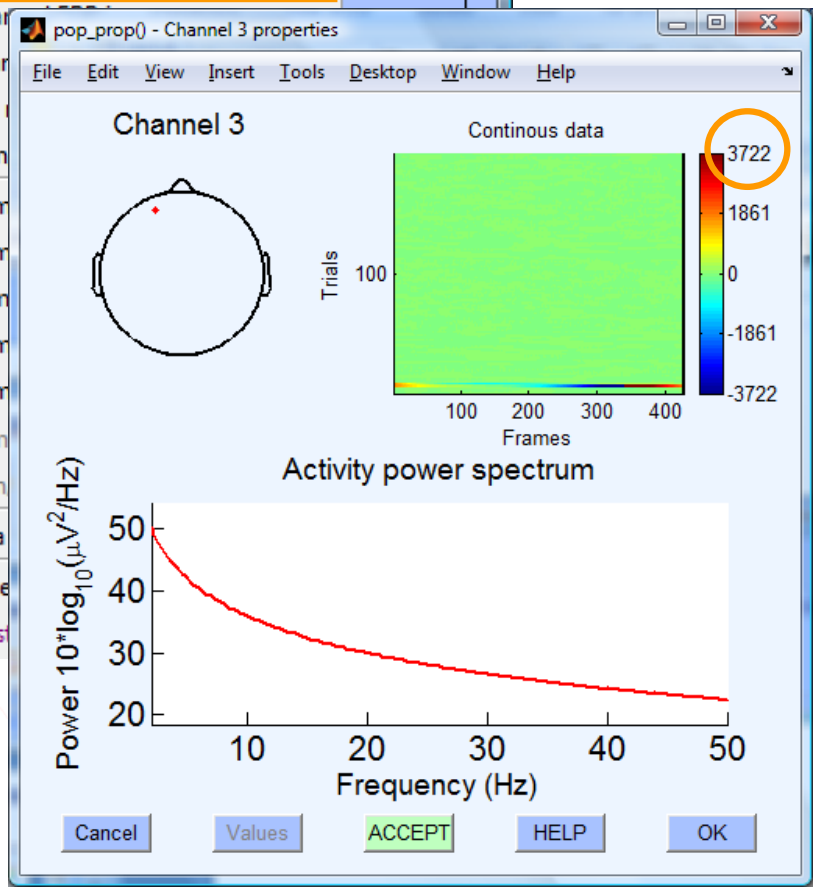


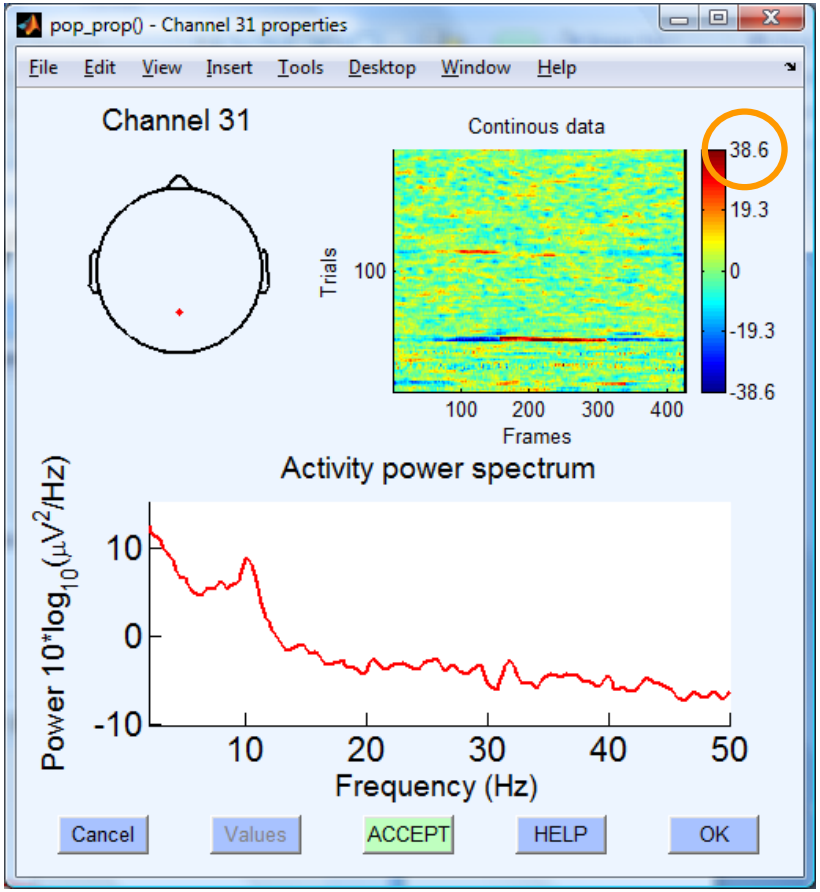
Manually identifying bad channels



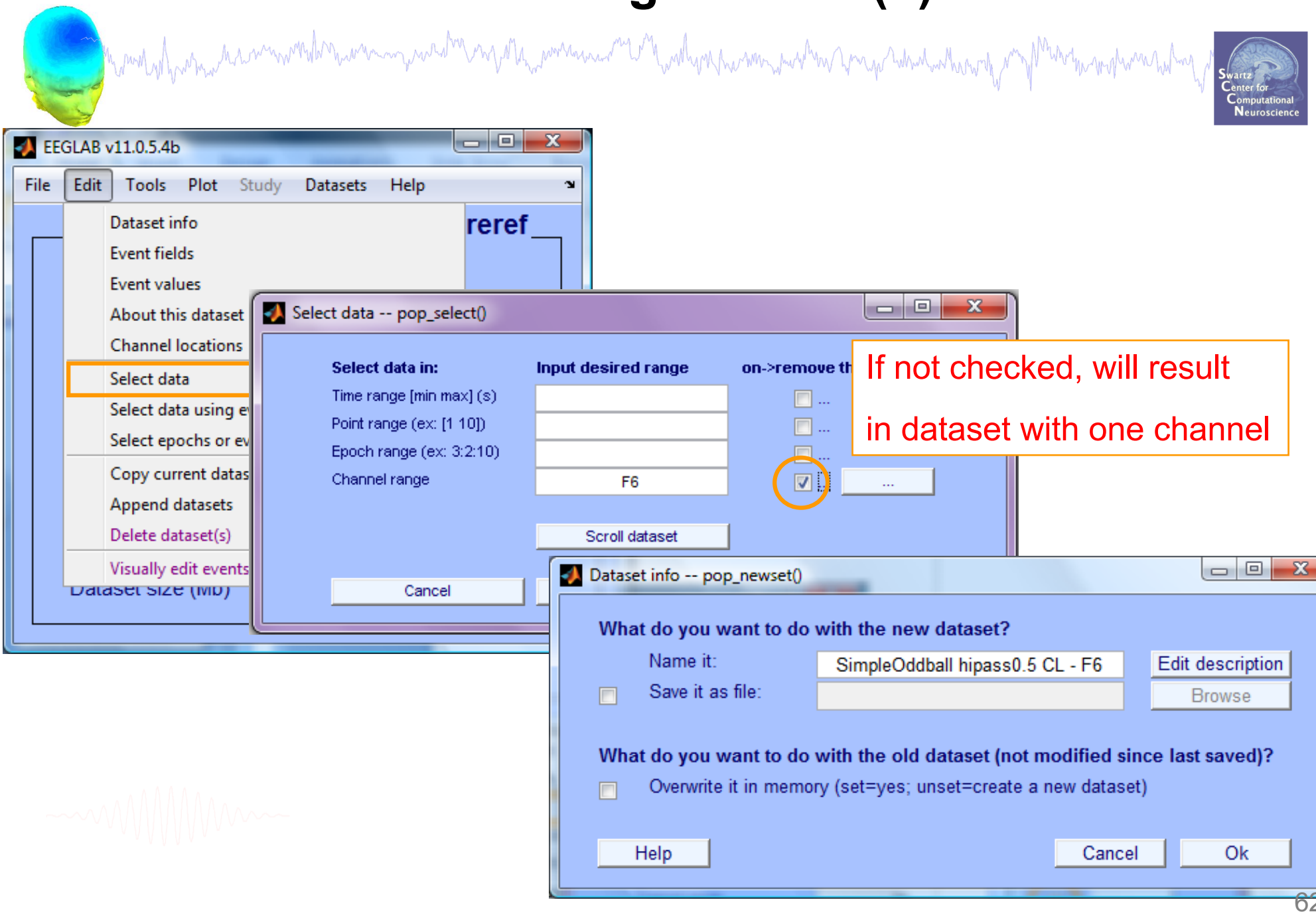




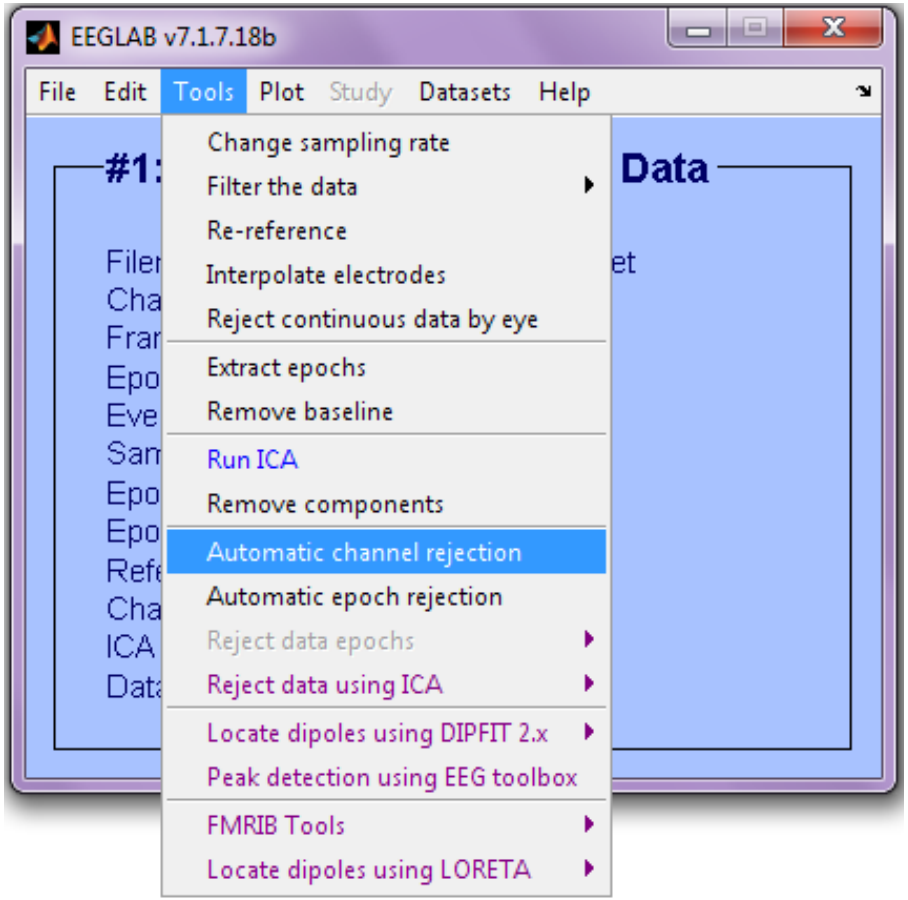


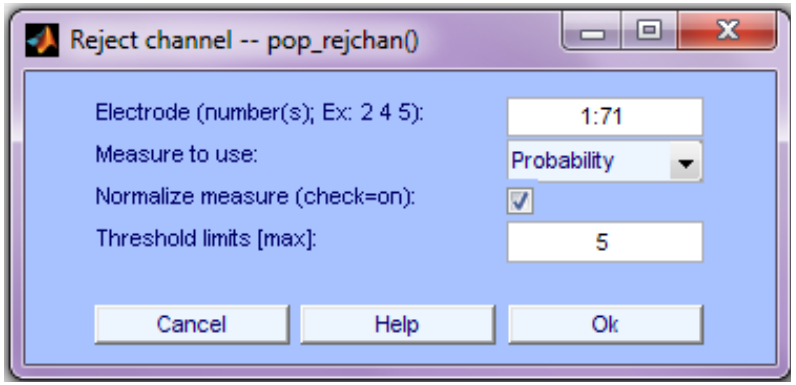


Removing channel(s)



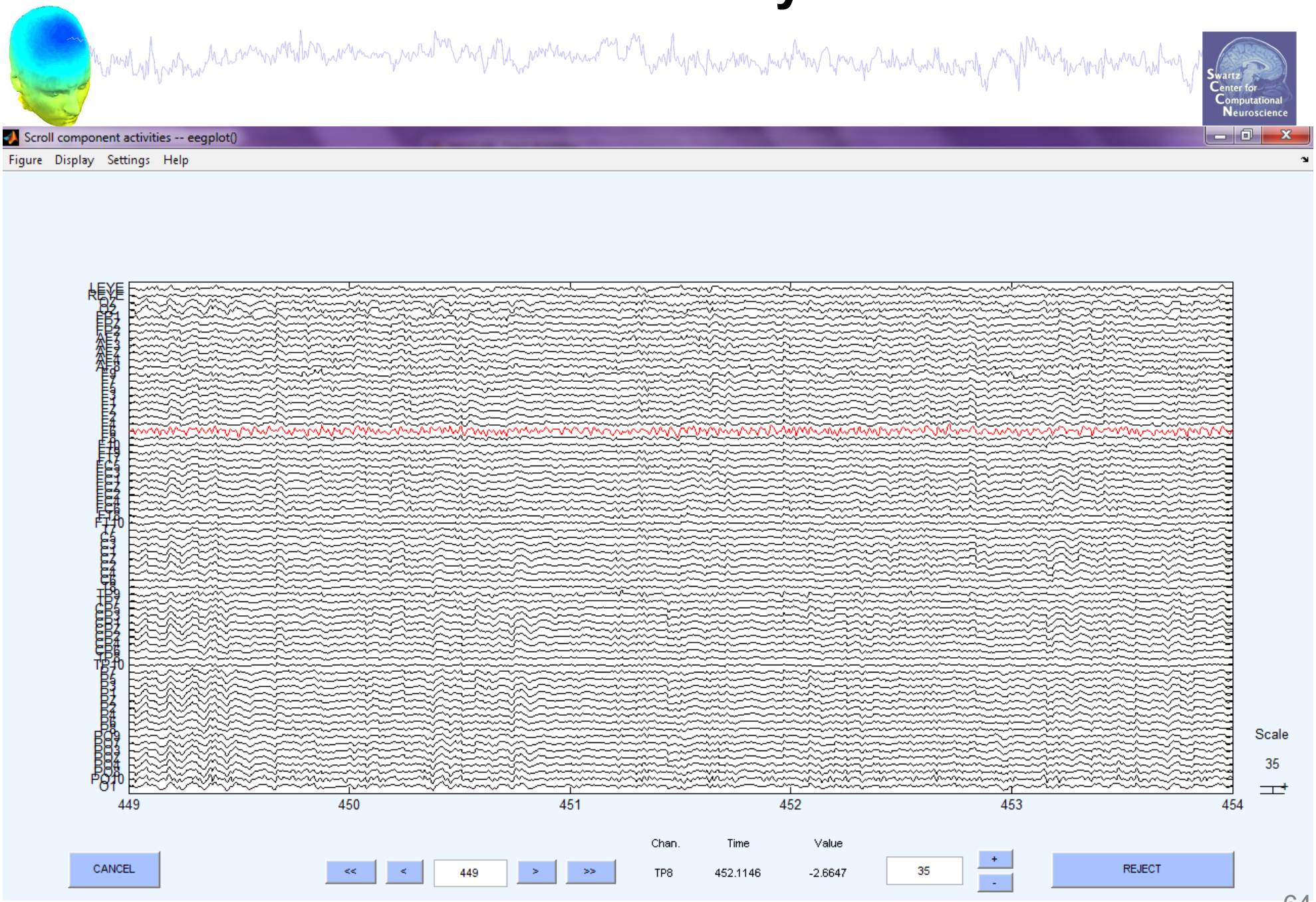
Auto-detection of noisy channels



