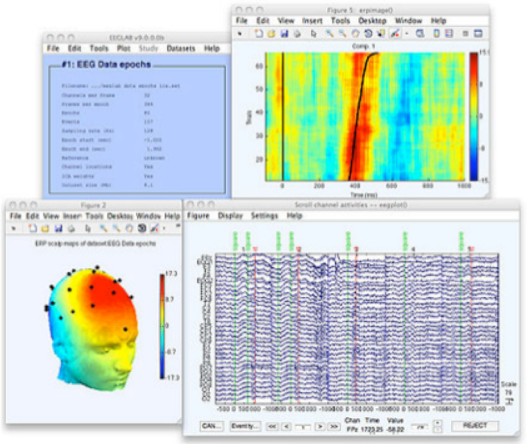
EEGLAB overview

EEGLAB history



1997 – EEG/ICA Toolbox (Salk Institute)

2001 – 1st EEGLAB for artifact rejection (Salk Institute)

2003 – 1st integrated EEGLAB issued to wide audience (Salk Institute)

2004 – 1st EEGLAB support from US. NIH and reference paper (UCSD)

2006 – 1st EEGLAB plug-ins, STUDY structure, and component clustering tools

2009+ – New associated toolboxes: NFT, SIFT, BCILAB, MPT,

2011 – EEGLAB, the most widely used EEG research environment

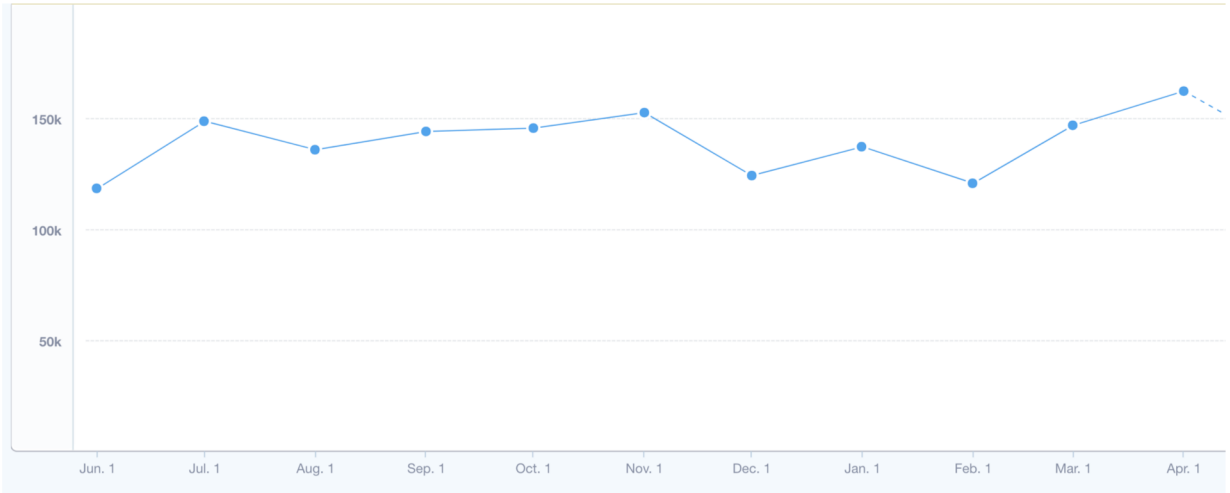
2014 – EEGLAB plugin manager

2018 – EEGLAB single trial and LIMO integration

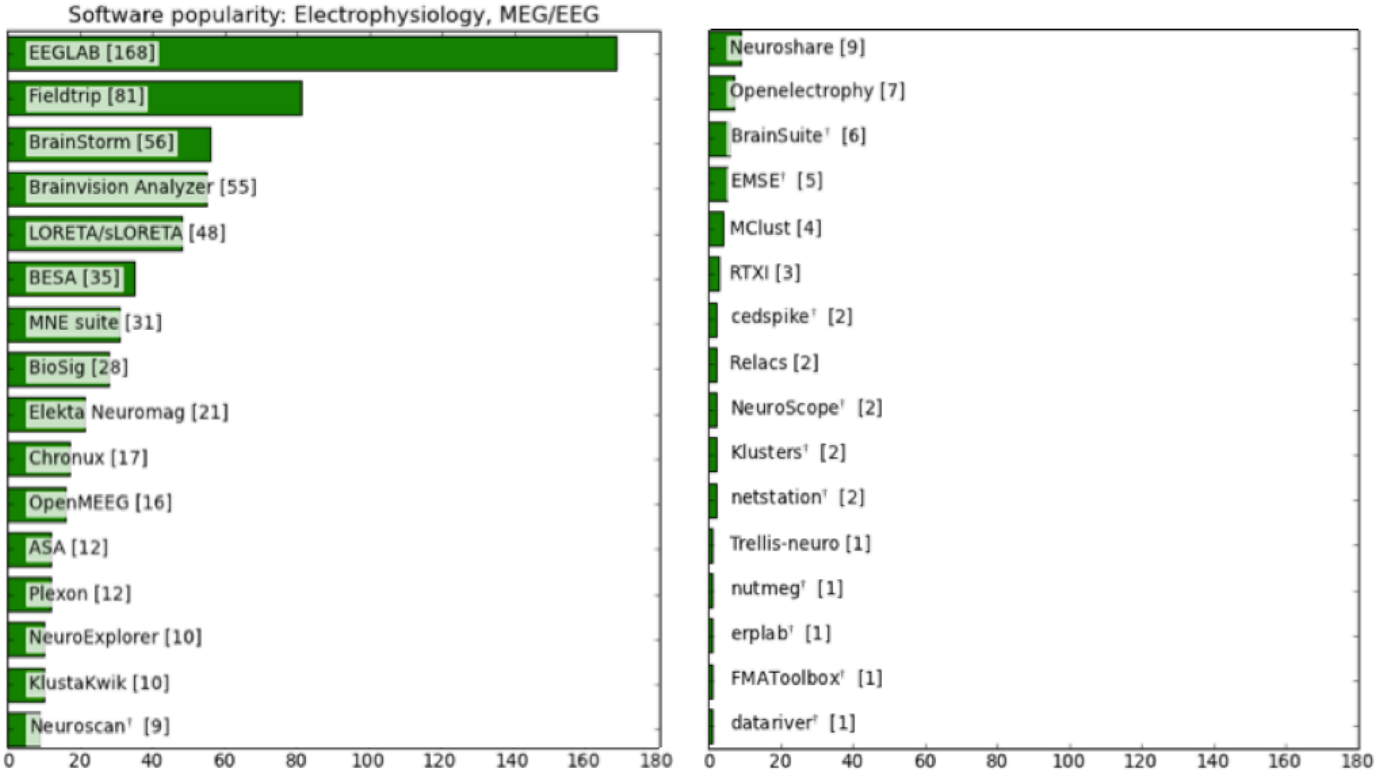
EEGLAB overview

- Collection of about 600 functions (70 000 lines of code)
- About 250 000 download over the past 10 years
- 6,500 users on the discussion list and 15,000 on the diffusion list
- NIH funding since 2003
- 75 plugins
- Supporting 288 million of dollars of research as of 2017

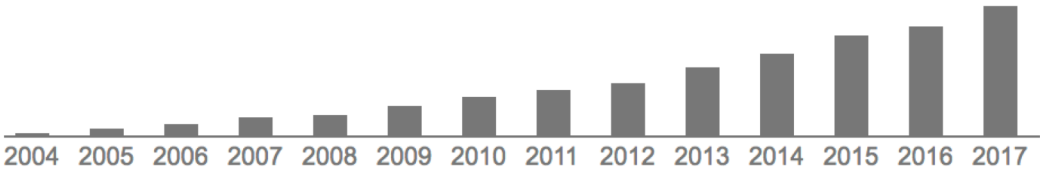
140,000 EEGLAB session/month (mixpanel)



Hanke & Helcencko, 2011, Frontier in Neuroinformatics



EEGLAB reference article
8524 citations (June 2018)

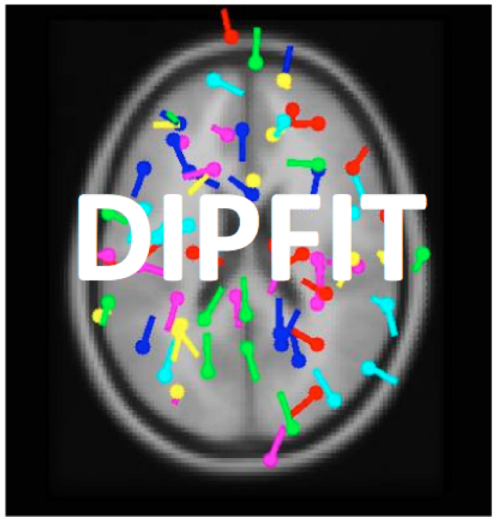


EEGLAB compared to other EEG software packages

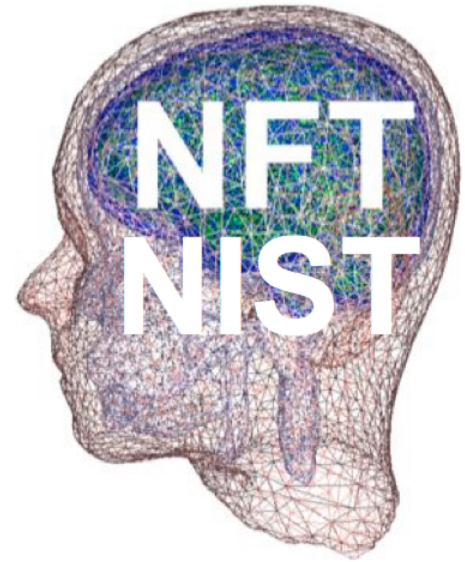
EEG Data Analysis Environments	EEGLAB	Fieldtrip	Brainstorm	BVA*	BESA	ERPLAB#	SPM§	Curry	ASA	EMSE
License (Open Source, Commercial)	Open	Open	Open	Com	Com	Open	Open	Com	Com	Com
User base***	&&&&&&&&&&&&	&&&&&	&&&	&&&	&&	&	&	&	&	&
Matlab based (Y/N)	Y	Y	Y	N	N	Y	Y	N	N	N
Time-freq. decomposition	Y	Y	N	Y	N	N	Y	N	N	N
Source localization capabilities	+++	++++	++++	+	++++		§	++++ +	++	++++
Plug-ins & scripting (Yes/No/Basic)	Y	Y	B	Y	B	B	B	B	?N	?N
Statistics (Yes/No/B=basic)	Y	Y	N	N	N	B	Y	N	N	N
ICA (Y/N/B=basic)	Y	Y**	N	B	B	N	N	B	?N	?
Group level analysis (Y/N/B=basic)	Y	B	Y	Y	Y	B	?	Y	Y	Y
Cloud & GPU computing	B	B	N	N	N	N	N	N	N	N

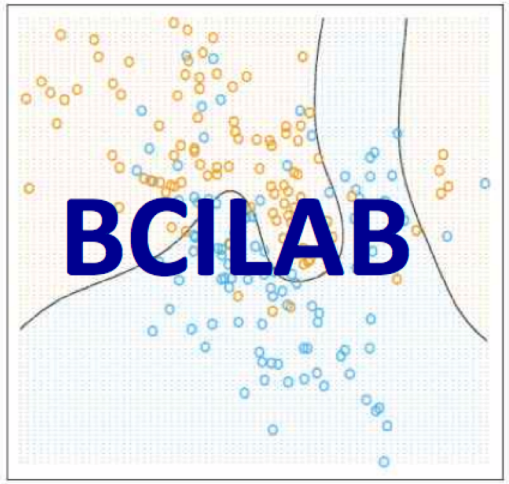
*Brain Vision Analyzer (Brain Products Inc.);
**Uses an EEGLAB function for ICA
***As per a 2011 survey by (Hanke et al., 2011)

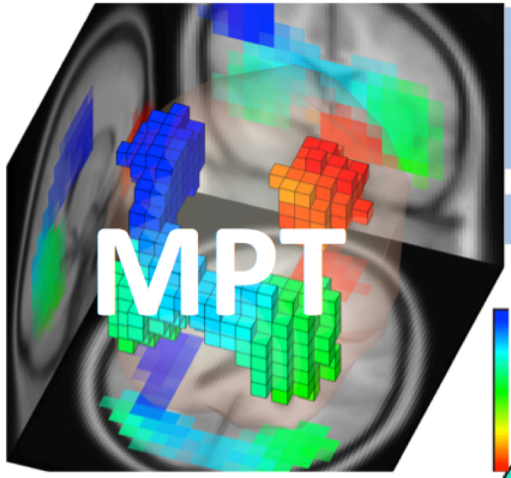
Built as a plug-in to EEGLAB for ERP research
§ SPM and DCM (Dynamical Causal Modeling) for ERPs