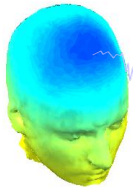


See also clean_rawdata plugin of EEGLAB

Auto-detected noisy channel

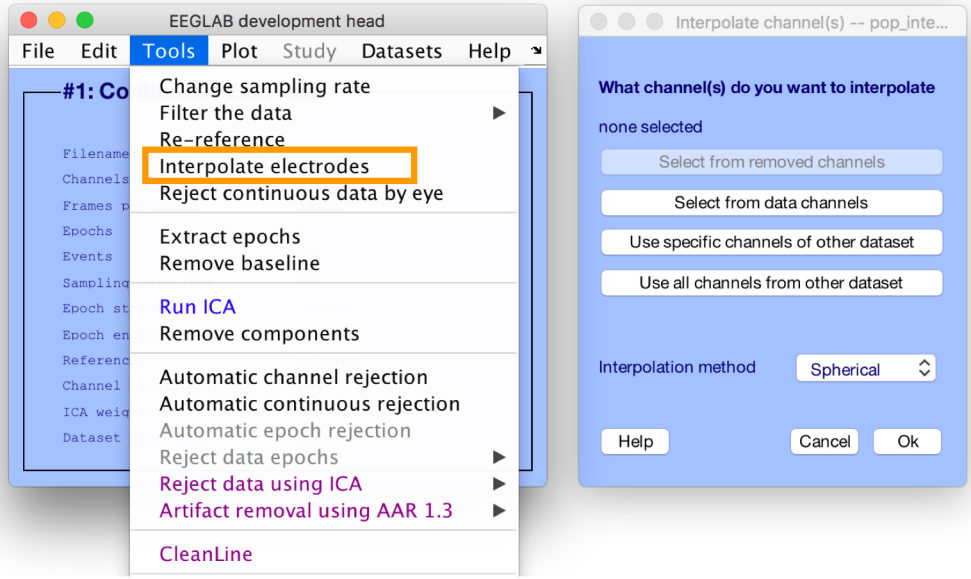


Removed channel(s)

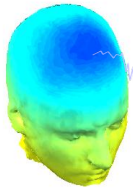


- In EEGLAB, removed channels are not only labeled for rejection, they are actually removed from the data.

- Interpolating channels instead of removing them?



Pre-processing pipeline



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

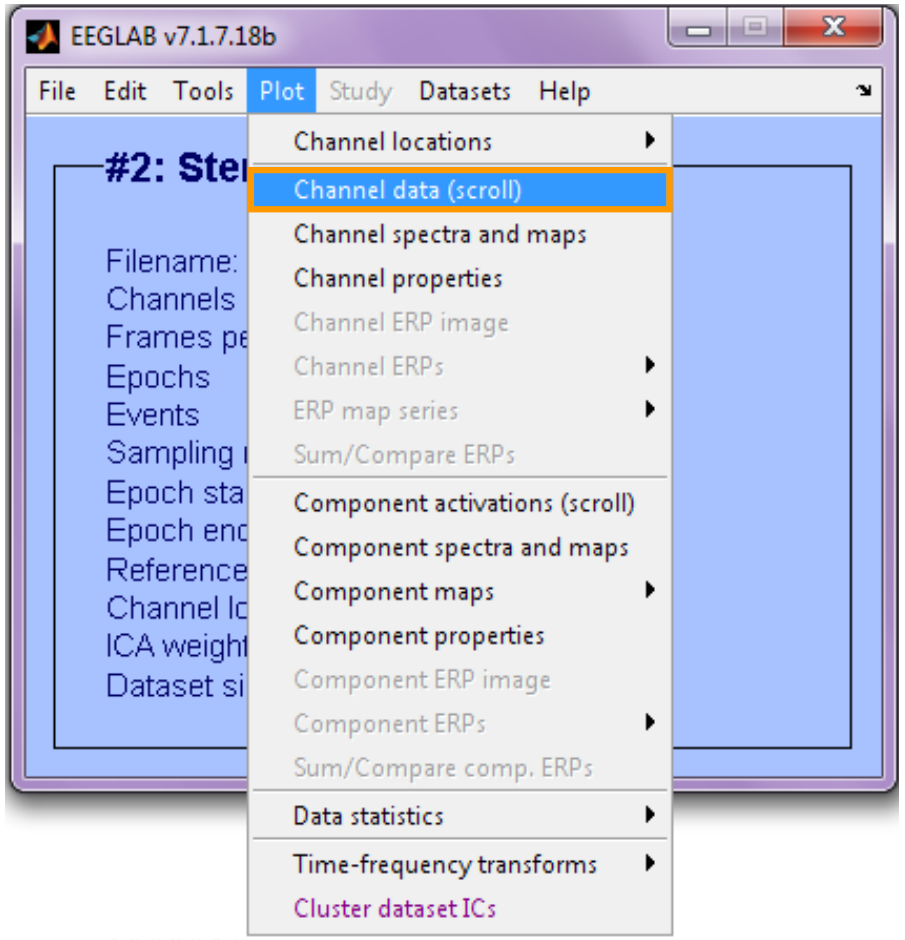
Reject large artifact time points

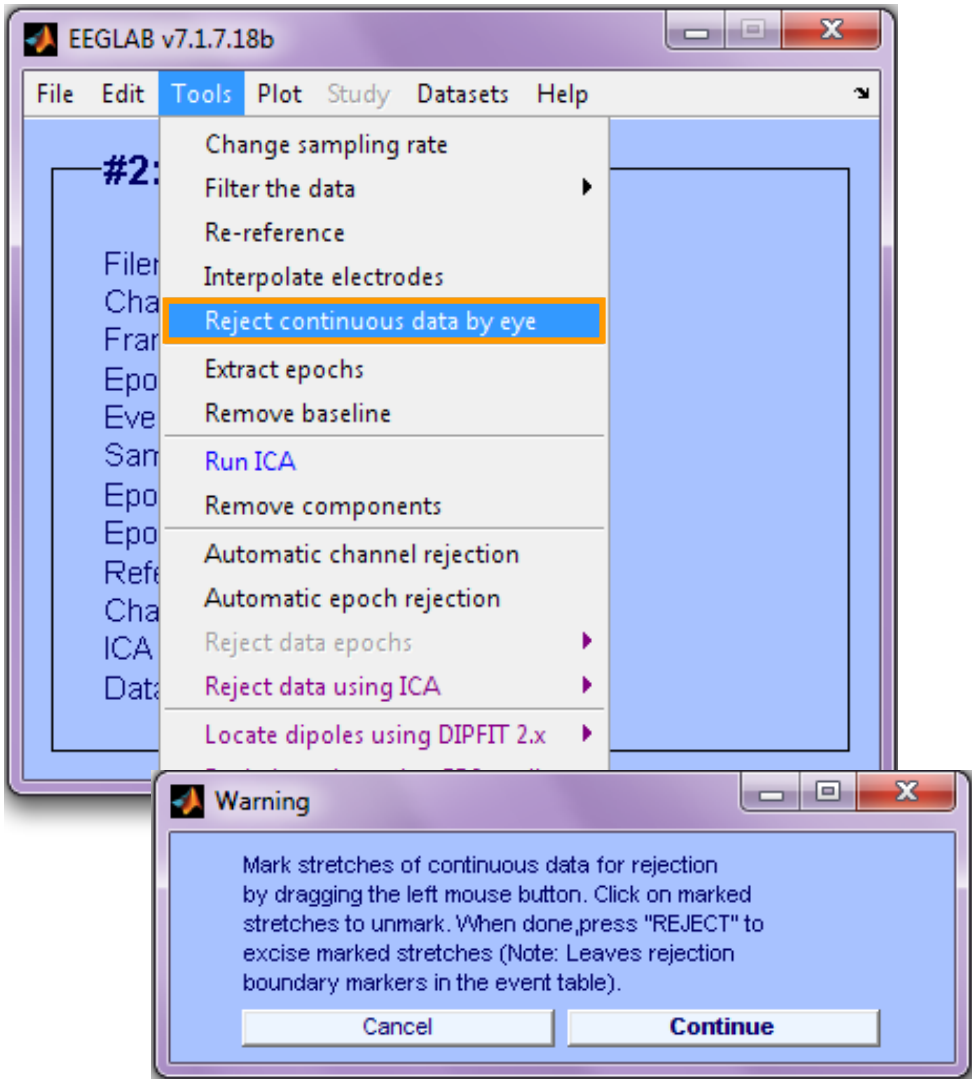
Run ICA and reject components

Done

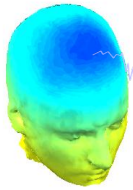
Reject continuous data

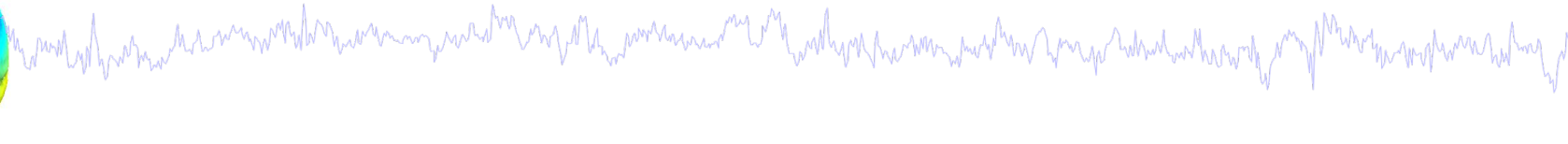
Equivalent





Reject continuous data





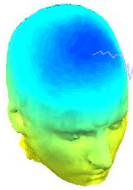
Swartz Center for Computational Neuroscience

Scroll channel activities -- eegplot()

Figure Display Settings Help

Click and drag with mouse over noisy data to reject

Rejecting data for ICA

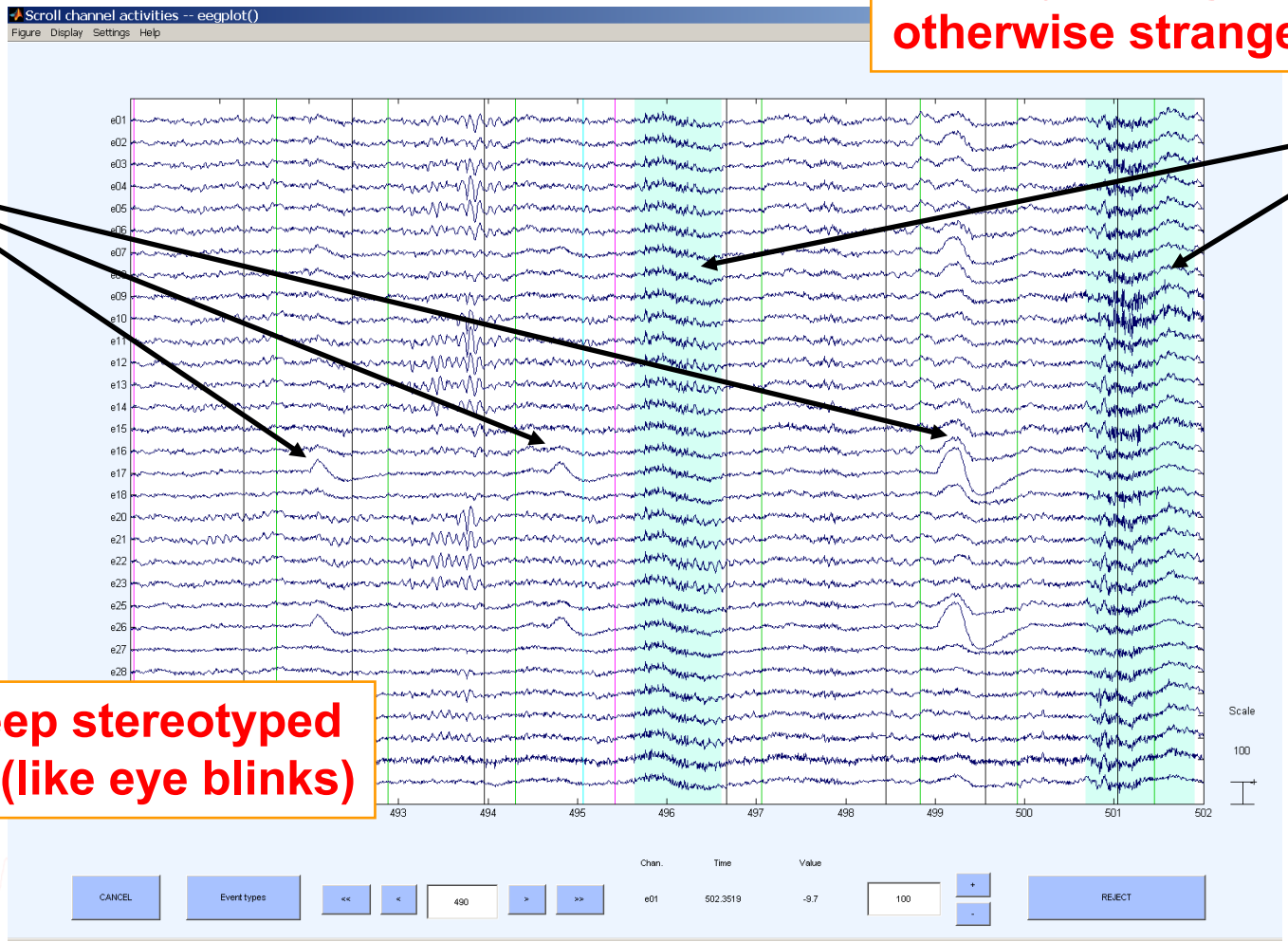


To prepare data for ICA:

Reject large muscle or otherwise strange events...