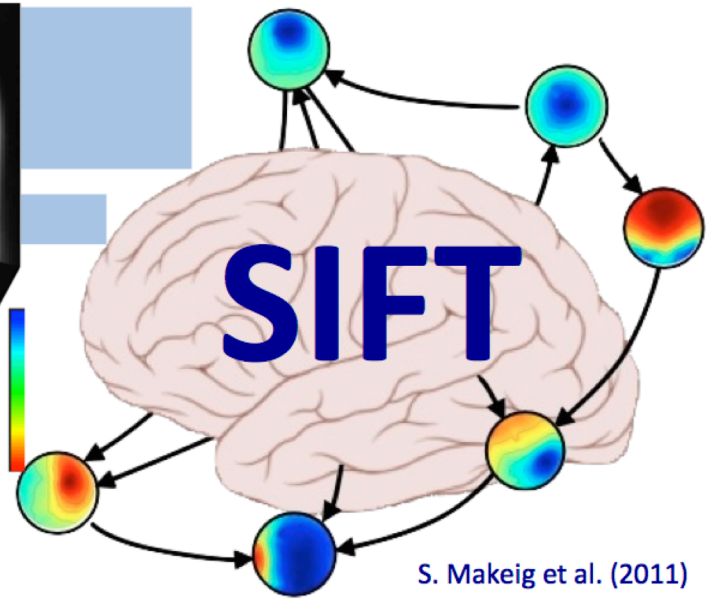


EEGLAB Plug-In Extensions

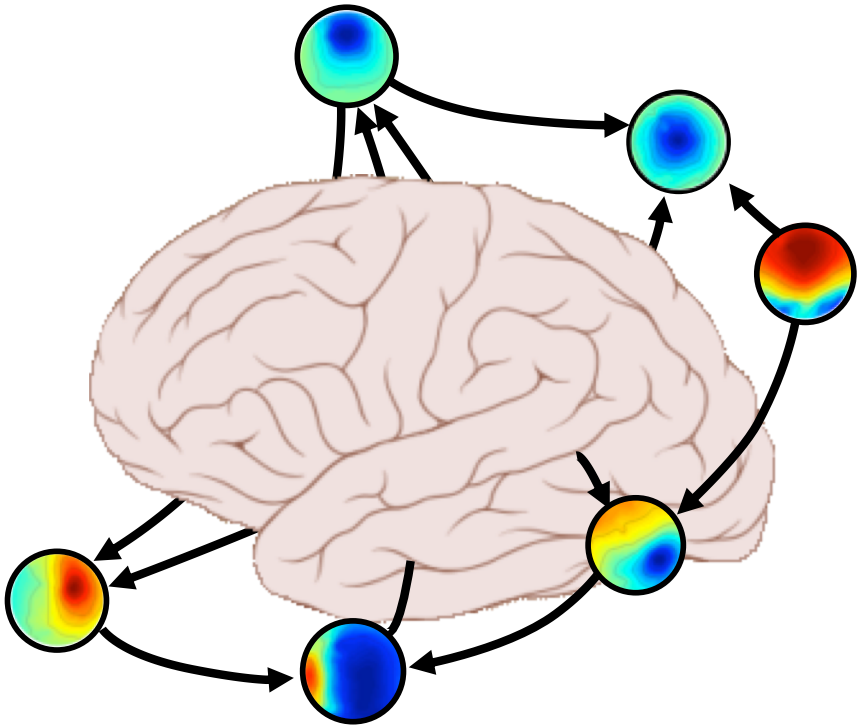






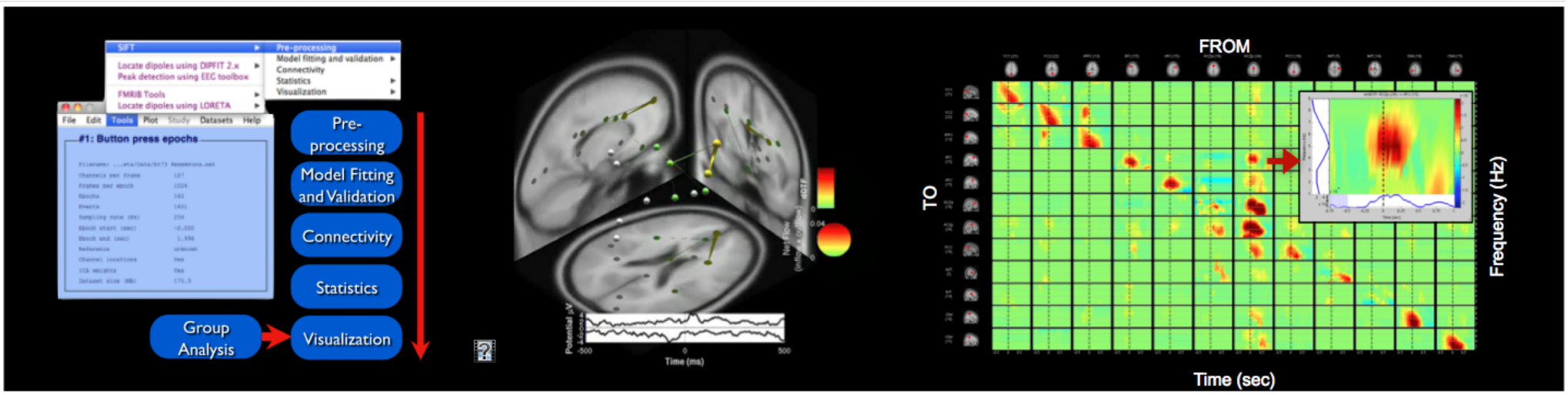


S. Makeig et al. (2011)

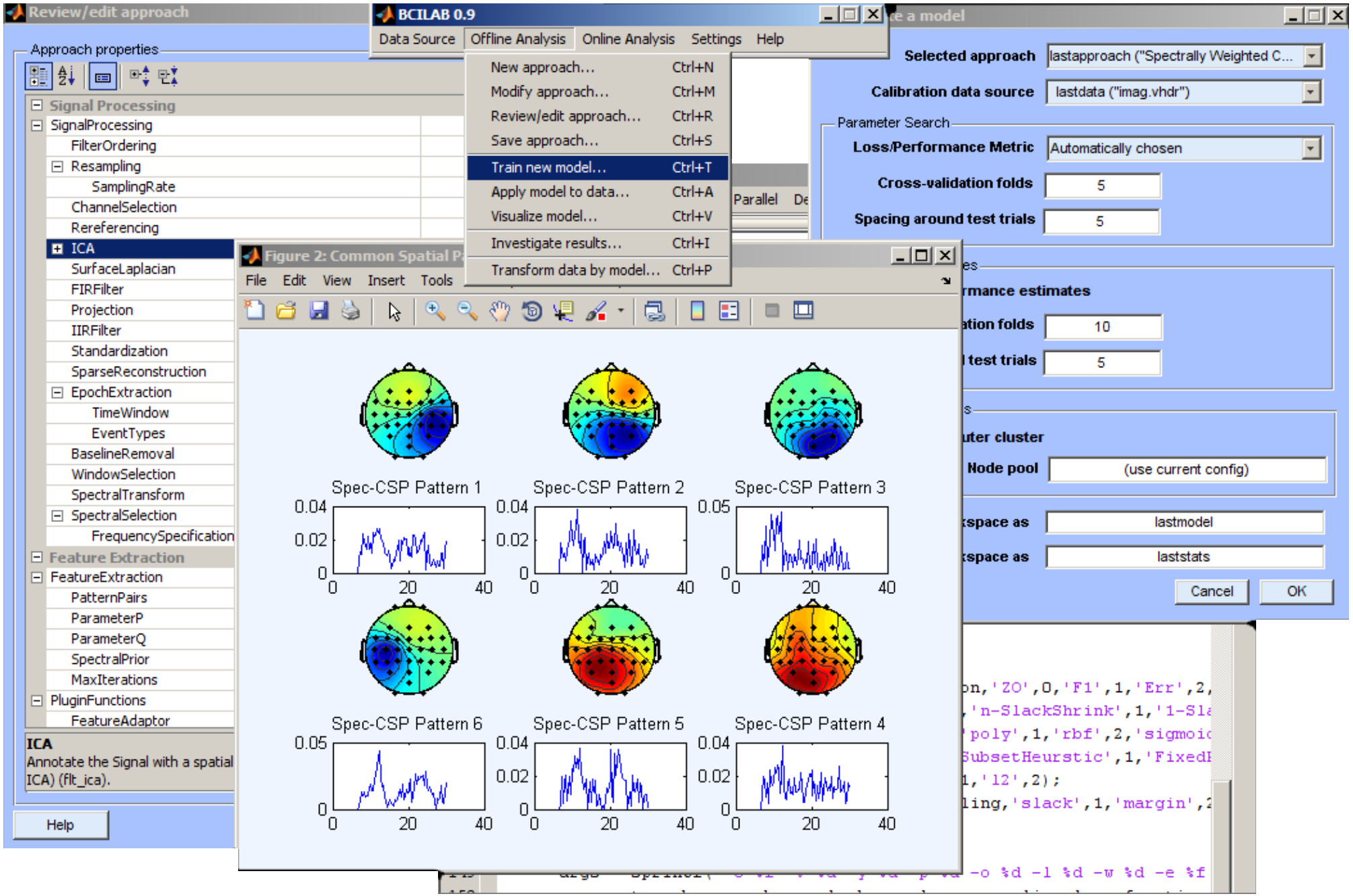


SIFT

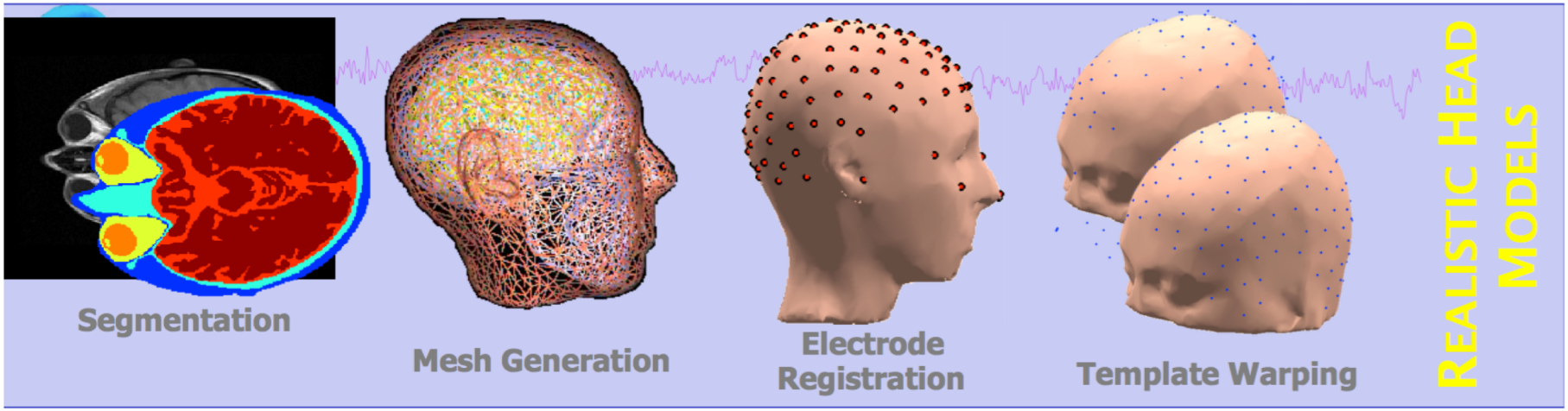
Source Information Flow Toolbox

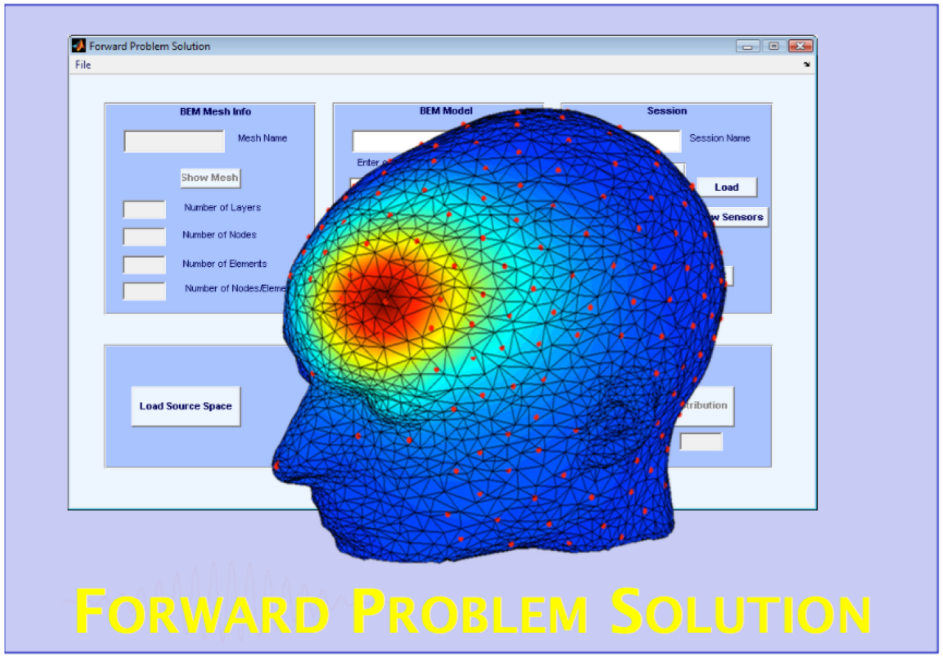


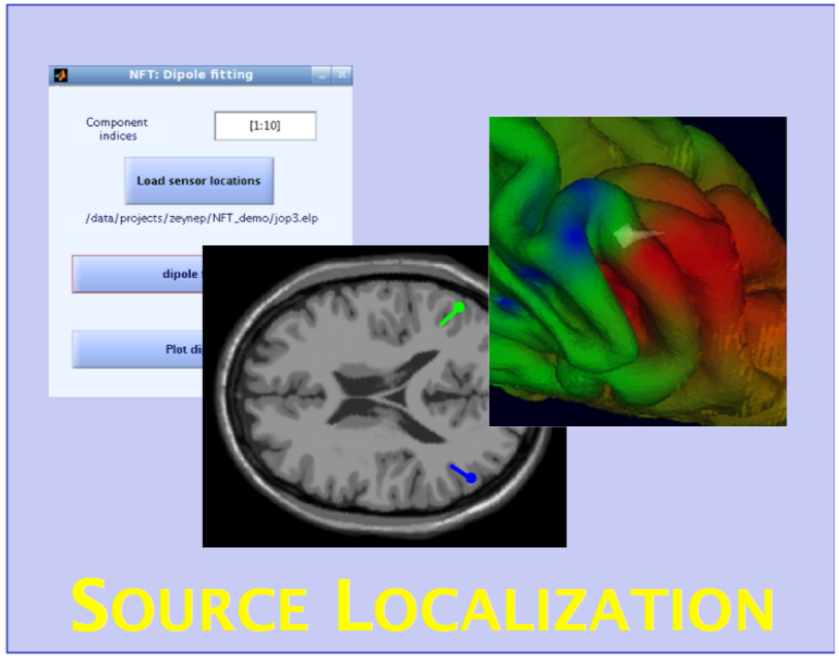
BCILAB - C. Kothe



NFT: Neuroelectromagnetic Forward Head Modeling Toolbox







http://sccn.ucsd.edu/nft

List of data import extensions

Plug-in name	Version	Short plug-in description	Link	Contact	Comments
MFFimport	1.00	Import MFF files from the EGI company	Download	S. Chennu	User comments
ANTeepimport	1.10	Import ANT .cnt data and trigger files	Download	M. van de Velde	User comments
BCI2000import	0.36	Import BCI2000 data files	Download	C. Boulay	User comments
BDFimport	1.10	Import BDF data files	Download	A. Delorme	User comments
biopac	1.00	Import BIOPAC data files	Download	A. Delorme	User comments
ctfimport	1.04	Import CTF (MEG) data files	Download	D. Weber	User comments
erpssimport	1.01	Import ERPSS data files	Download	A. Delorme	User comments
INSTEPascimport	1.00	Import INSTEP ASCII data files	Download	A. Delorme	User comments
neuroimaging4d	1.00	Import Neuroimaging4d data files	Download	C. Wienbruch	User comments
ProcomInfinity	1.00	Import Procom Infinity data files	Download	A. Delorme	User comments
WearableSensing	1.09	Import Wearable Sensing files	Download	S. Pillen	User comments
NihonKoden	0.10	Import Nihon Koden M00 files (beta)	Download	M. Miyakoshi	User comments
xdfimport	1.12	Import files in XDF format	Download	C. Kothe	User comments
bva-io	1.5.12	Import Brain Vision Analyser data files	Download	A. Widmann	User comments
Fileio	Daily	Import multiple data files formats	Download	R. Oostenveld	User comments
Biosig	2.88	Import multiple data files formats	Download	A. Schloegl	User comments
Cogniscan	1.1	Import Cogniscan data files	Download	P. Sajda	User comments
NeurOne	1.0.3.2	Import NeurOne data files	Download	Support	User comments
loadhdf5	1.0	Load hdf5 files recorded with g.recorder	Download	Simon L. Kappel	User comments

List of data processing extensions

Plug-in name	Version	Short plug-in description	Link	Contact	Comments
rERP	0.4	Estimate overlapping ERPs using multiple regression	Download	M. Burns	User comments
LIMO	1.5	LInear MOdelling of EEG data	Download	C. Pernet	User comments
corrmap	2.02	Cluster ICA components using correlation of scalp maps	Download	S. Debener	User comments
bioelectromag	1.01	Uses Bioelectromagnetism toolbox for ERP peak detection	Download	D. Weber	User comments
VisEd	1.05	Add/Edit dataset events	Download	J. Desjardins	User comments
loreta	1.10	Export and import data to and from LORETA software	Download	A. Delorme	User comments
iirfilt	1.02	Non linear filtering using IIR filter	Download	M. Pozdin	User comments
std_envtopo	2.39	Plot STUDY ICA cluster contribution to ERP	Download	M. Miyakoshi	User comments
std_selectICsByCluster	0.10	Forward-project clustered ICs to channels (beta)	Download	M. Miyakoshi	User comments
std_dipoleDensity	0.23	Plot STUDY ICA cluster dipole density (beta)	Download	M. Miyakoshi	User comments
std_ErpCalc	0.11	Test and visualize simple effects on ERP (beta)	Download	M. Miyakoshi	User comments
pvaftopo	0.10	Plot topography of percent variance accounted for (beta)	Download	M. Miyakoshi	User comments
trimOutlier	0.16	Trim outlier channels and datapoints interactively (beta)	Download	M. Miyakoshi	User comments
clean_rawdata	0.31	Cleans continuous data using Artifact Subspace Reconstruction	Download	Miyakoshi and Kothe	User comments
ARfitStudio	0.10	Cleans spiky artifacts using AFfit (beta)	Download	Miyakoshi and Mullen	User comments
Mutual_Info_Clustering	1.00	Group single dataset ICA components by Mutual Information	Download	N. Bigdely	User comments
mass_univ	130502	Mass Univariate ERP Toolbox	Download	D. Groppe	User comments
REGICA	1.00	ICA regression based EOG removal	Download	M. Klados	User comments
MARA	1.1	Multiple Artifact Rejection Algorithm	Download	I. Winkler	User comments
firfilt	1.6.1	Routines for designing linear filters	Download	A. Widmann	User comments
PACT	0.17	Computes phase-amplitude coupling for continuous data	Download	M. Miyakoshi	User comments
fMRIb	2.00	Remove fMRI artifacts from EEG	Download	J. Dien & R. Niazy	User comments
SIFT	1.33	Analysis and visualization of multivariate connectivity	Download	T. Mullen	User comments
AAR	131130	ICA-based Automatic Artifact Removal	Download	G. Gomez-Herrero	User comments
Adjust	1.1	Automatic Detector - Joint Use of Spatial and Temporal features	Download	Adjust Support	User comments
Cleanline	1.02	Removes sinusoidal artifacts (line noise)	Download	T. Mullen	User comments
Fieldtrip-lite	Daily	Adds source localization and statistics tools to EEGLAB	Download	R. Oostenveld	User comments
EYE-EEG	0.41	Open source MATLAB tool for simultaneous eye tracking & EEG	Download	O. Dimigen	User comments

EEGLAB standard processing pipeline

Single subject

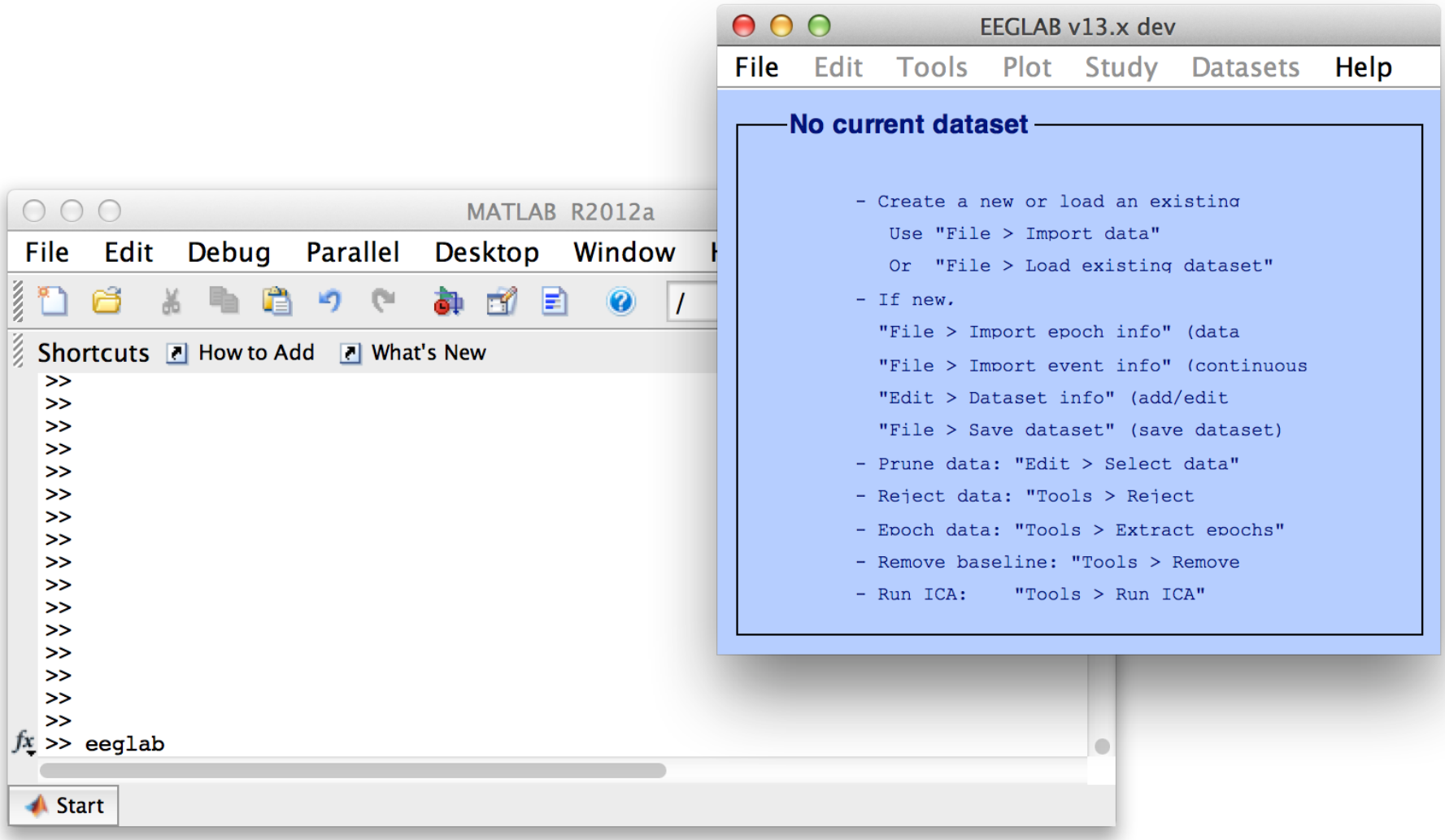
1. Import binary data, events and channel location
2. Edit, Re-reference, Resample, High pass filter data
3. Reject artifacts in continuous data by visual inspection
4. Extract epochs from data & reject artifactual epochs
5. Visualize data measures
6. Perform ICA decomposition
   - Perform source localization of components
   - Analyze components contribution to ERP
   - Analyze components contribution to spectrum