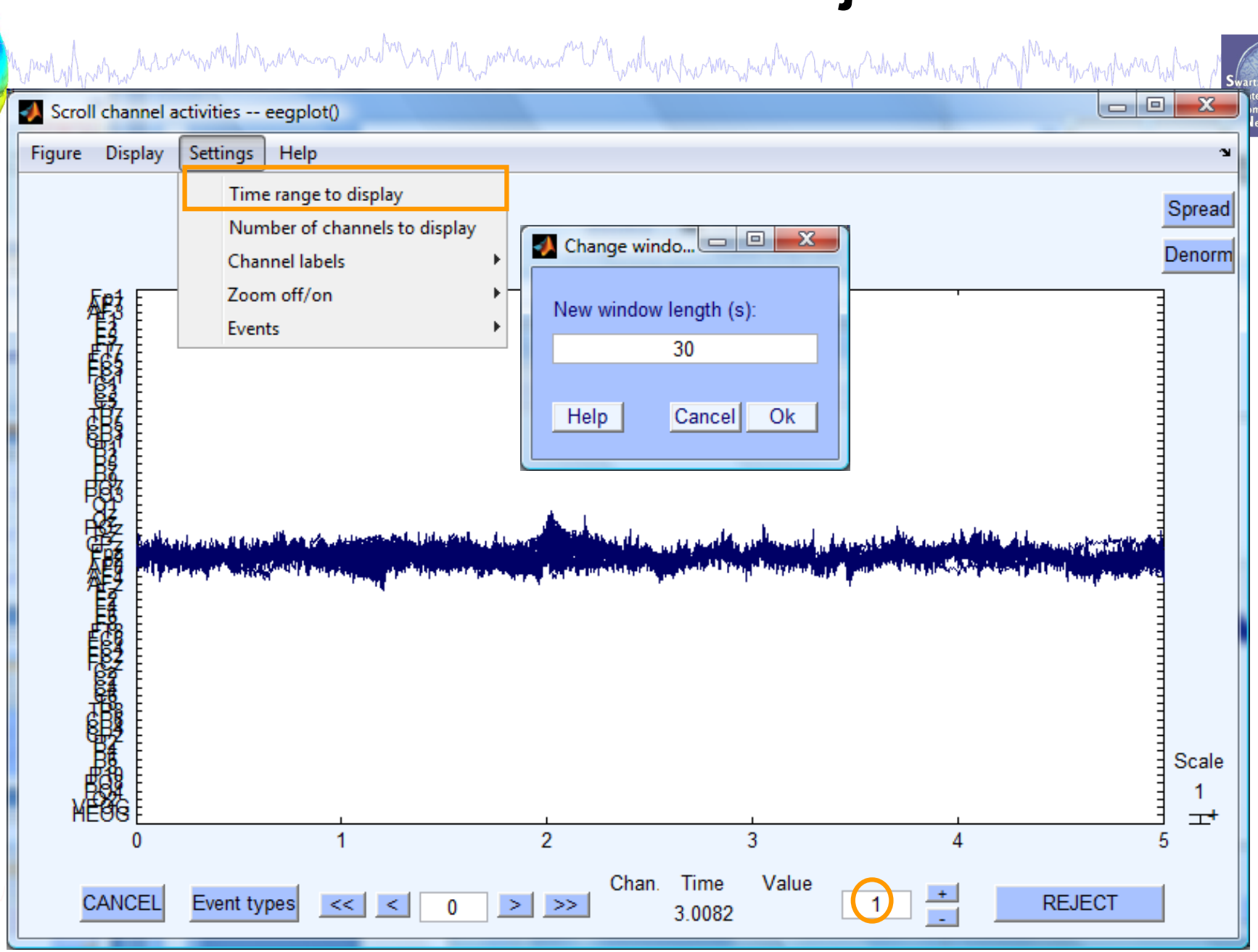
Keep

Reject

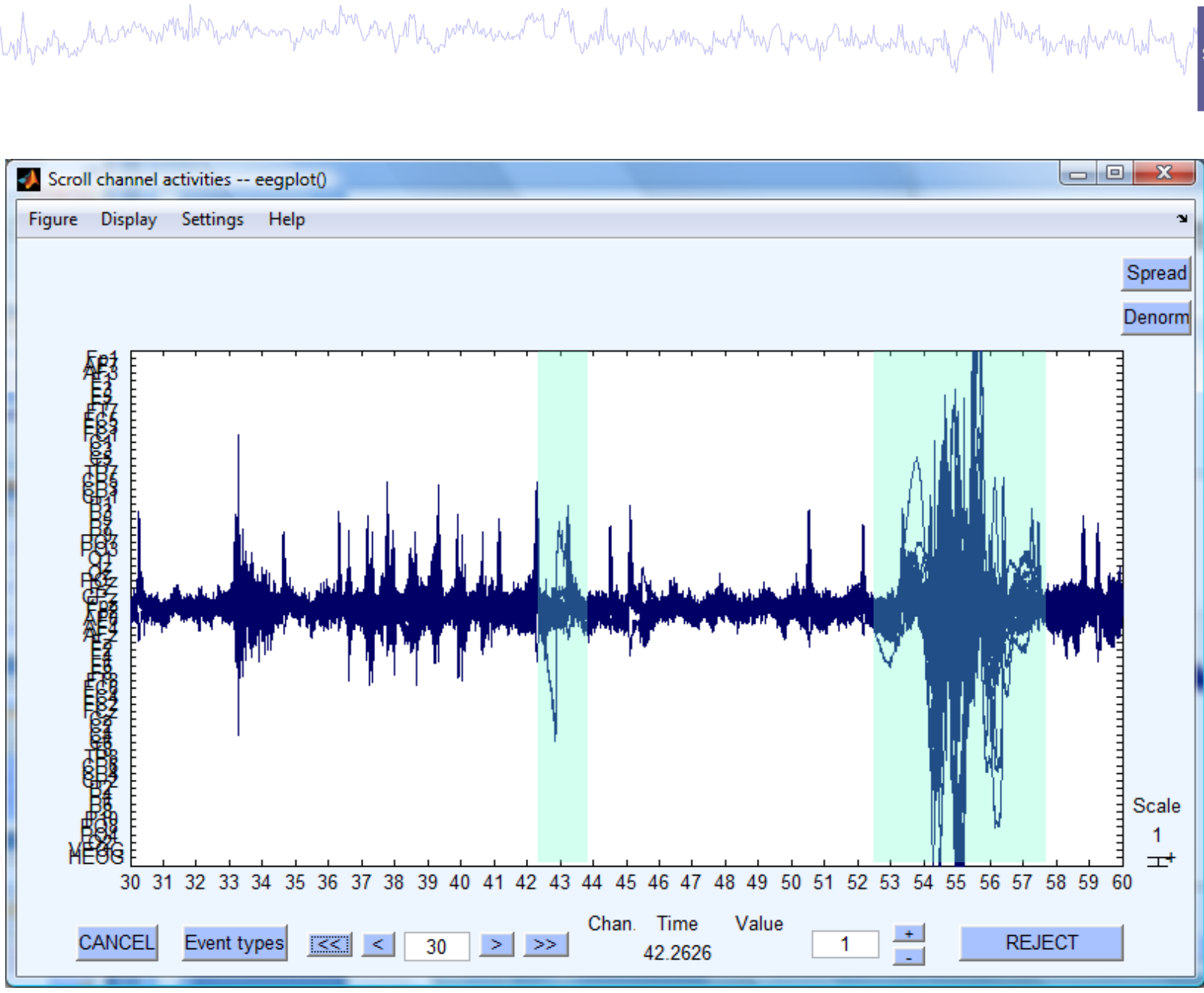


... but keep stereotyped artifacts (like eye blinks)

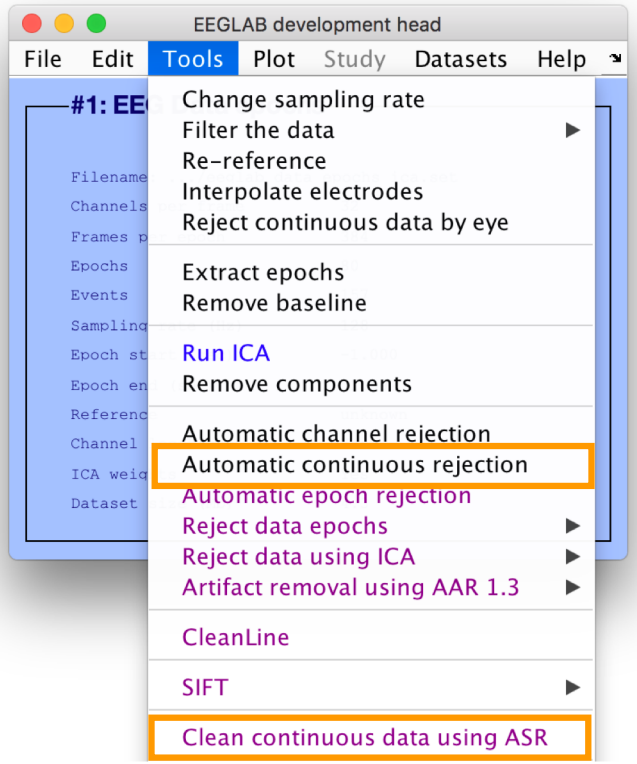
Fast manual artifact rejection

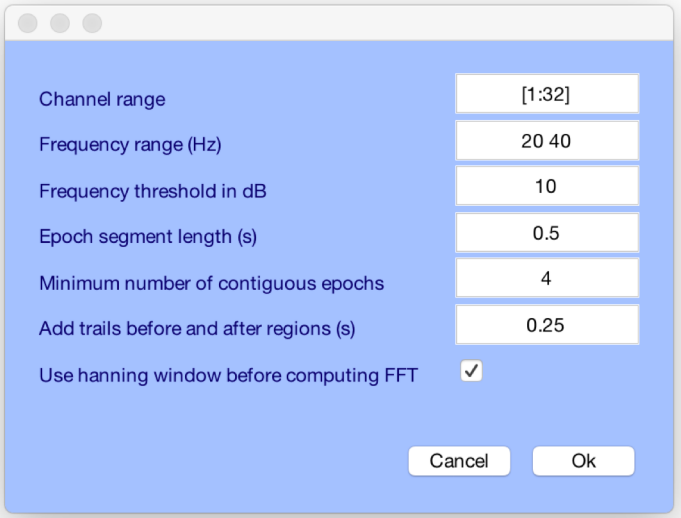


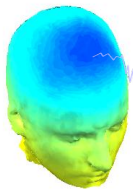
Fast manual artifact rejection



Automatic rejection of continuous data

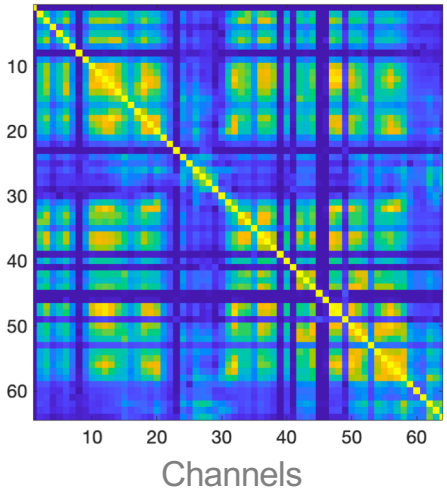




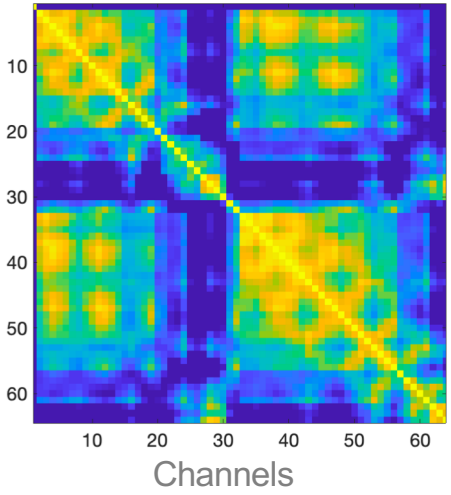


Pairwise correlation to find bad channels

Bad data



Good data



ASR finds and reconstructs bad portions of data

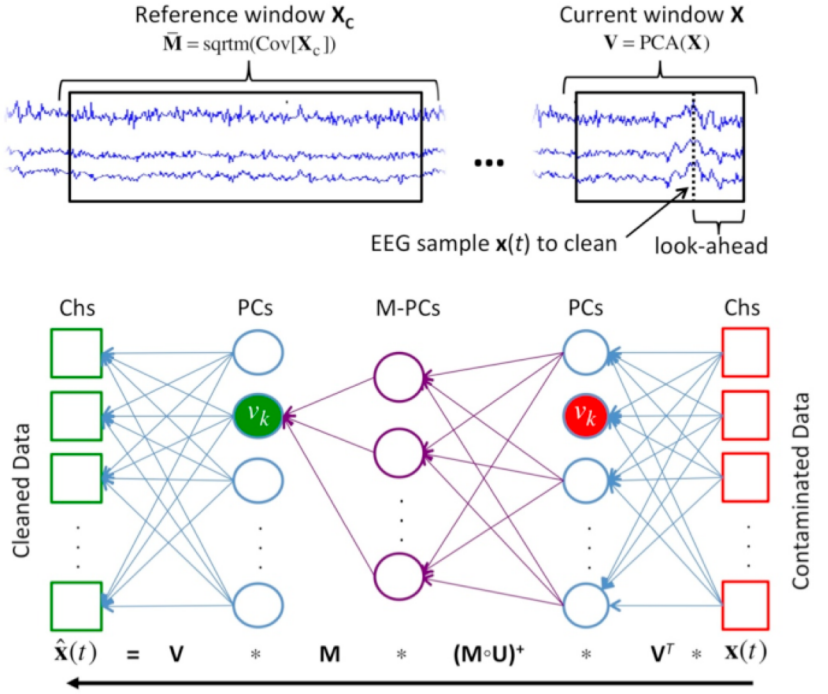
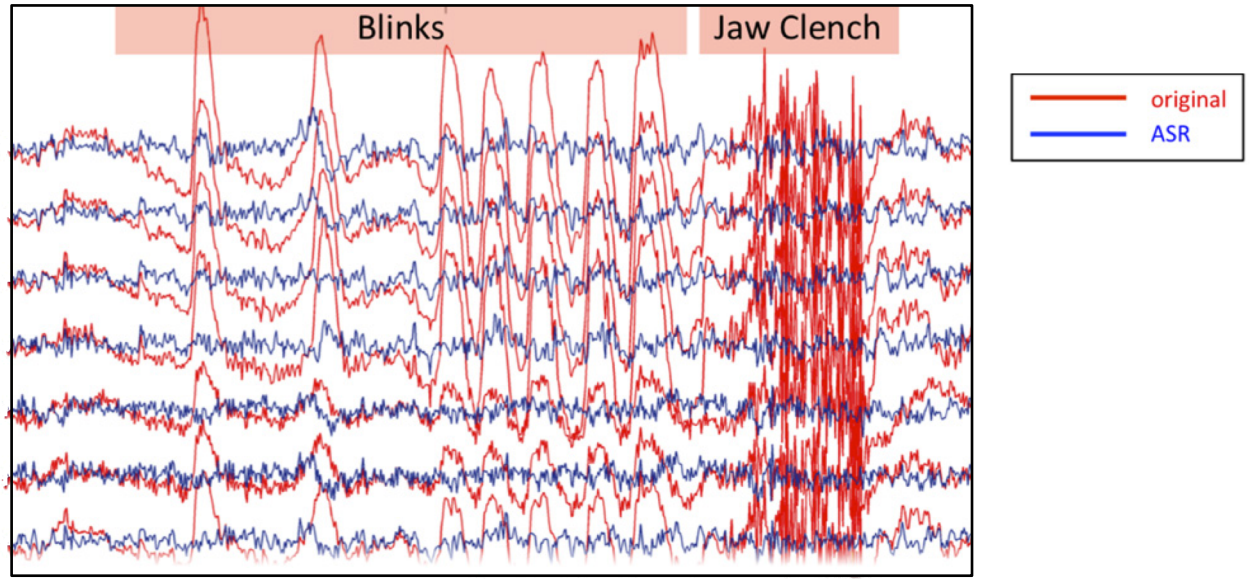


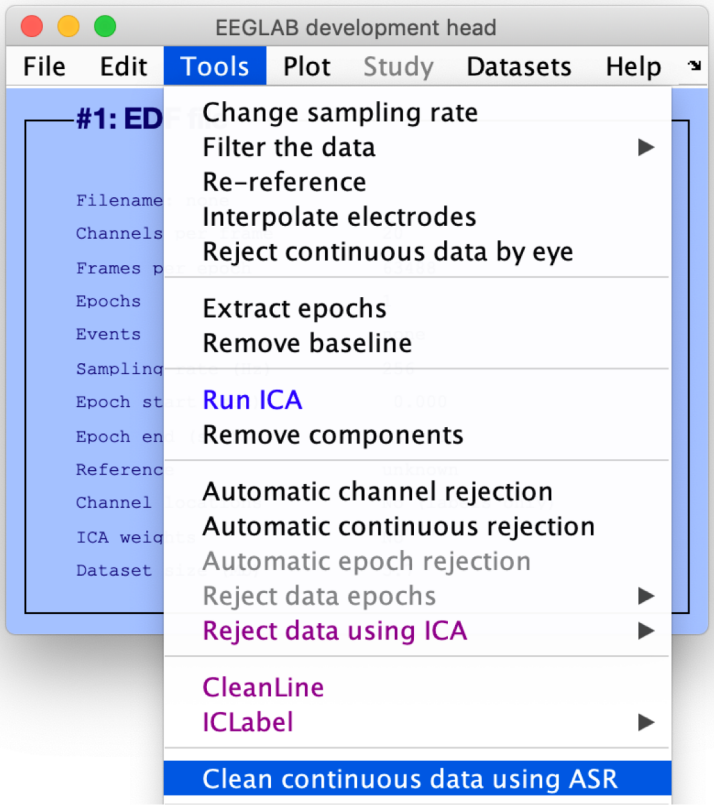
Fig. 3. The Artifact Subspace Reconstruction method. High-variance

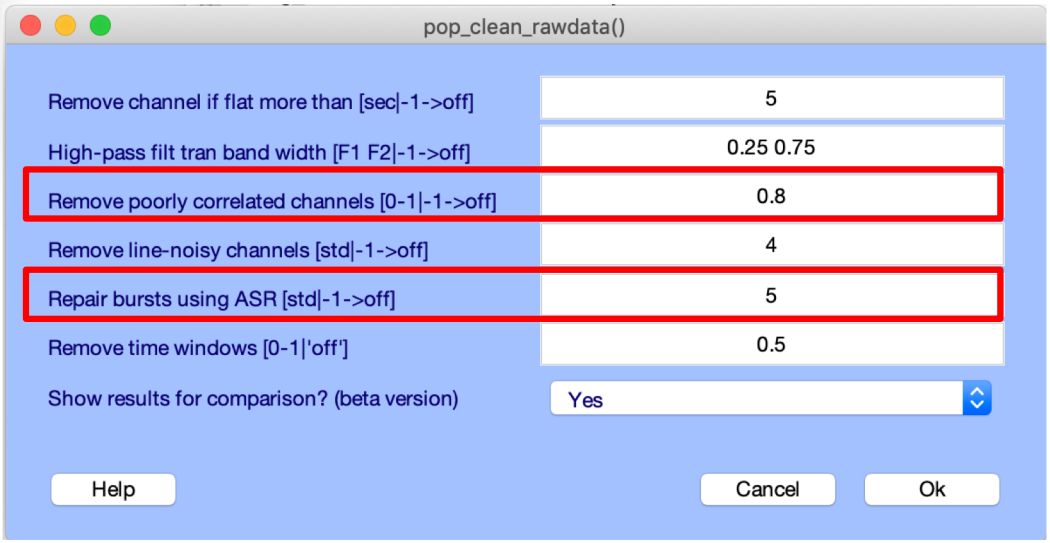
Tim R. Mullen, Christian Kothe, et al.(2015) Real-time neuroimaging and cognitive monitoring using wearable dry EEG. Published in IEEE Transactions on Biomedical Engineering. DOI:10.1109/TBME.2015.2481482



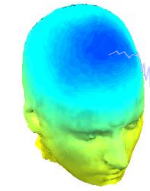
Validation: Chang CY, Hsu SH, Pion-Tonachini L, Jung TP. Evaluation of Artifact Subspace Reconstruction for Automatic EEG Artifact Removal. Conf Proc IEEE Eng Med Biol Soc. 2018 Jul;2018:1242-1245. doi: 10.1109/EMBC.2018.8512547.