Multi-subjects

1. Build study and STUDY design
2. Pre-compute measures
3. Cluster components
4. Analyze clusters

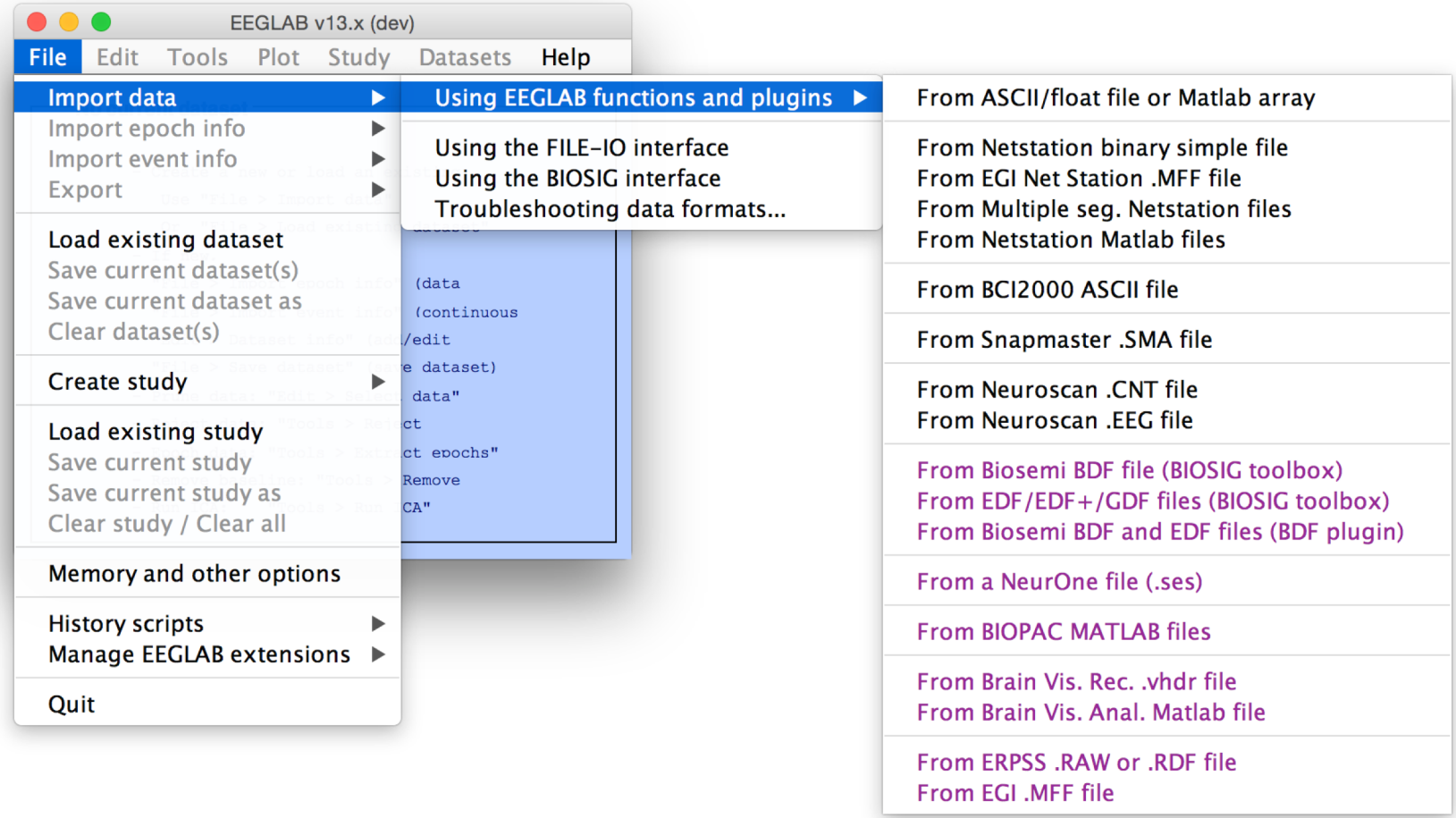
Advanced analysis using scripting and EEGLAB command line functions