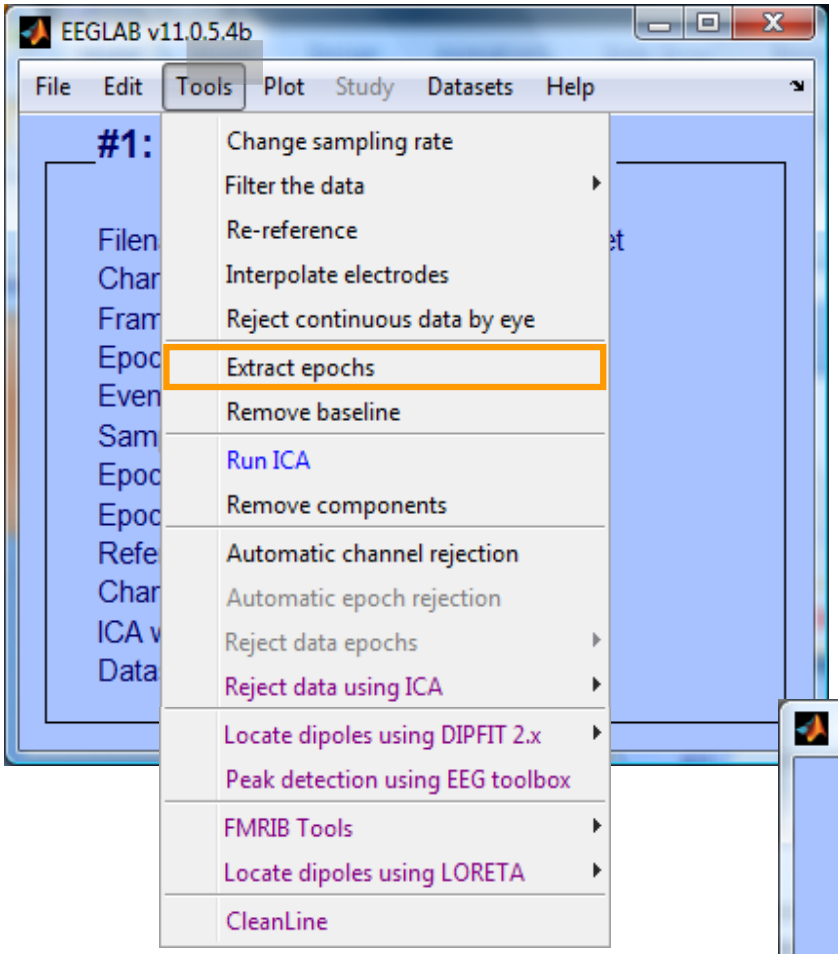
Variation: Sarah Blum*, Nadine S. J. Jacobsen, Martin G. Bleichner and Stefan Debener (2019) A Riemannian Modification of Artifact Subspace Reconstruction for EEG Artifact Handling. Front. Hum. Neurosci., https://doi.org/10.3389/fnhum.2019.00141.

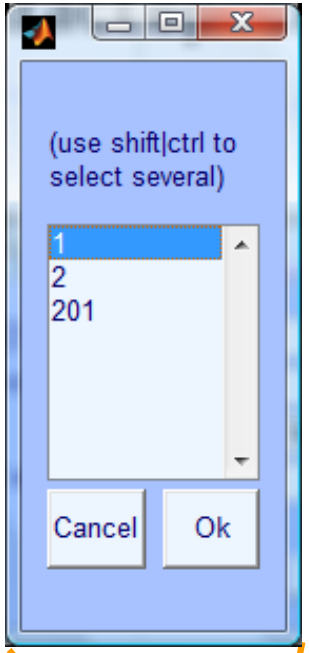

EEGLAB development head
File
Edit
Tools
Plot
Study
Datasets
Help
#1: ED
Filename
Channels
Frames p
Epochs
Events
Samplinq
Epoch st
Epoch en
Referenc
Channel
ICA weiq
Dataset
Change sampling rate
Filter the data
Re-reference
Interpolate electrodes
Reject continuous data by eye
Extract epochs
Remove baseline
Run ICA
Remove components
Automatic channel rejection
Automatic continuous rejection
Automatic epoch rejection
Reject data epochs
Reject data using ICA
CleanLine
ICLabel
Clean continuous data using ASR

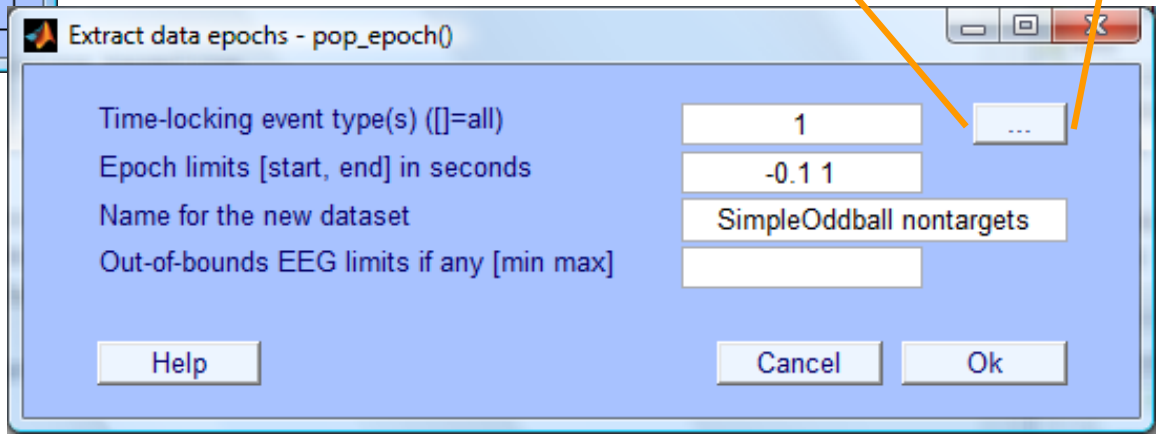

pop_clean_rawdata()
Remove channel if flat more than [sec|-1->off]
5
High-pass filt tran band width [F1 F2|-1->off]
0.25 0.75
Remove poorly correlated channels [0-1|-1->off]
0.8
Remove line-noisy channels [std|-1->off]
4
Repair bursts using ASR [std|-1->off]
5
Remove time windows [0-1|'off']
0.5
Show results for comparison? (beta version)
Yes
Help
Cancel
Ok