The EEGLAB Matlab software



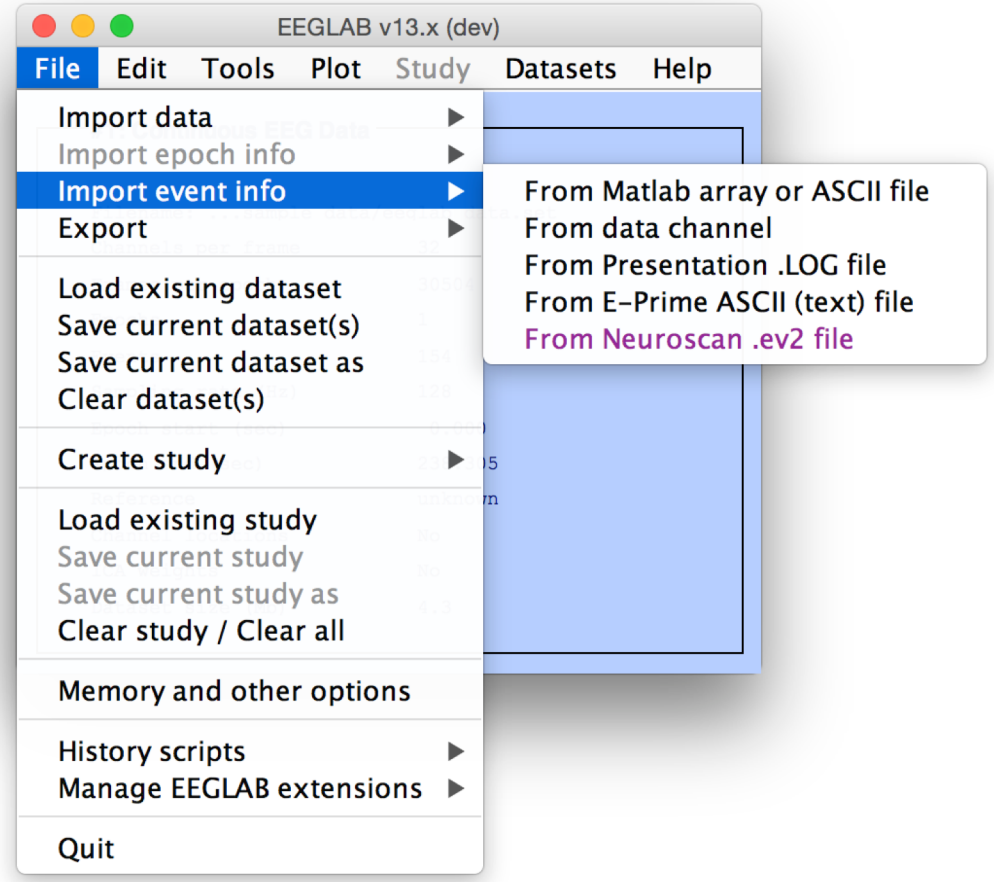
1. Importing data

Import/load data



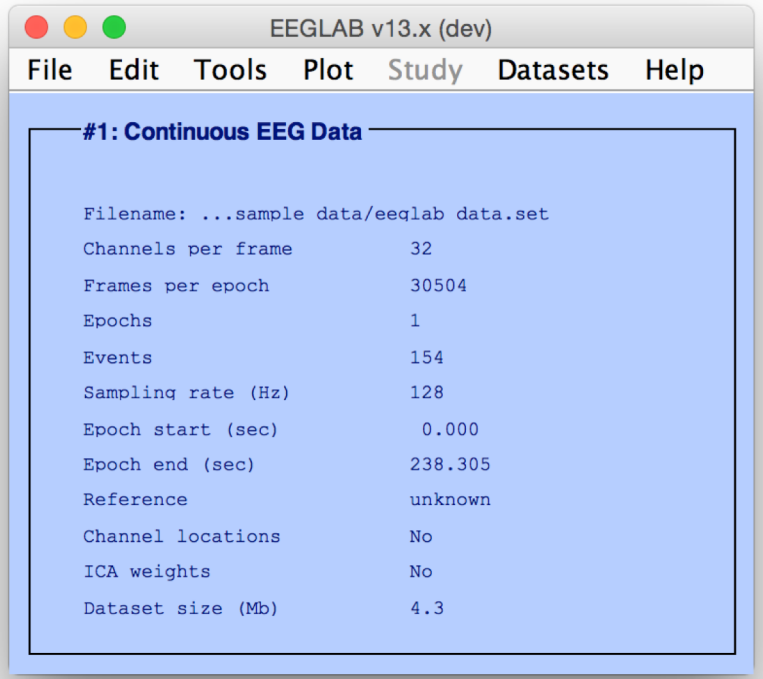
1. Importing data

Import events

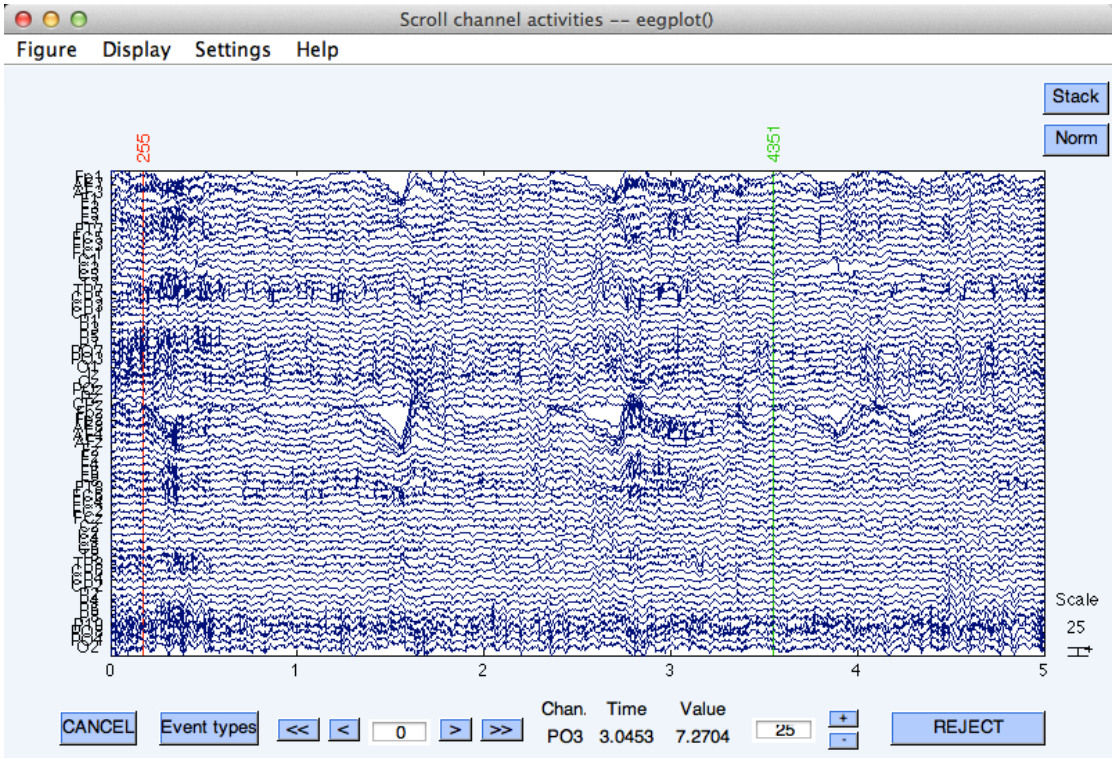


1. Importing data

Data info

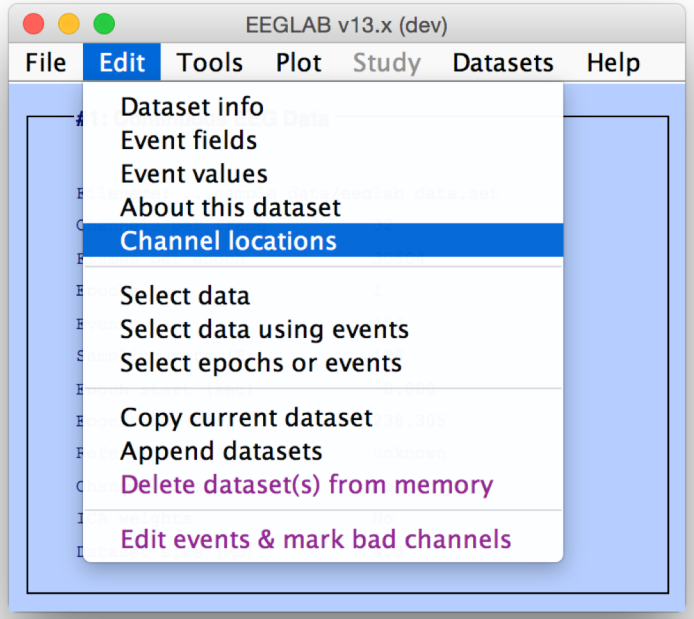


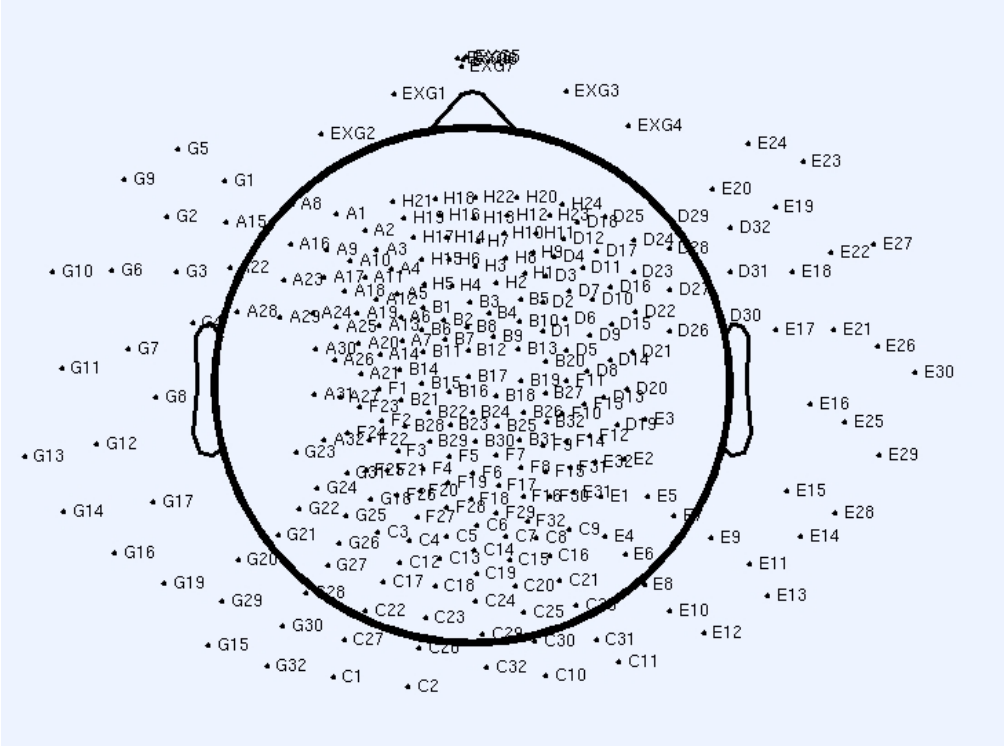
Scrolling data



1. Importing channel location

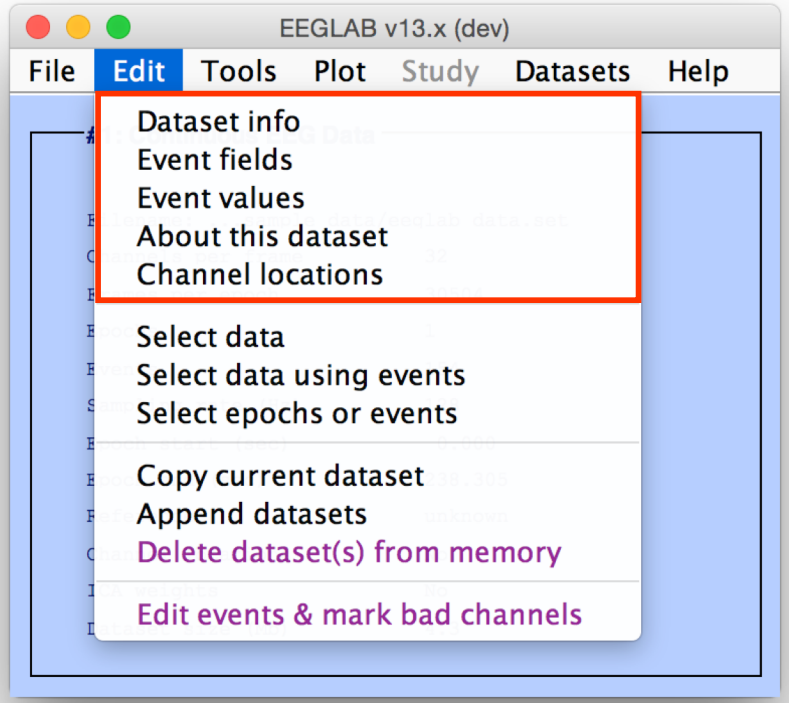
Import channel location



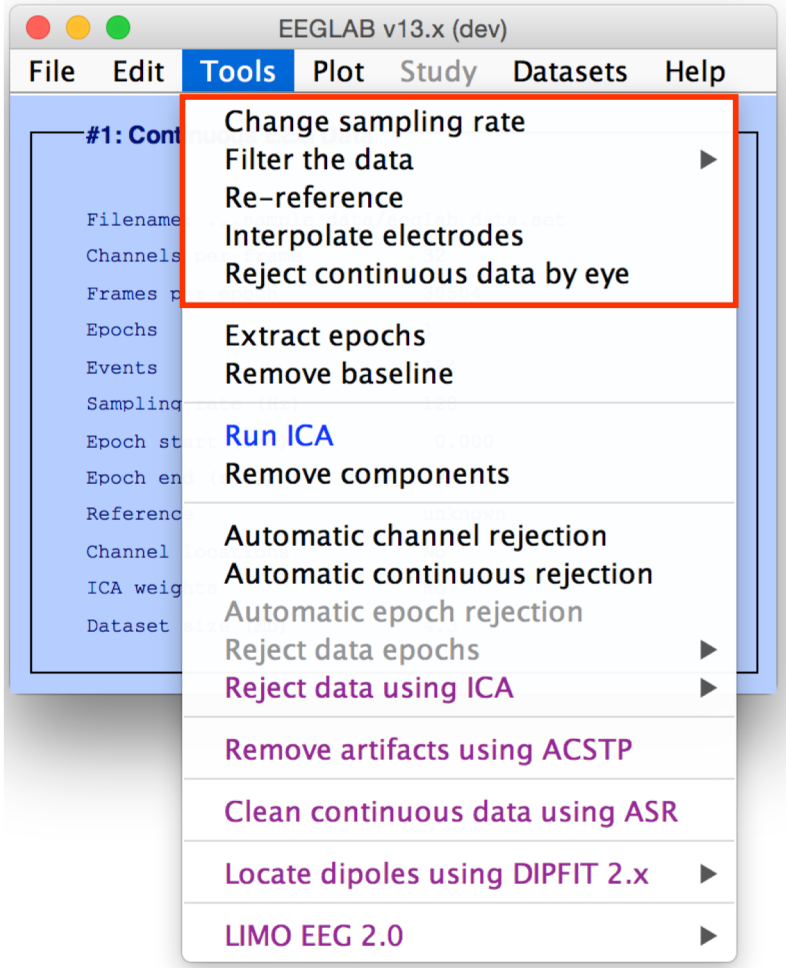


2. Edit, Re-reference, Resample, High pass filter data

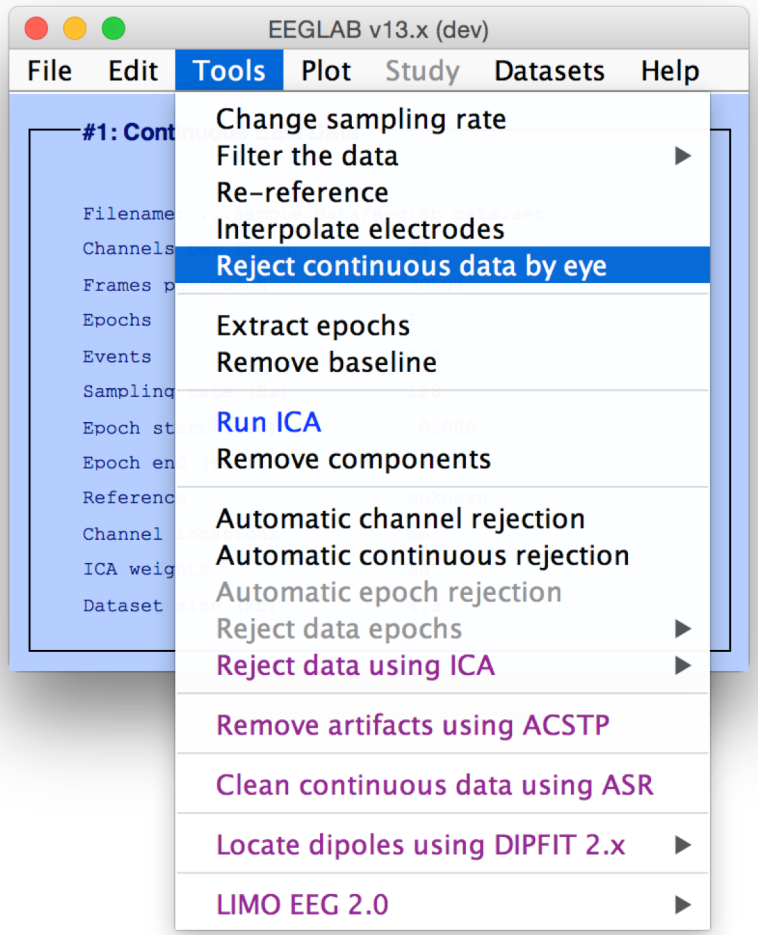
Edit/select data



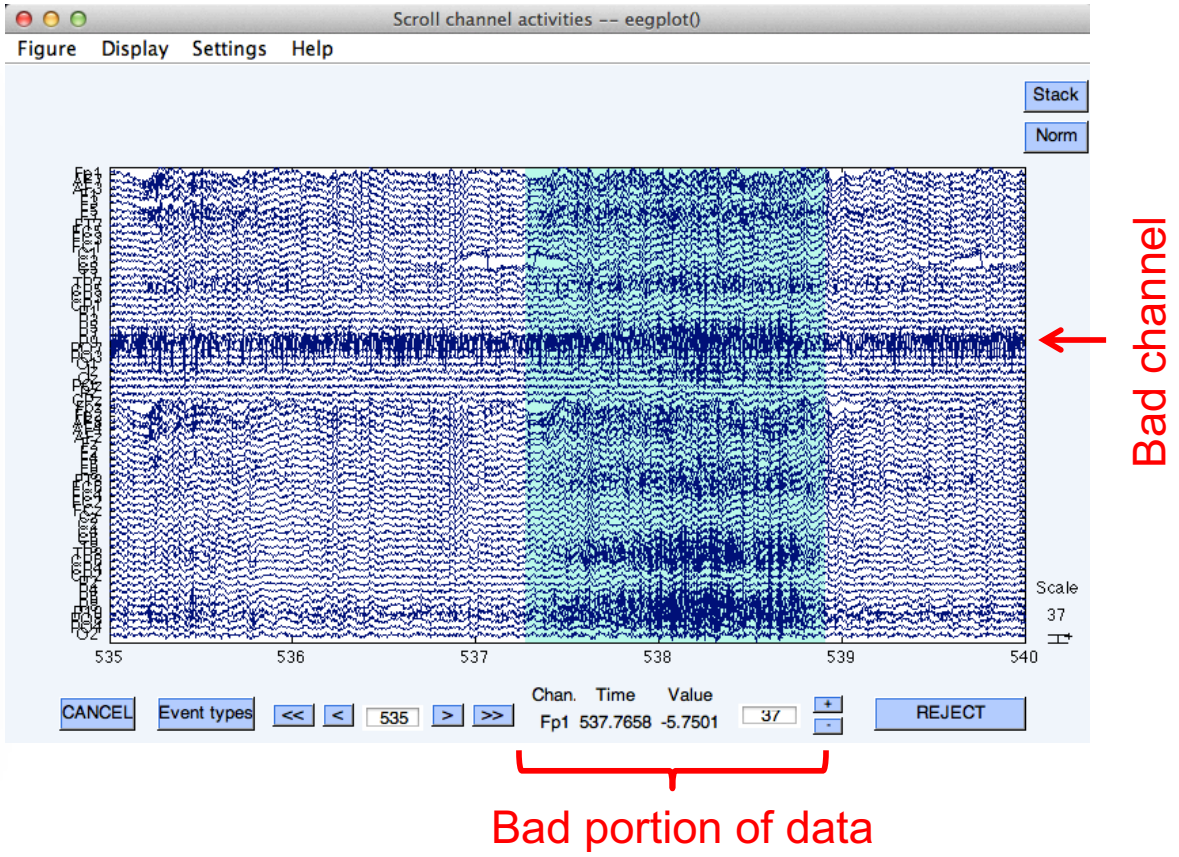
Preprocessing data



3. Reject artifacts in continuous data by visual inspection

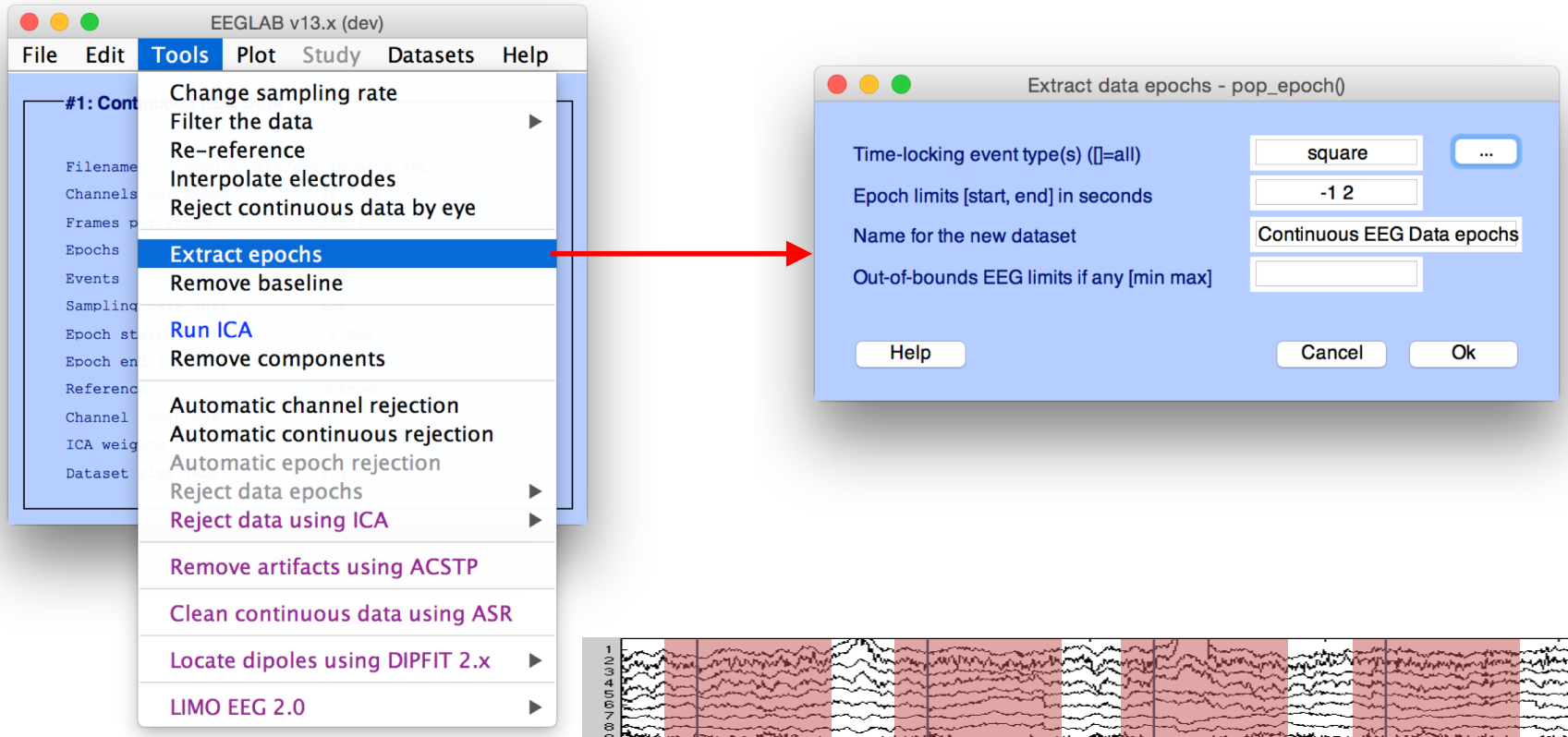


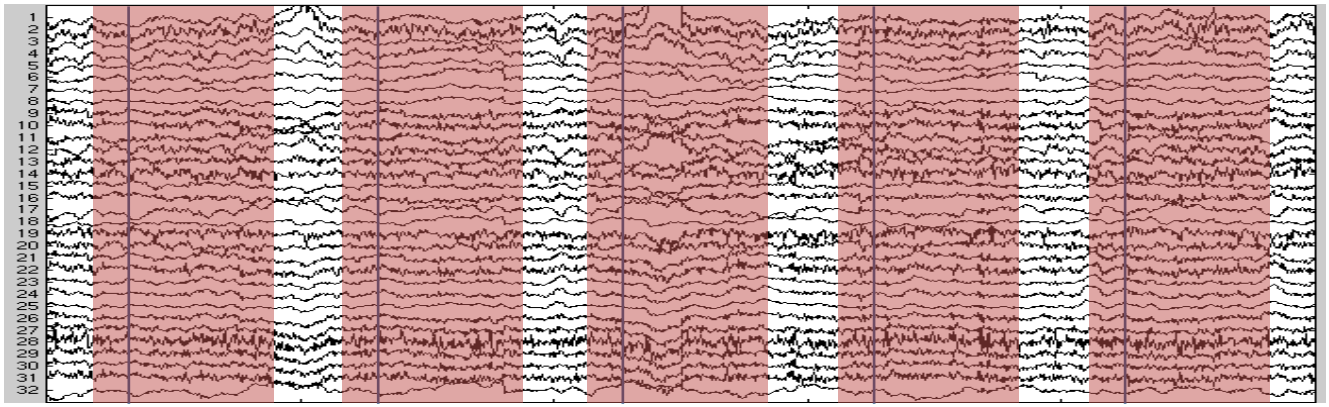
Reject portions of continuous data



4. Extract epochs from data & reject artifactual epochs

Preprocessing data





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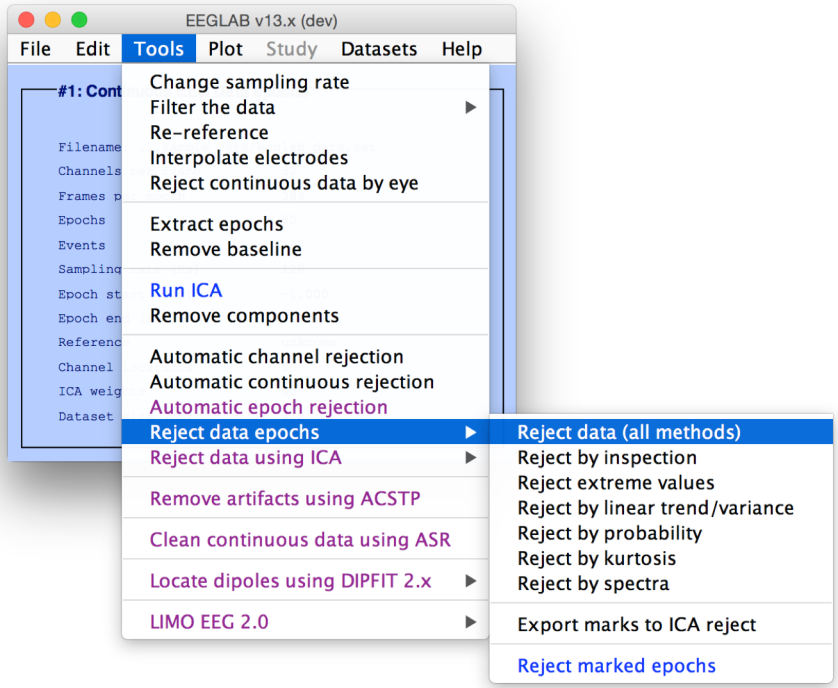
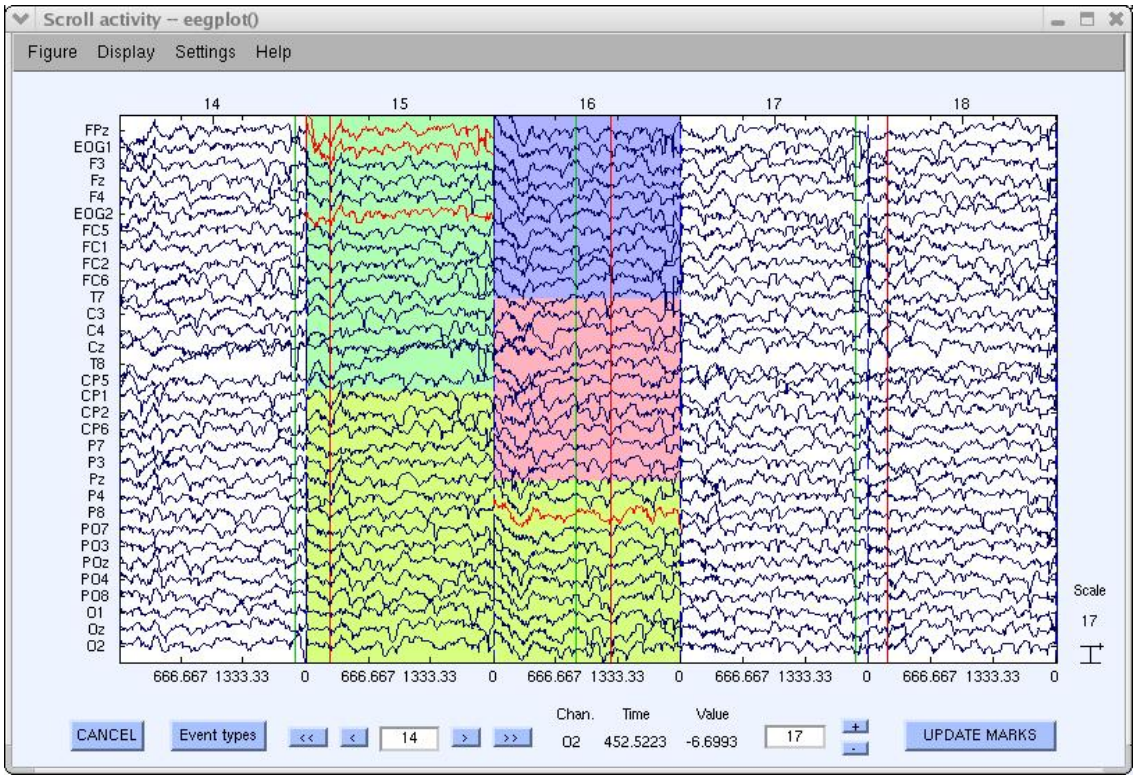
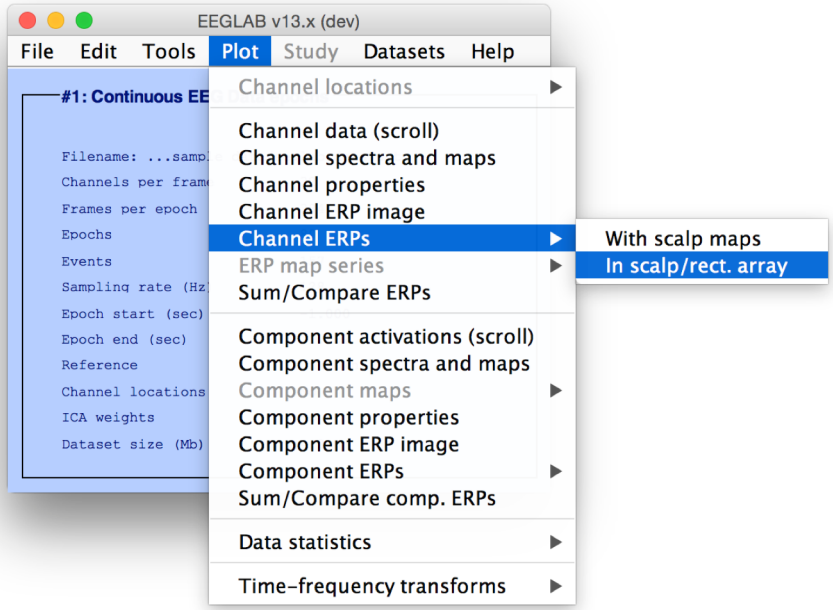


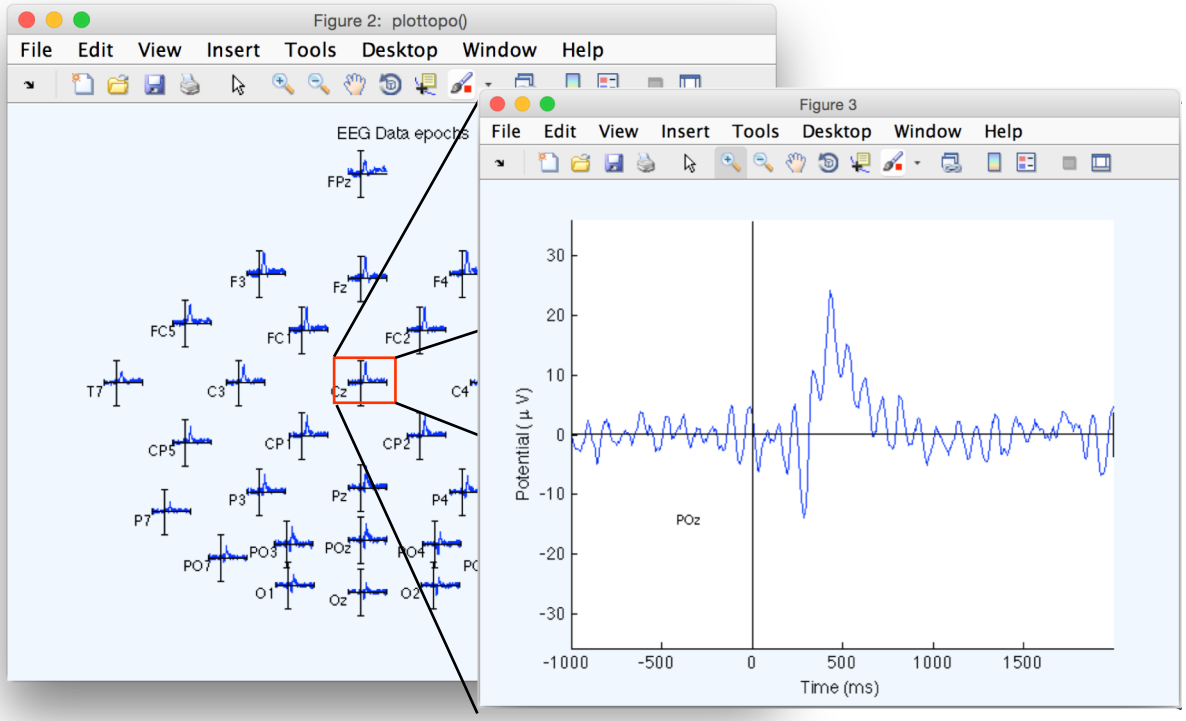
Different color = different rejection methods