Extract epochs

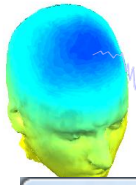


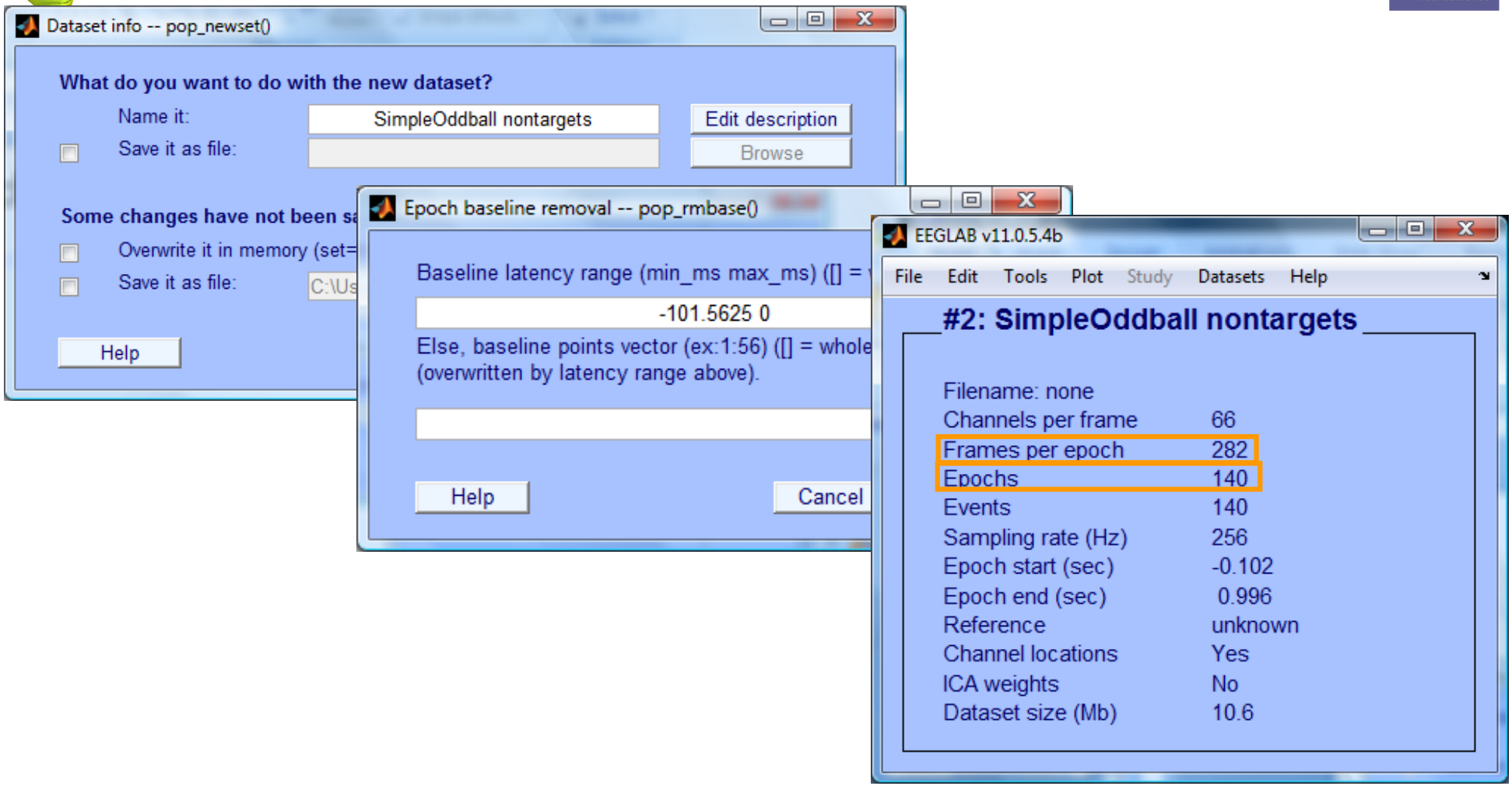




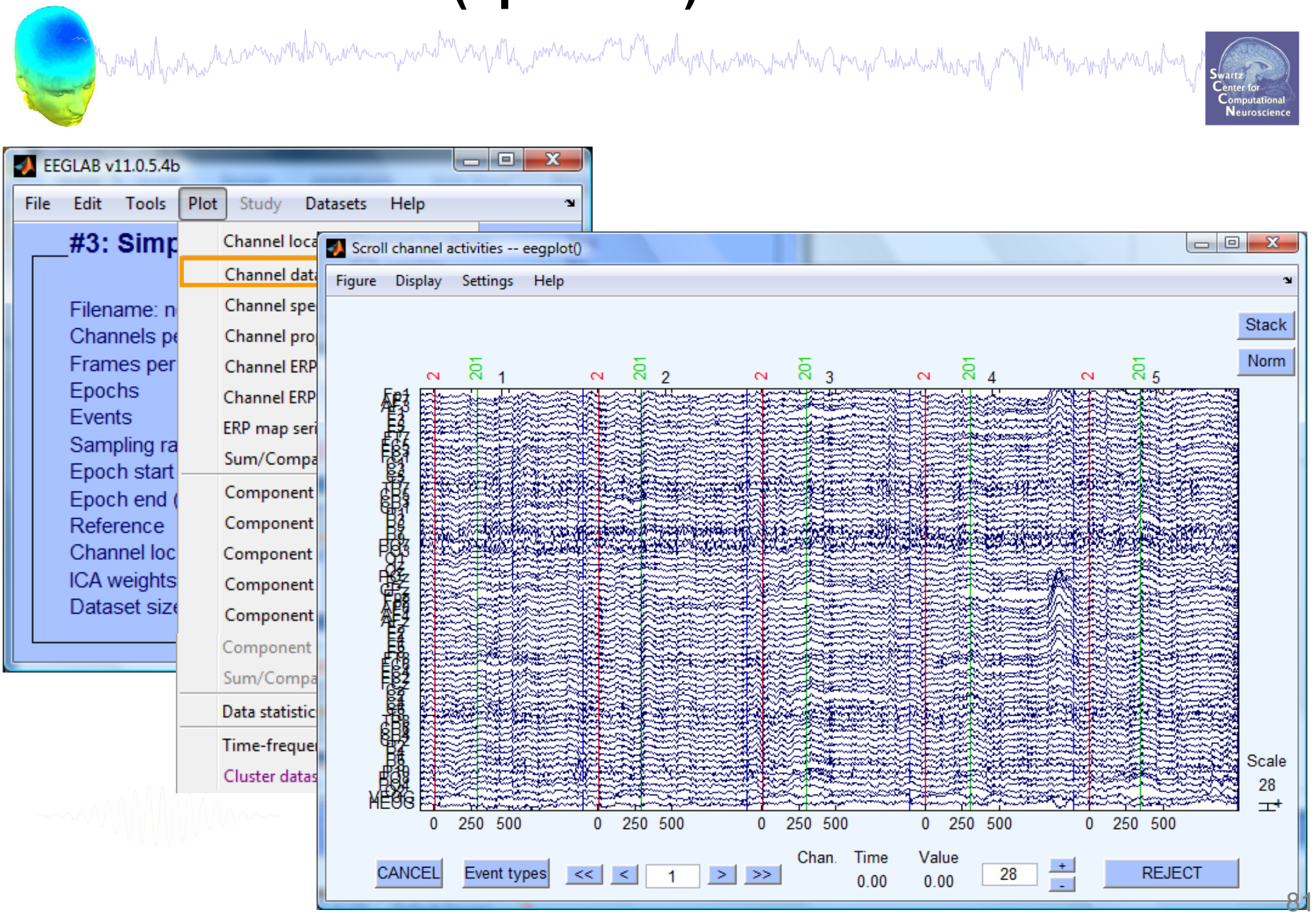


Extract epochs

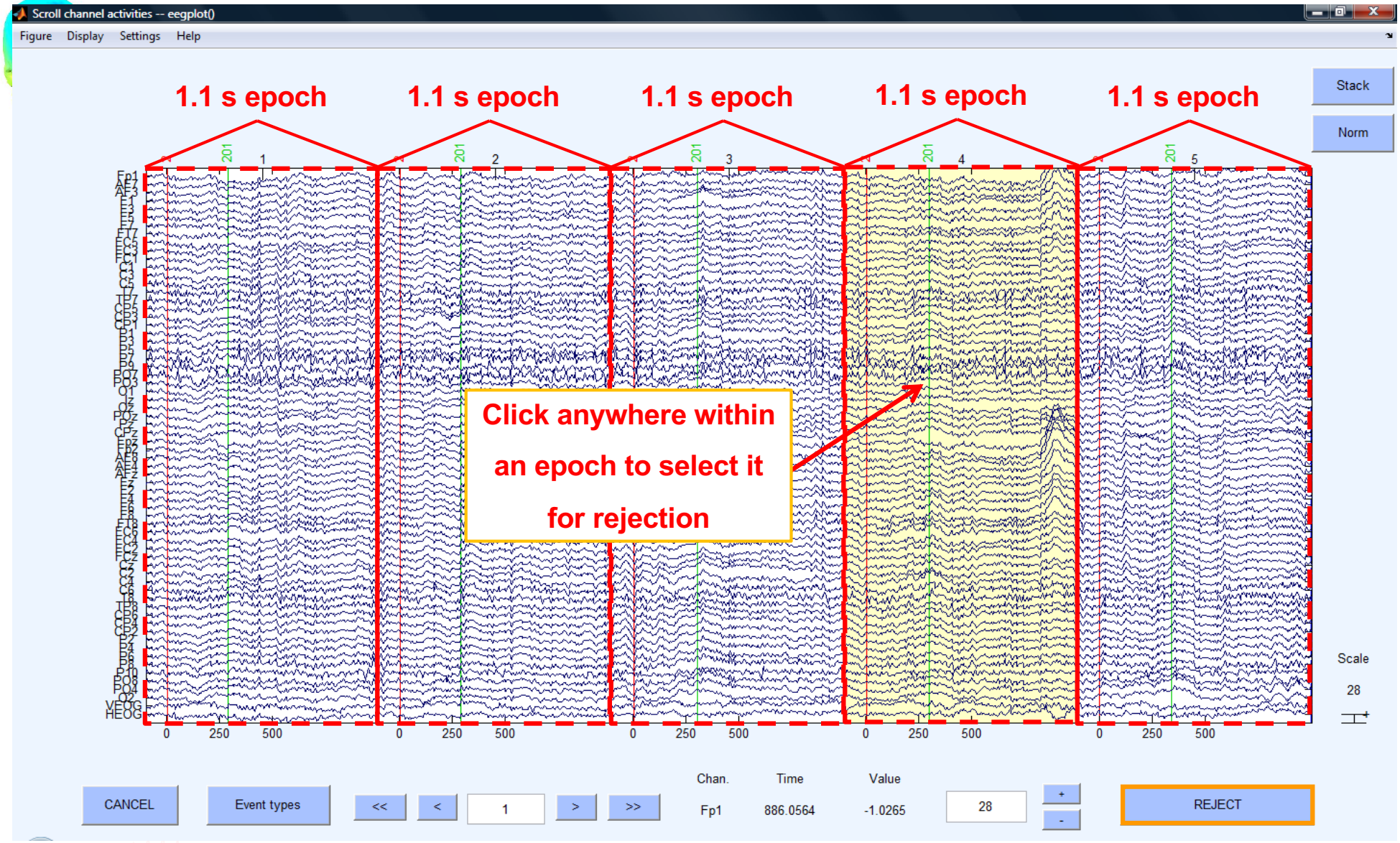




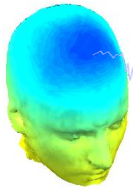
Scroll (epoched) channel data

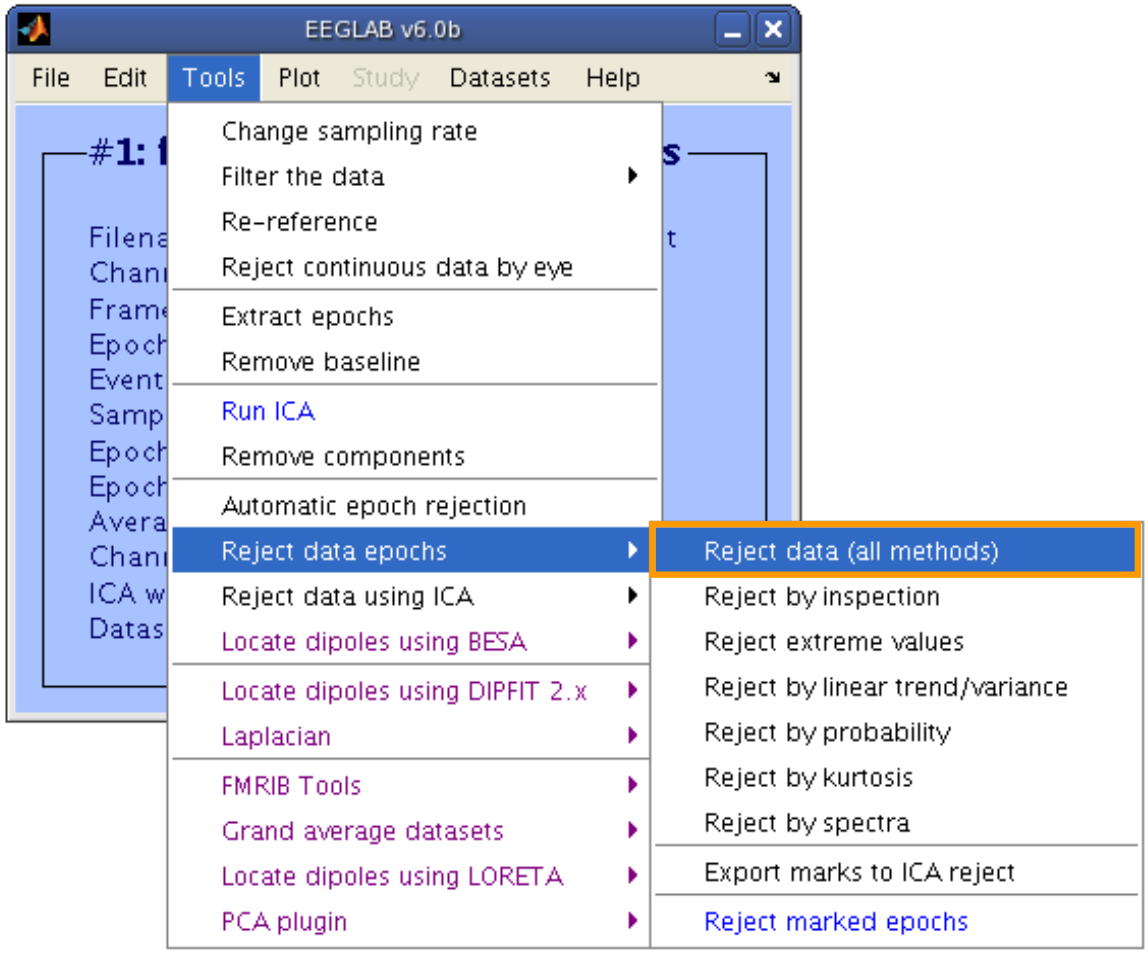


Reject epochs with artifact

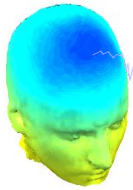


Reject data epochs





Reject data epochs



visual inspection

probability

Reject trials using data statistics - pop_rejmenu()