5. Visualize data measures

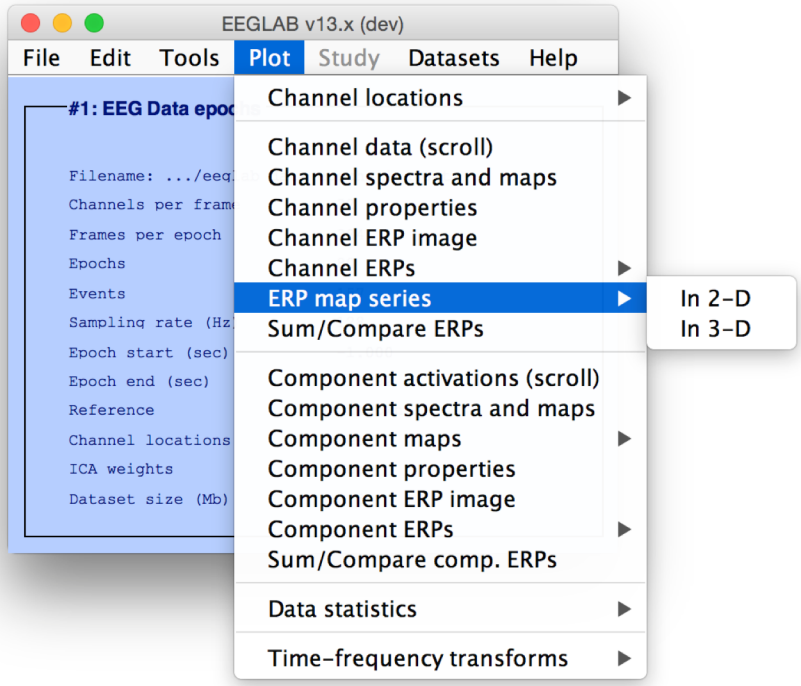


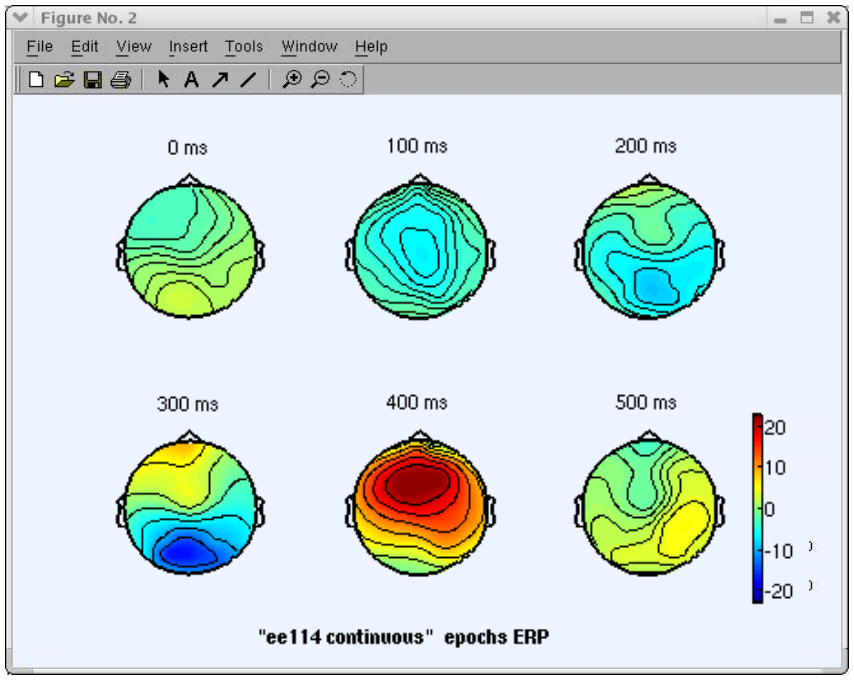
Plot ERP

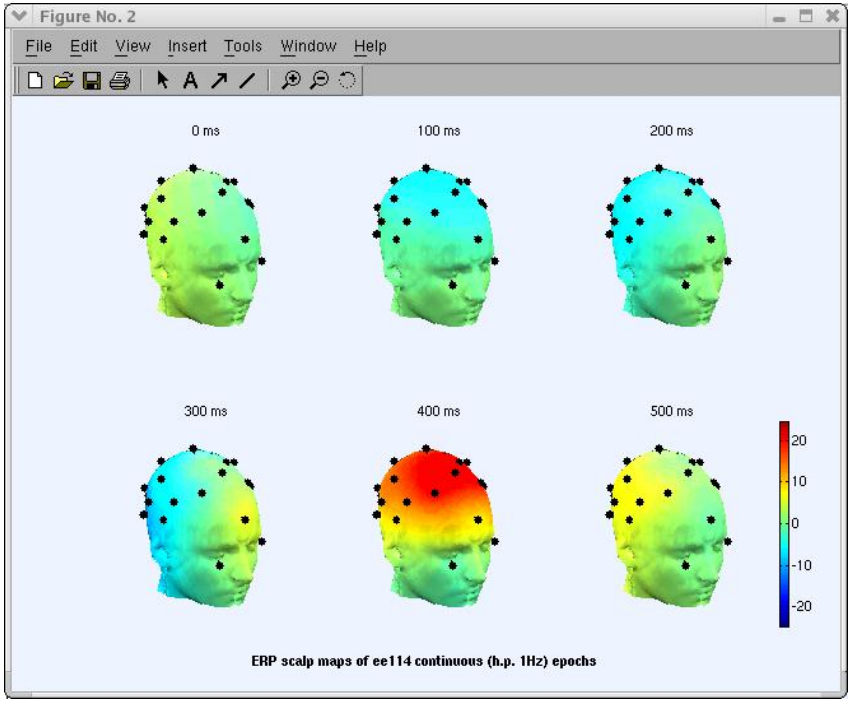


5. Visualize data measures

Plot ERP
map series

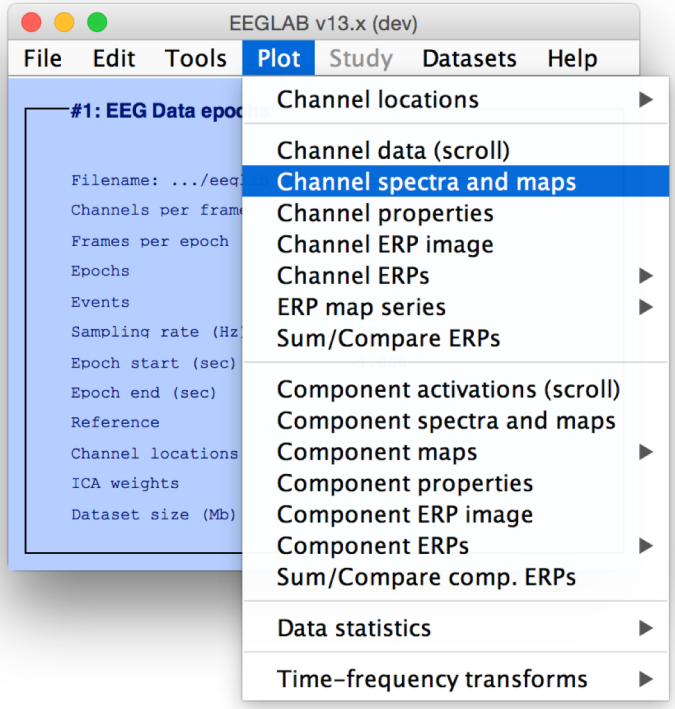


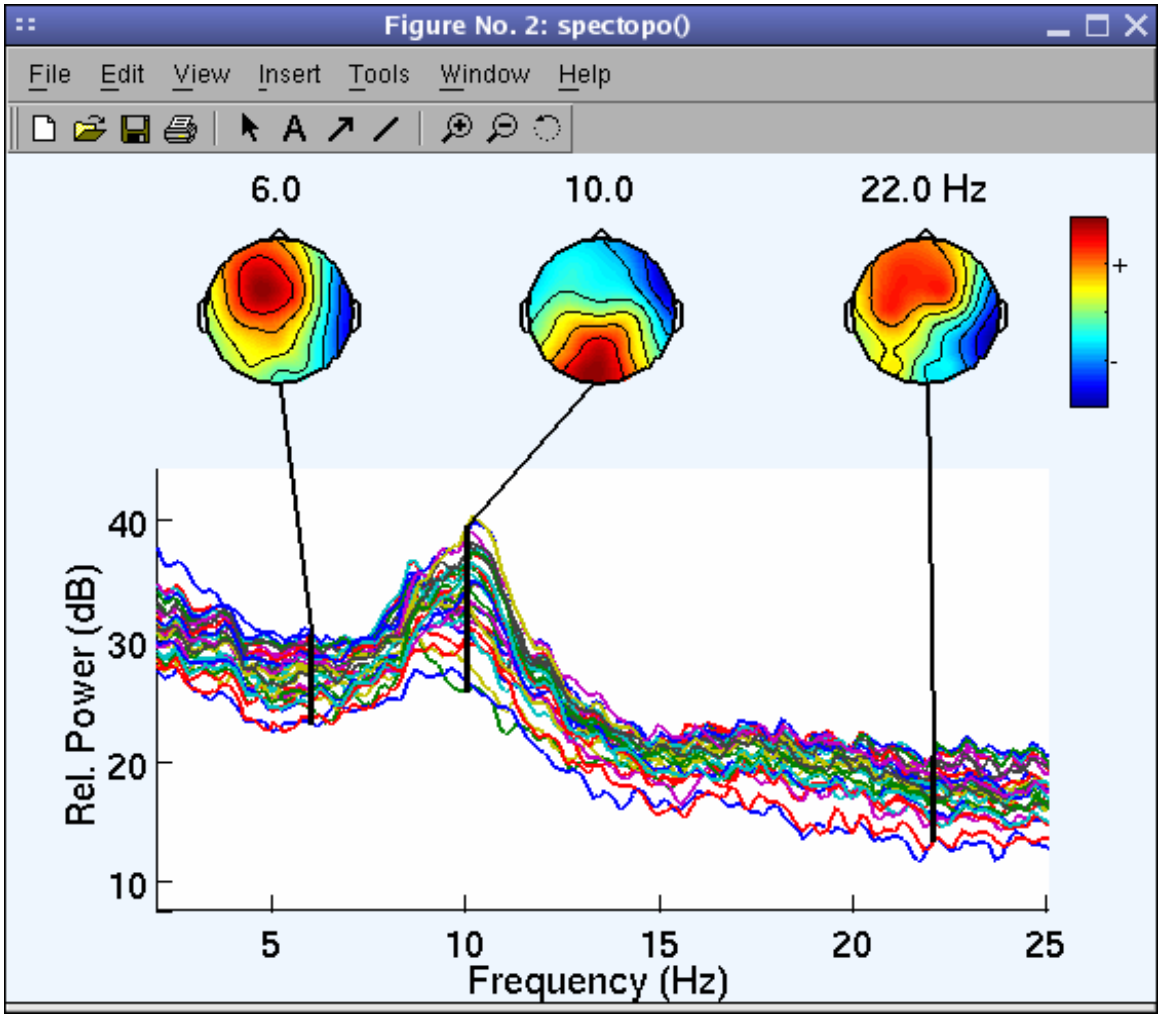




5. Visualize data measures

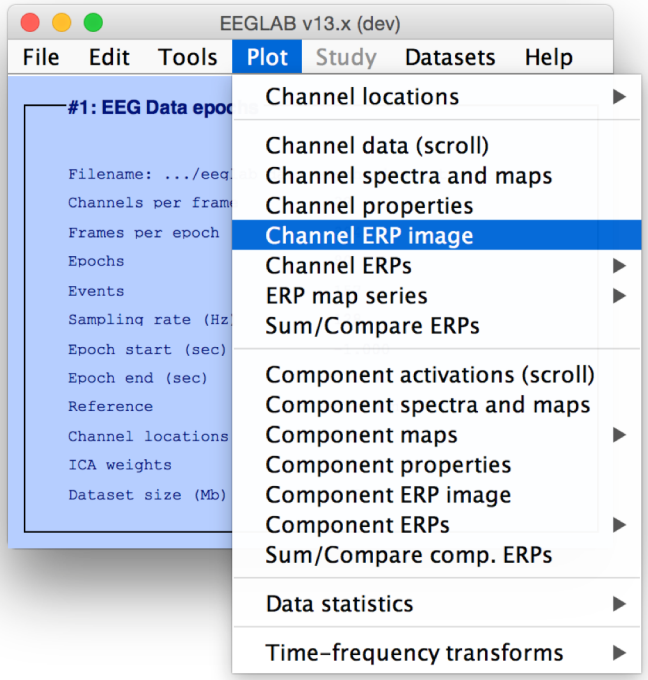
Plot data spectrum and maps

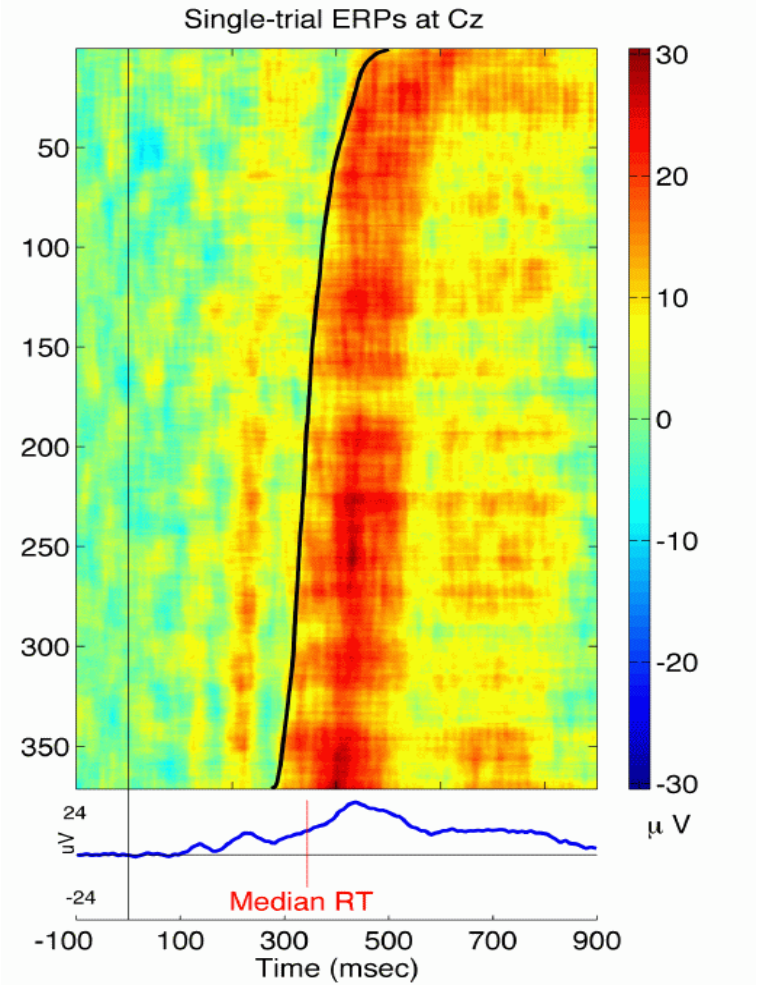




5. Visualize data measures

Plot channel ERPimage





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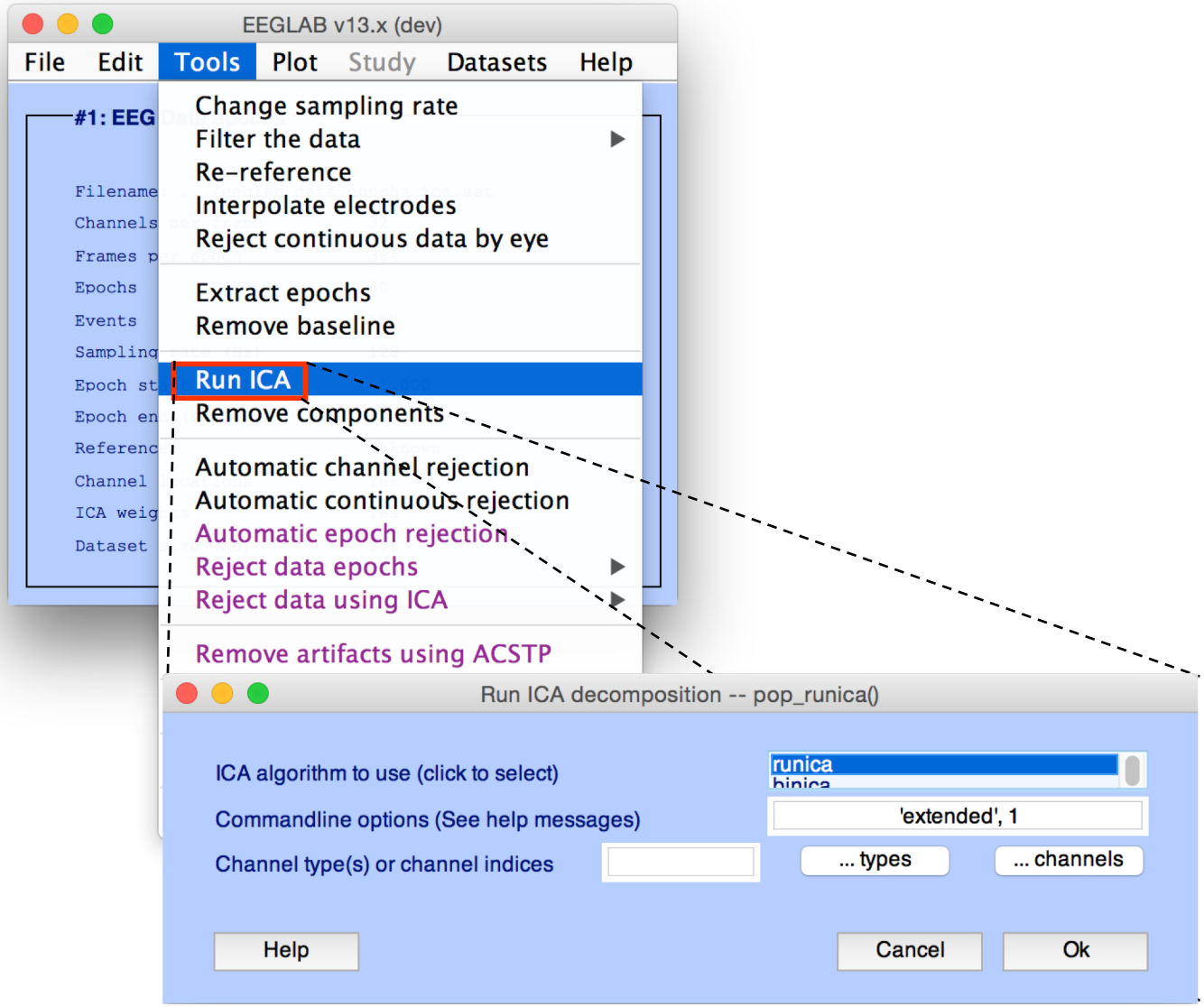
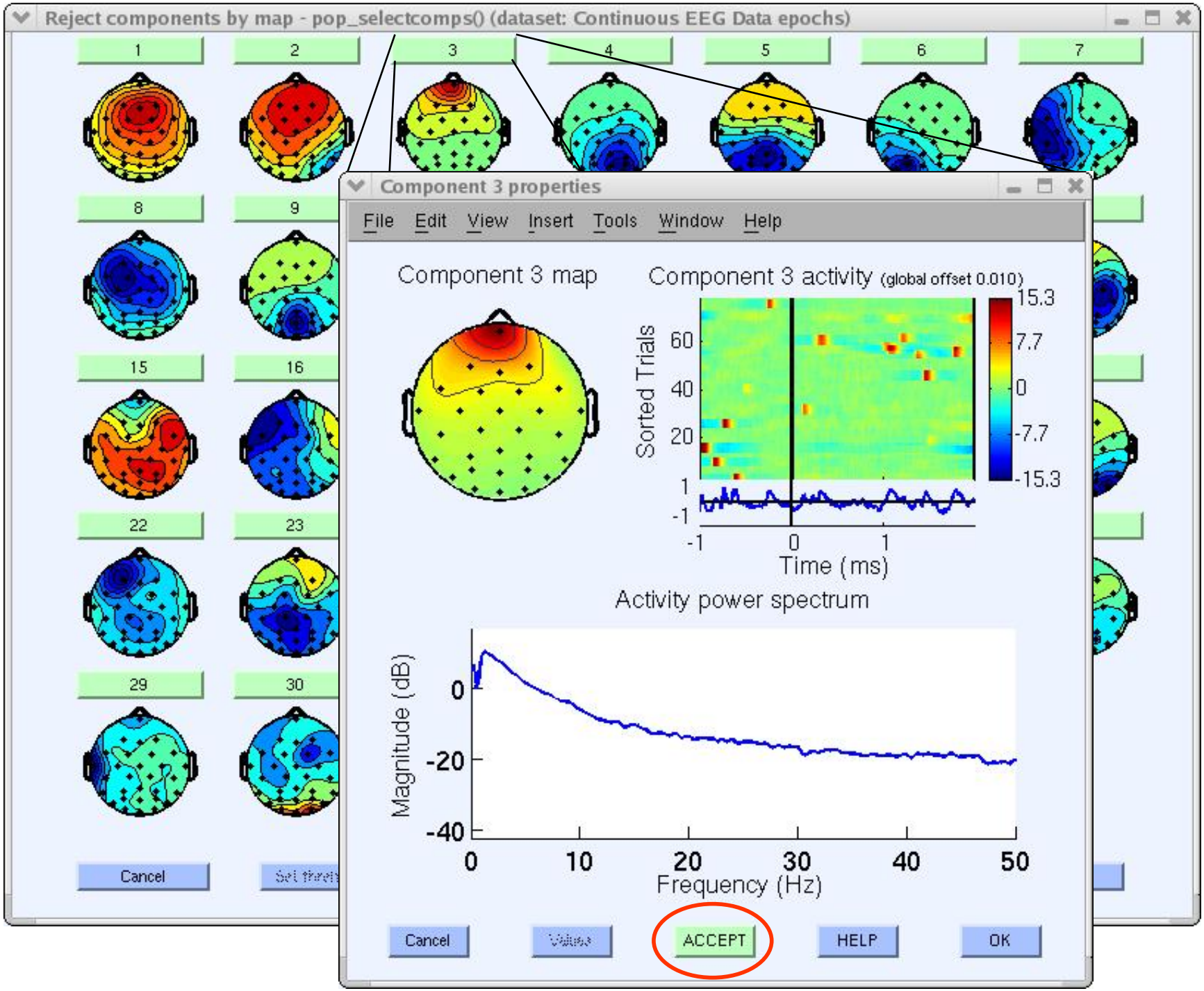
1. Build study
2. Pre-compute measures
3. Cluster components
4. Analyze clusters

Advanced analysis using scripting and EEGLAB command line functions

6. Perform ICA decomposition




Reject components by map - pop_selectcomps() (dataset: Continuous EEG Data epochs)
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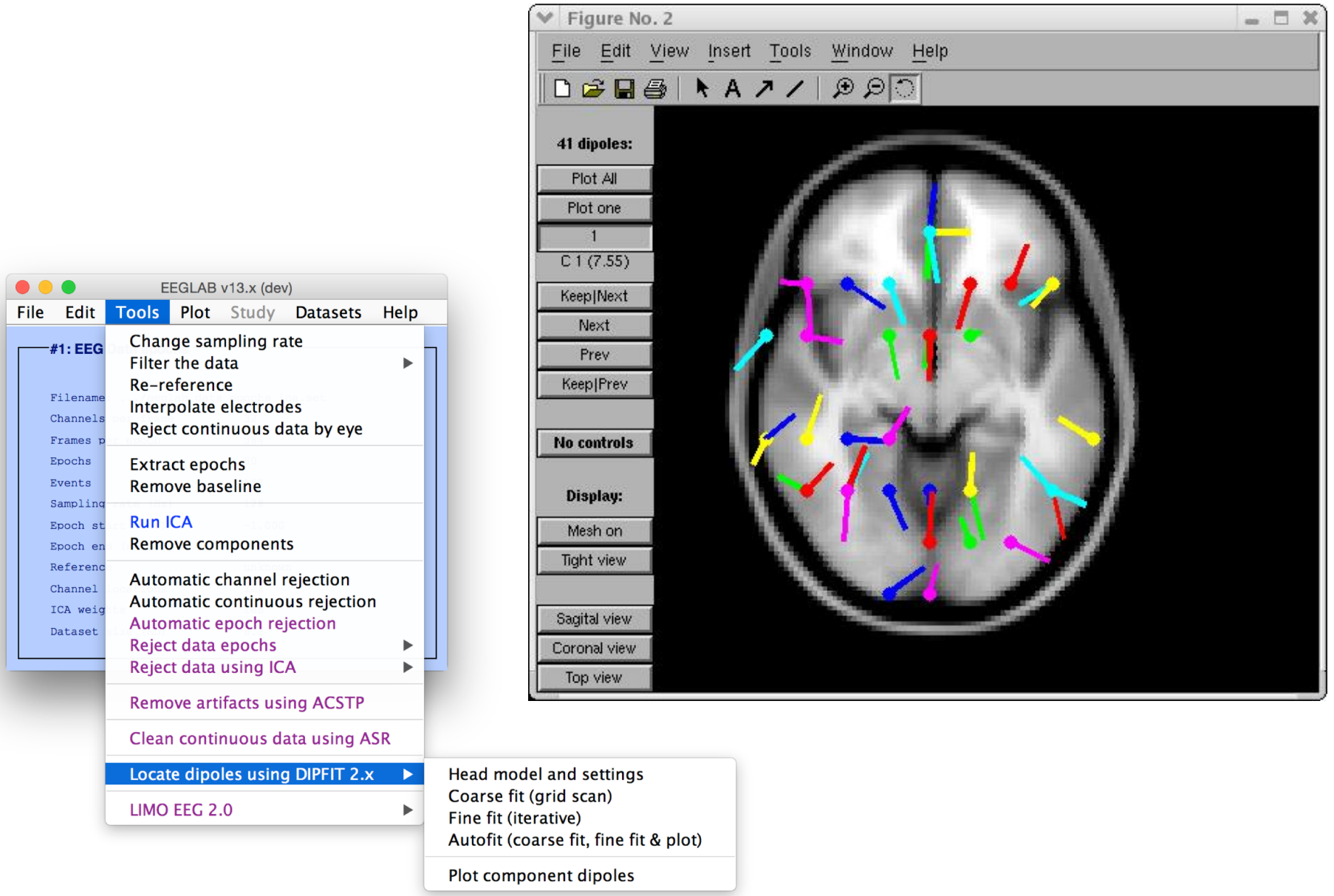
22
23
29
30
Cancel
Component 3 properties
File Edit View Insert Tools Window Help
Component 3 map
Component 3 activity (global offset 0.010)
Sorted Trials
60
40
20
1
-1
15.3
7.7
0
-7.7
-15.3
-1
0
1
Time (ms)
Activity power spectrum
Magnitude (dB)
0
-20
-40
0
10
20
30
40
50
Frequency (Hz)
Cancel
ACCEPT
HELP
OK

Localizing components



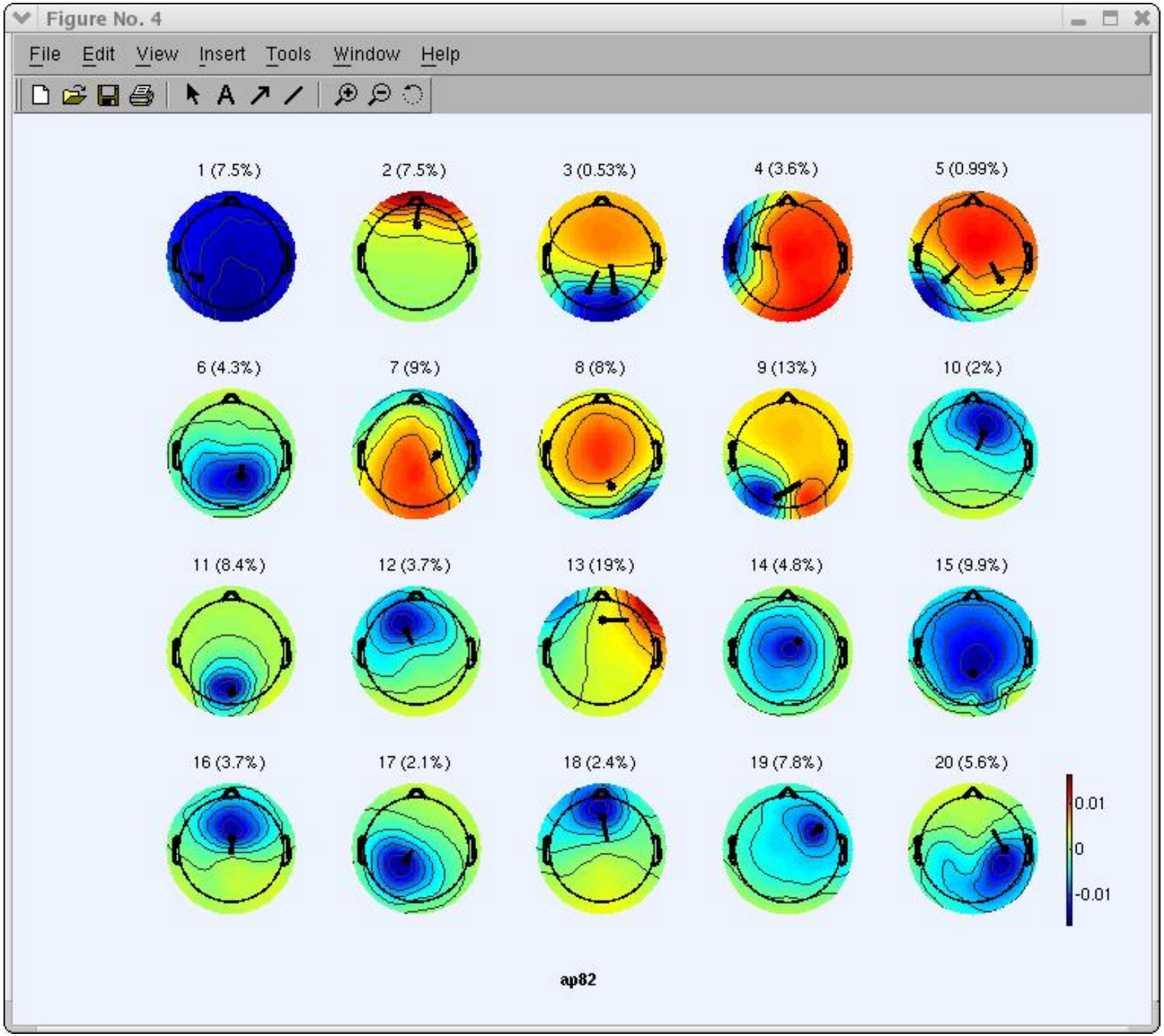
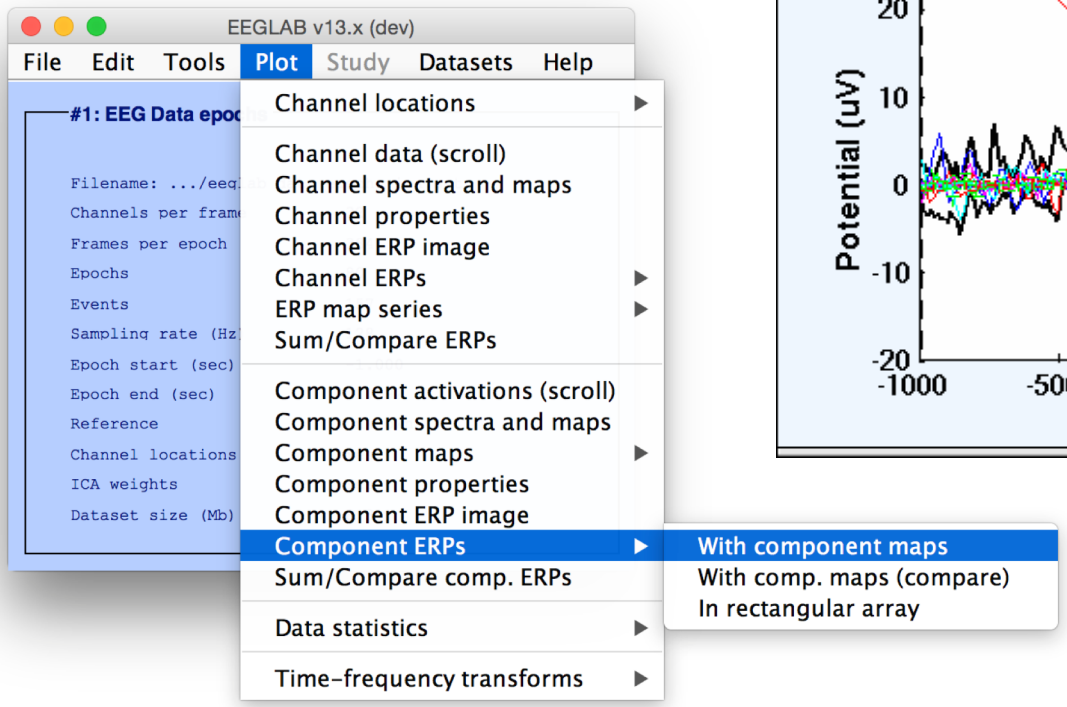
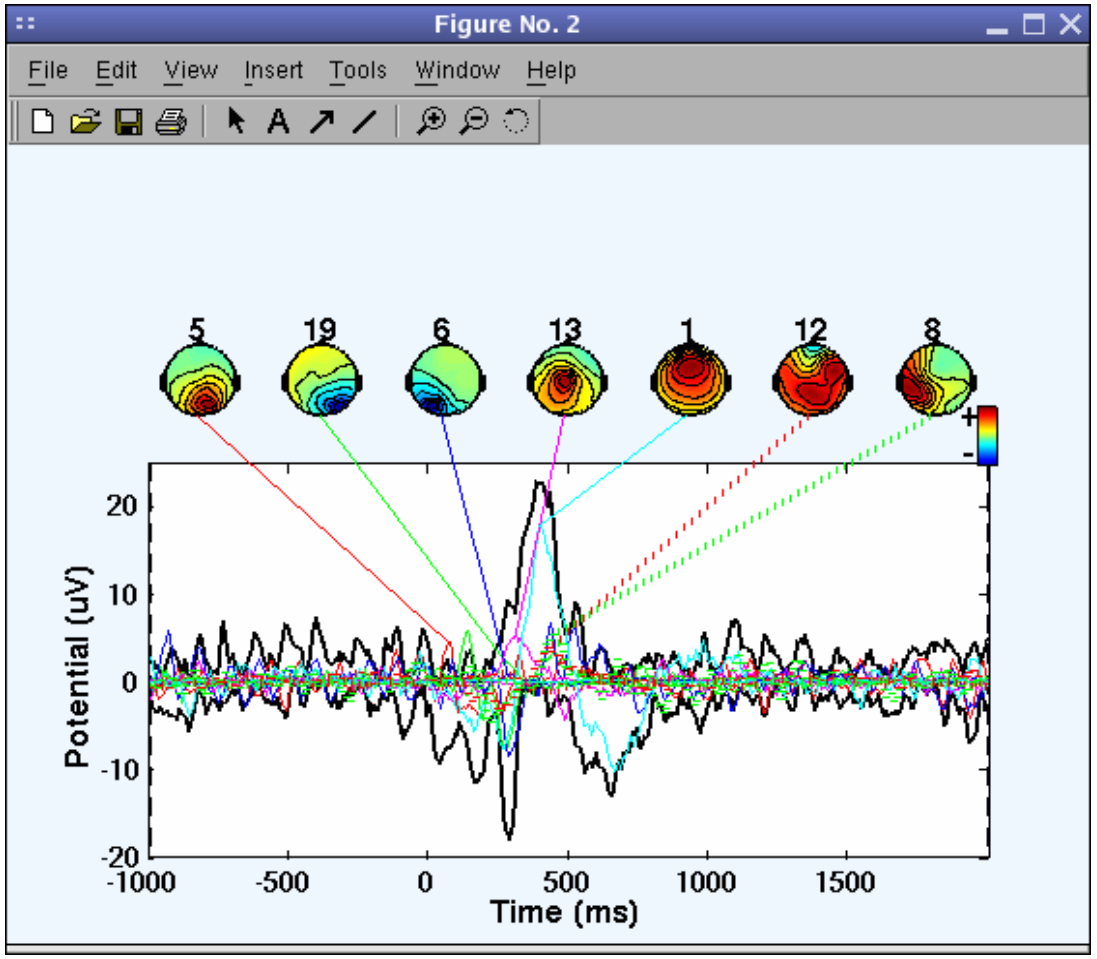


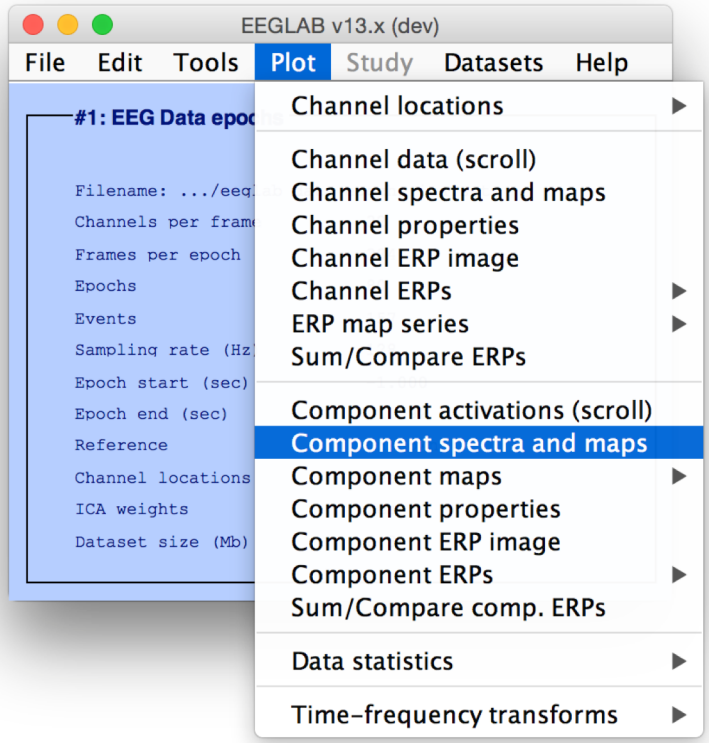
Figure No. 4
File Edit View Insert Tools Window Help
1 (7.5%)
2 (7.5%)
3 (0.53%)
4 (3.6%)
5 (0.99%)
6 (4.3%)
7 (9%)
8 (8%)
9 (13%)
10 (2%)
11 (8.4%)
12 (3.7%)
13 (19%)
14 (4.8%)
15 (9.9%)
16 (3.7%)
17 (2.1%)
18 (2.4%)
19 (7.8%)
20 (5.6%)
0.01
0
-0.01
ap82

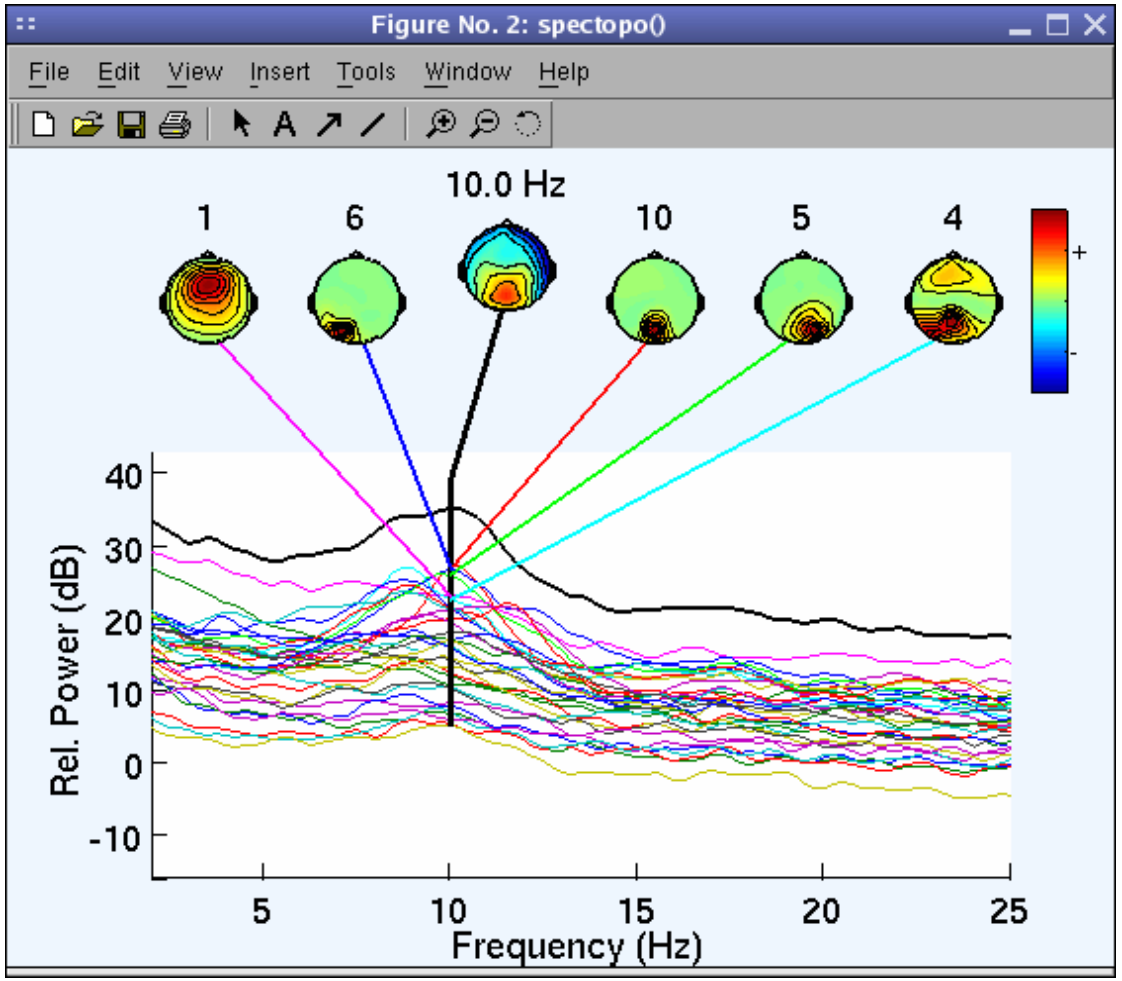
Component contribution to the ERP



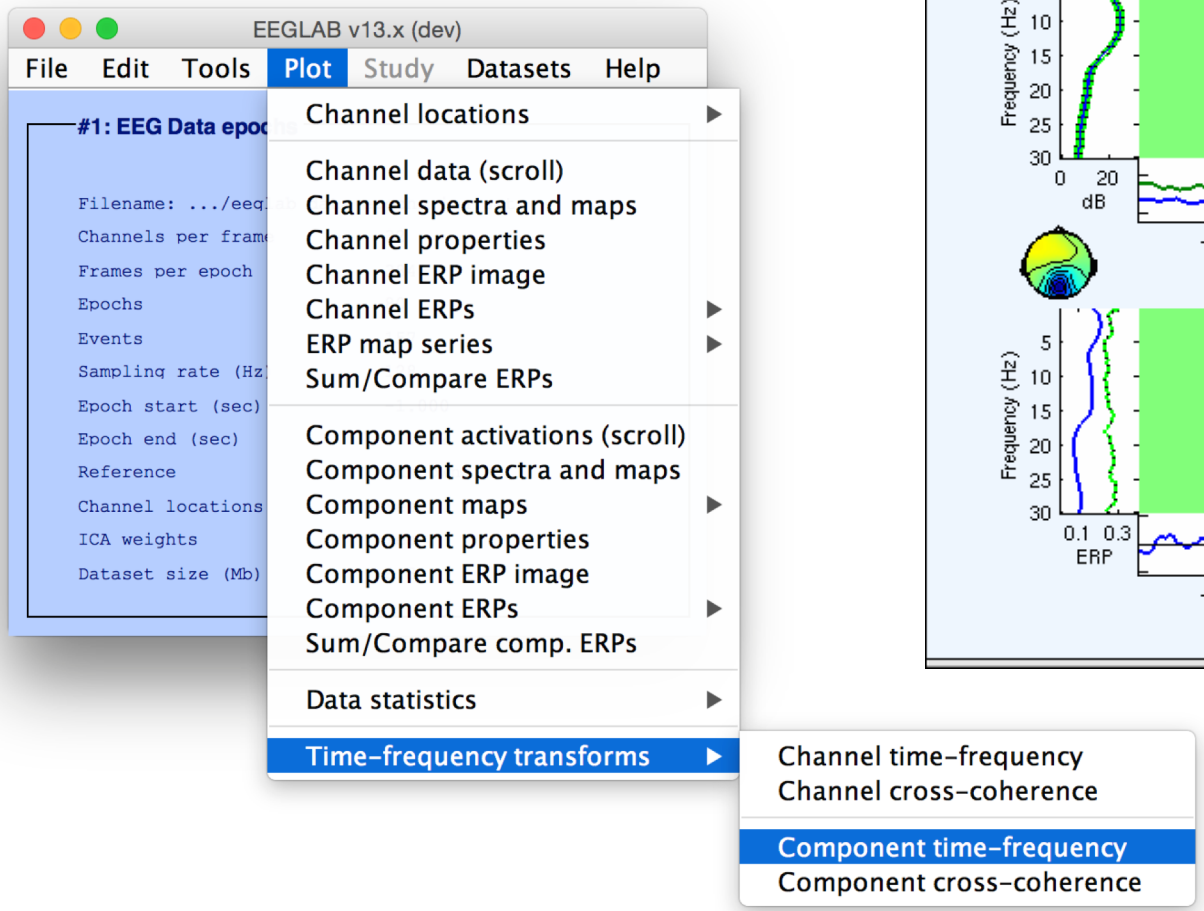


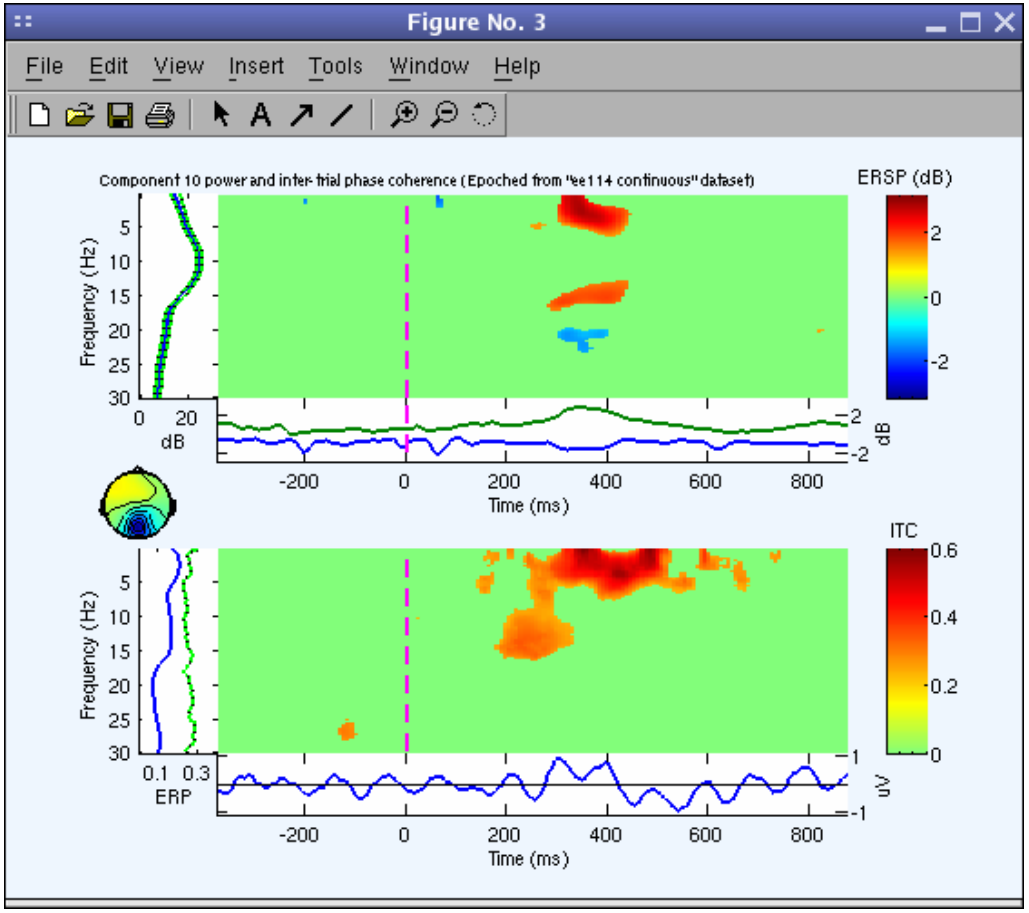
Component contribution to the EEG spectrum