Mark trials by appearance | Scroll Data | Marked trials 0

Find abnormal values

Upper limit(s) (uV)	25	Lower limit(s) (uV)	-25
Start time(s) (ms)	-1000	Ending time(s) (ms)	1996
Electrode(s)	1:31	Currently marked trials	0
Calc / Plot			Help

Find abnormal trends

Max slope (uV/epoch)	50	R-squared limit (0 to 1)	0.3
Electrode(s)	1:31	Currently marked trials	0
Calc / Plot			Help

Find improbable data

Single-channel limit (std. dev.)	5	All channels limit (std. dev.)	5
Electrode(s)	1:31	Currently marked trials	0
Calculate	Scroll Data	Plot	Help

Find abnormal distributions

Single-channel limit (std. dev.)	5	All channels limit (std. dev.)	5
Electrode(s)	1:31	Currently marked trials	0
Calculate	Scroll Data	Plot	Help

Find abnormal spectra (slow)

Upper limit(s) (dB)	25	Lower limit(s) (dB)	-25
Low frequency(s) (Hz)	0	High frequency(s) (Hz)	50
Electrode(s)	1:31	Currently marked trials	0
Calc / Plot			Help

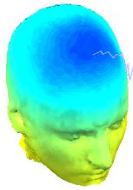
Plotting options

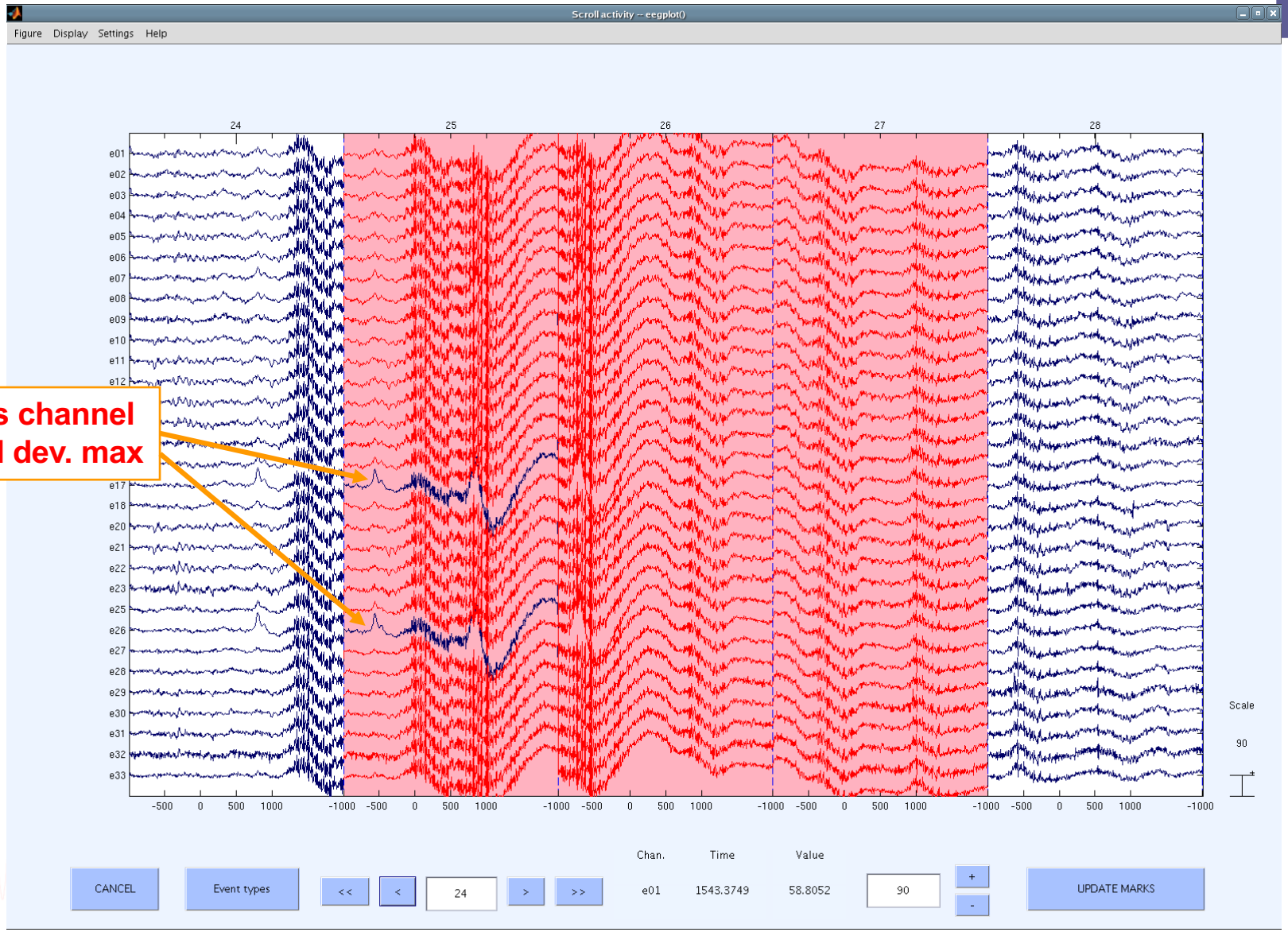
Show all trials marked for rejection by the measure selected above or checked below

☑ Abnormal appearance	☑ Abnormal values	☑ Abnormal trends
☑ Improbable epochs	☑ Abnormal distributions	☑ Abnormal spectra

Close (keep marks) | Clear all marks | Reject marked trials

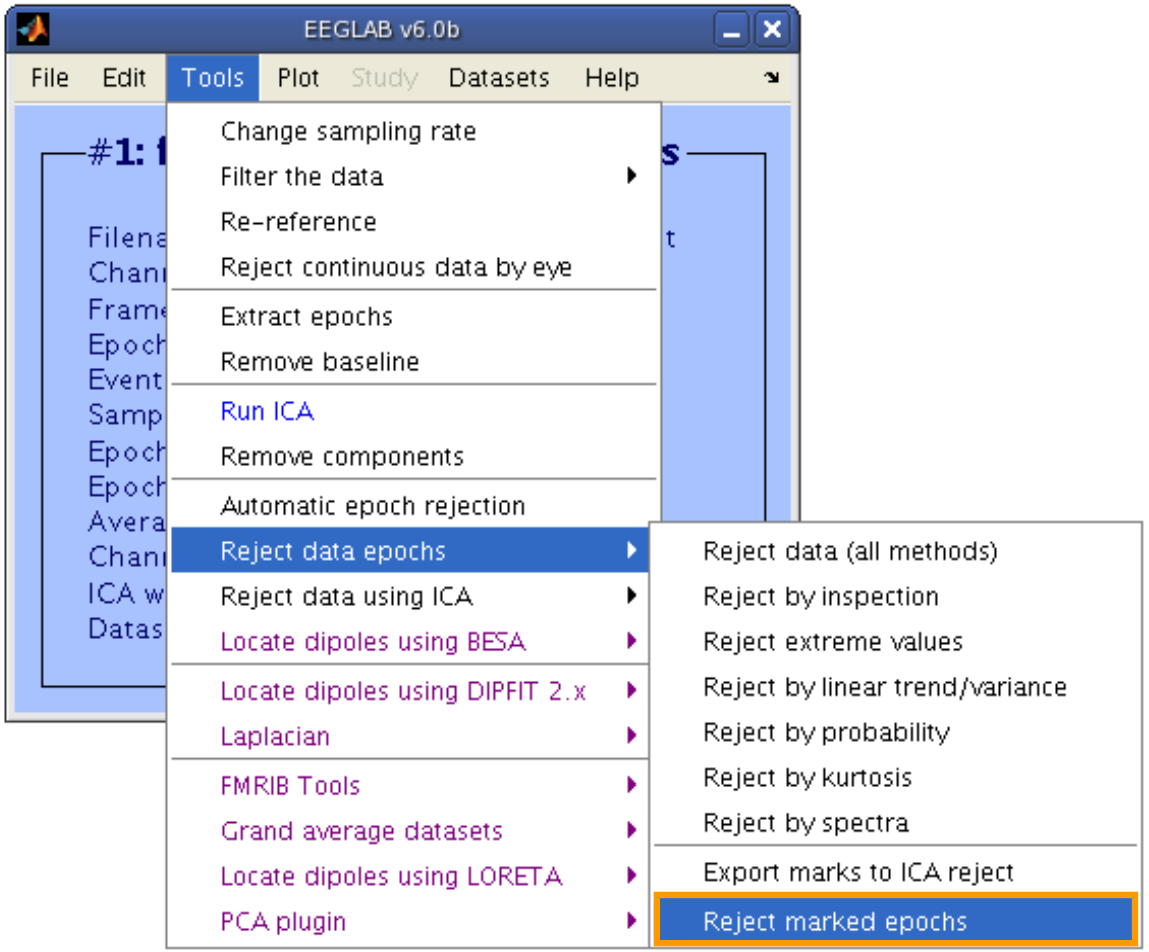
Reject data epochs





Exceeds channel standard dev. max

Reject data epochs



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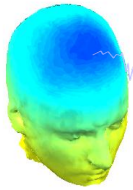

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