Component time-frequency





EEGLAB standard processing pipeline

Single subject

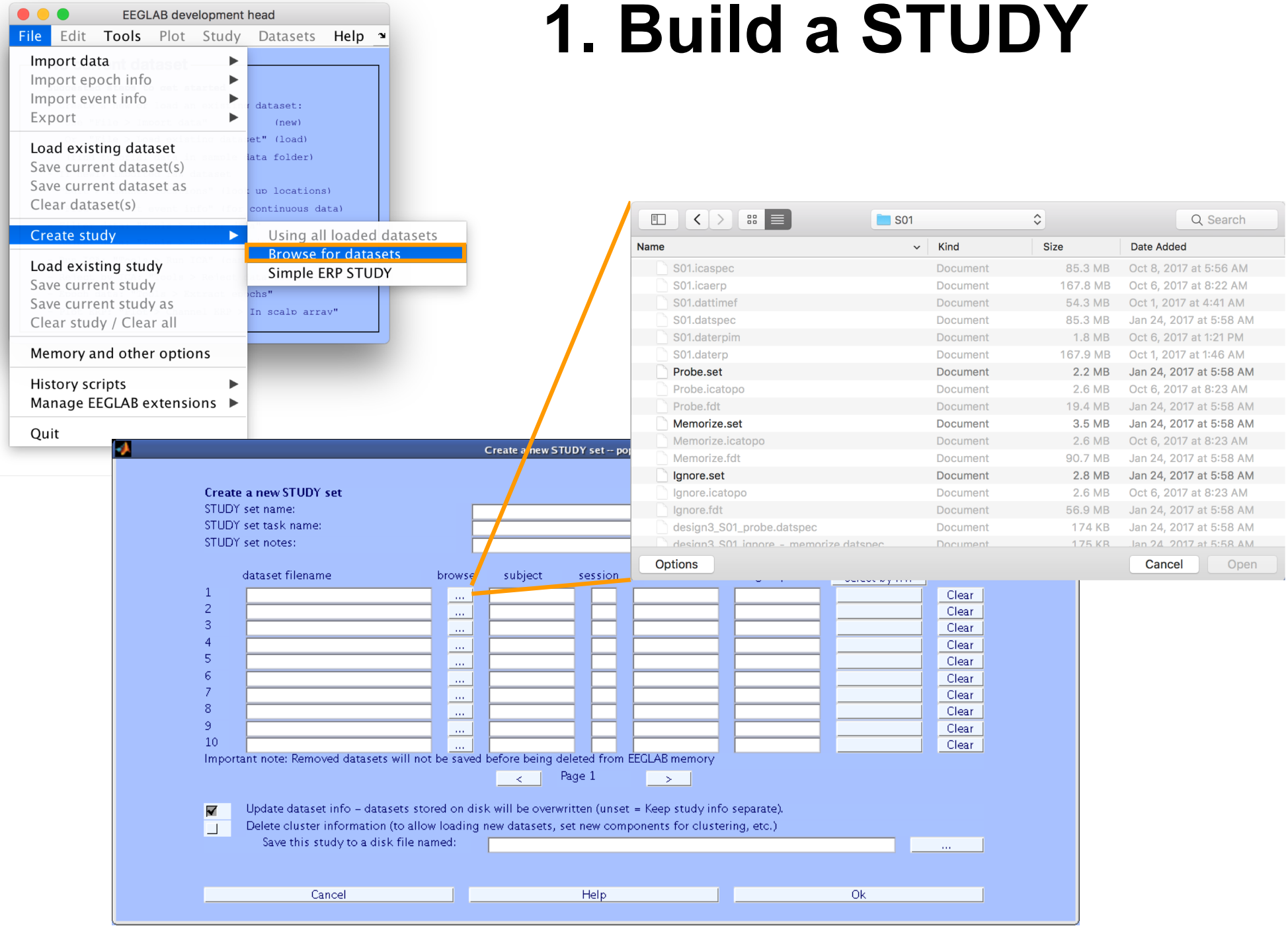
1. Import binary data, events and channel location
2. Edit, Re-reference, Resample, High pass filter data
3. Reject artifacts in continuous data by visual inspection
4. Extract epochs from data & reject artifactual epochs
5. Visualize data measures
6. Perform ICA decomposition
   - Perform source localization of components
   - Analyze components contribution to ERP
   - Analyze components contribution to spectrum

Multi-subjects

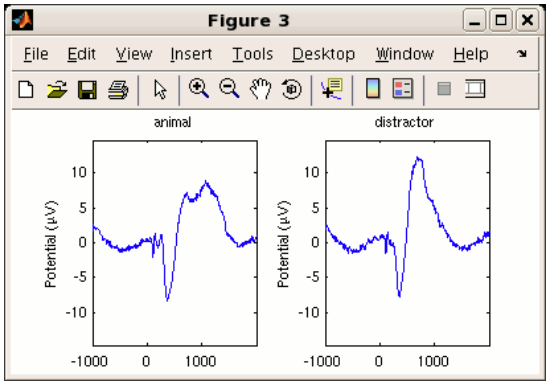
1. Build study and STUDY design
2. Pre-compute measures
3. Cluster components
4. Analyze clusters

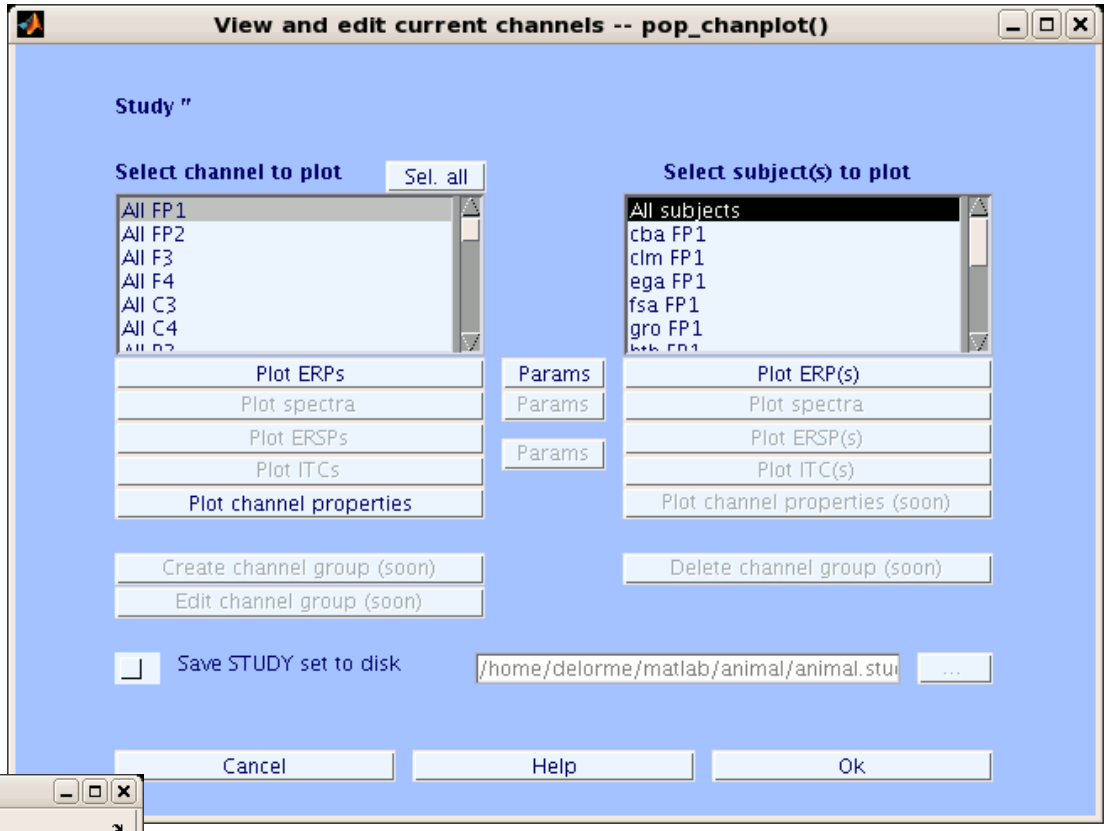
Advanced analysis using scripting and EEGLAB command line functions

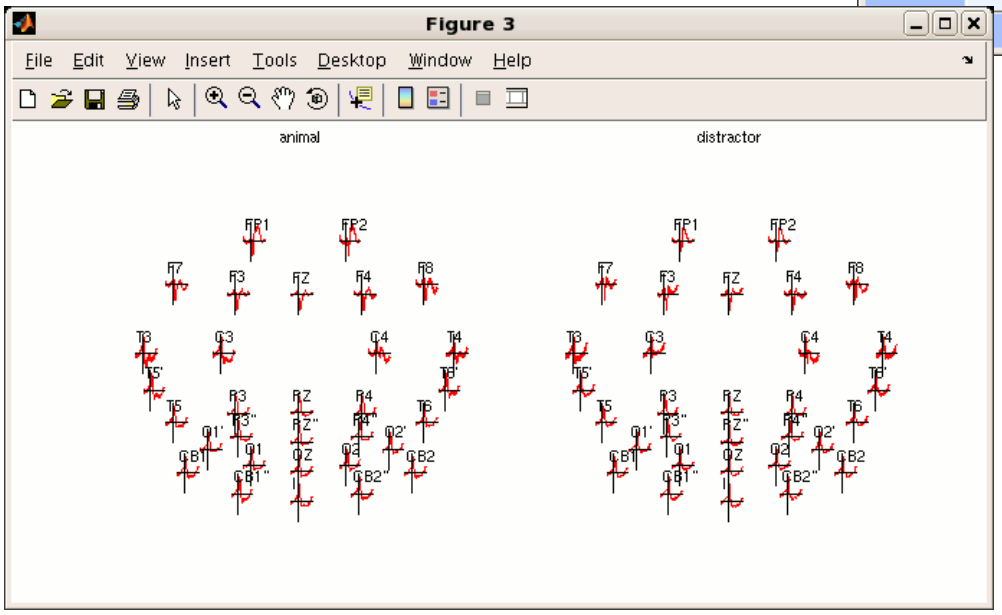
1. Build a STUDY

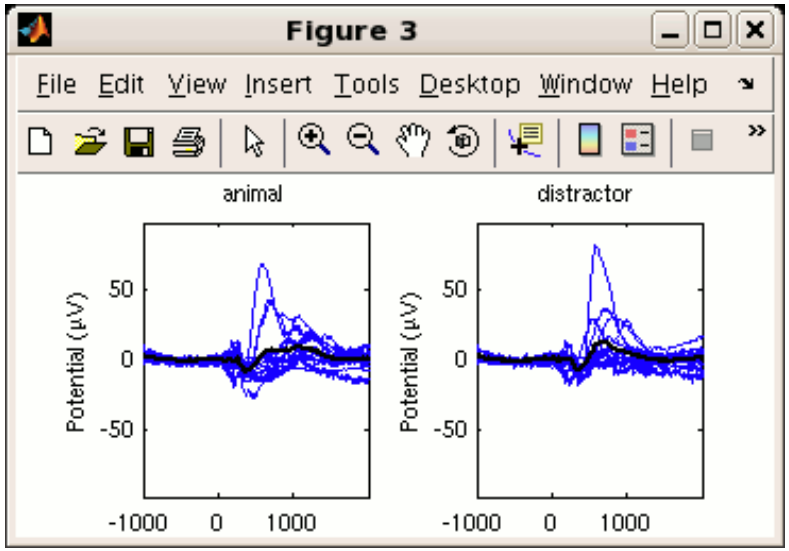


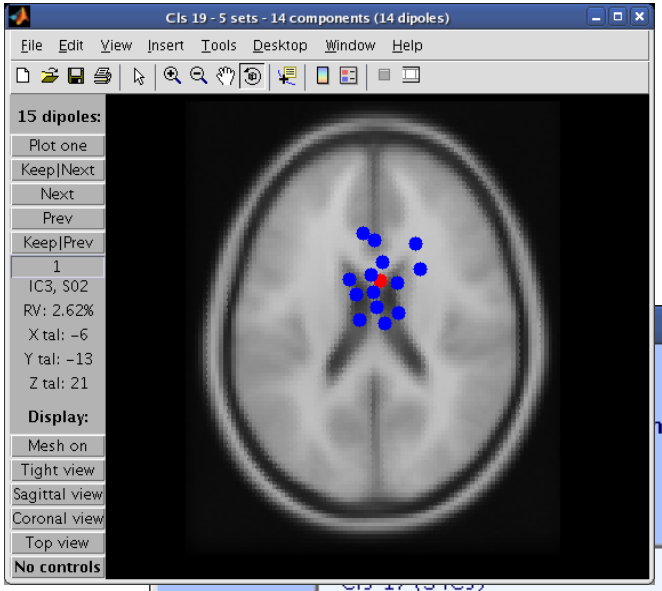
Channel plotting










Cls 19 - 5 sets - 14 components (14 dipoles)
File Edit View Insert Tools Desktop Window Help
15 dipoles:
Plot one
Keep|Next
Next
Prev
Keep|Prev
1
IC3, S02
RV: 2.62%
X tal: -6
Y tal: -13
Z tal: 21
Display:
Mesh on
Tight view
Sagittal view
Coronal view
Top view
No controls

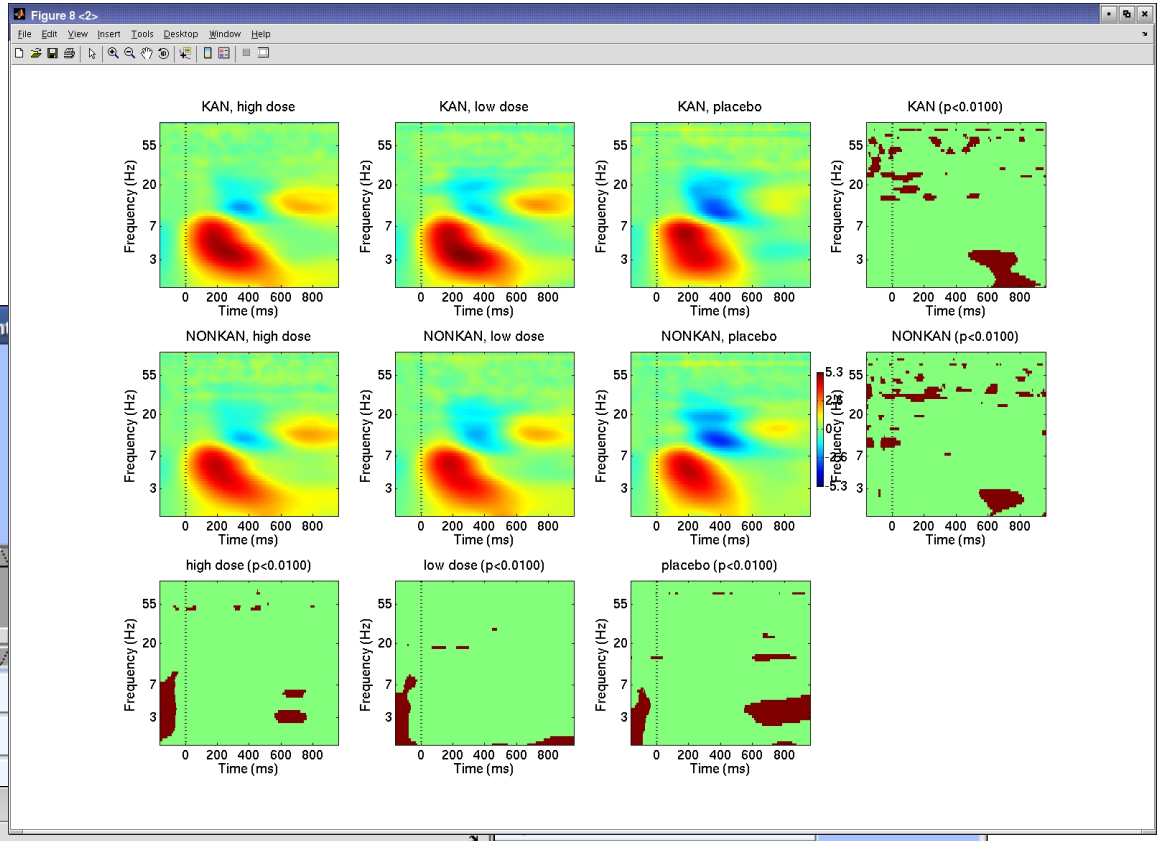
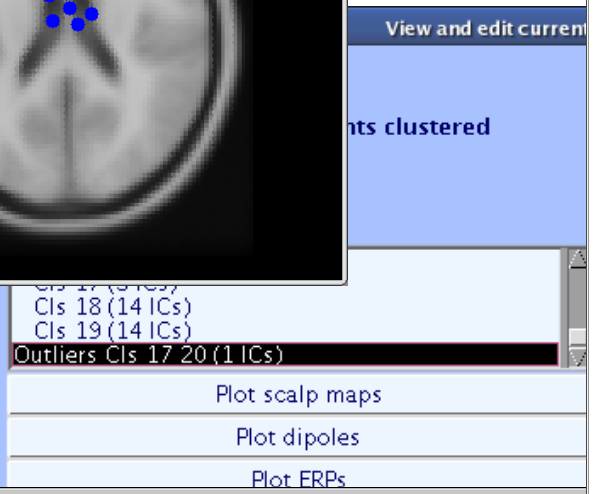


Figure 8 <2>
KAN, high dose
KAN, low dose
KAN, placebo
KAN (p<0.0100)
NONKAN, high dose
NONKAN, low dose
NONKAN, placebo
NONKAN (p<0.0100)
high dose (p<0.0100)
low dose (p<0.0100)
placebo (p<0.0100)
Frequency (Hz)
Time (ms)


View and edit current
Cls 18 (14 ICs)
Cls 19 (14 ICs)
Outliers Cls 17 20 (1 ICs)
Plot scalp maps
Plot dipoles
Plot ERPs

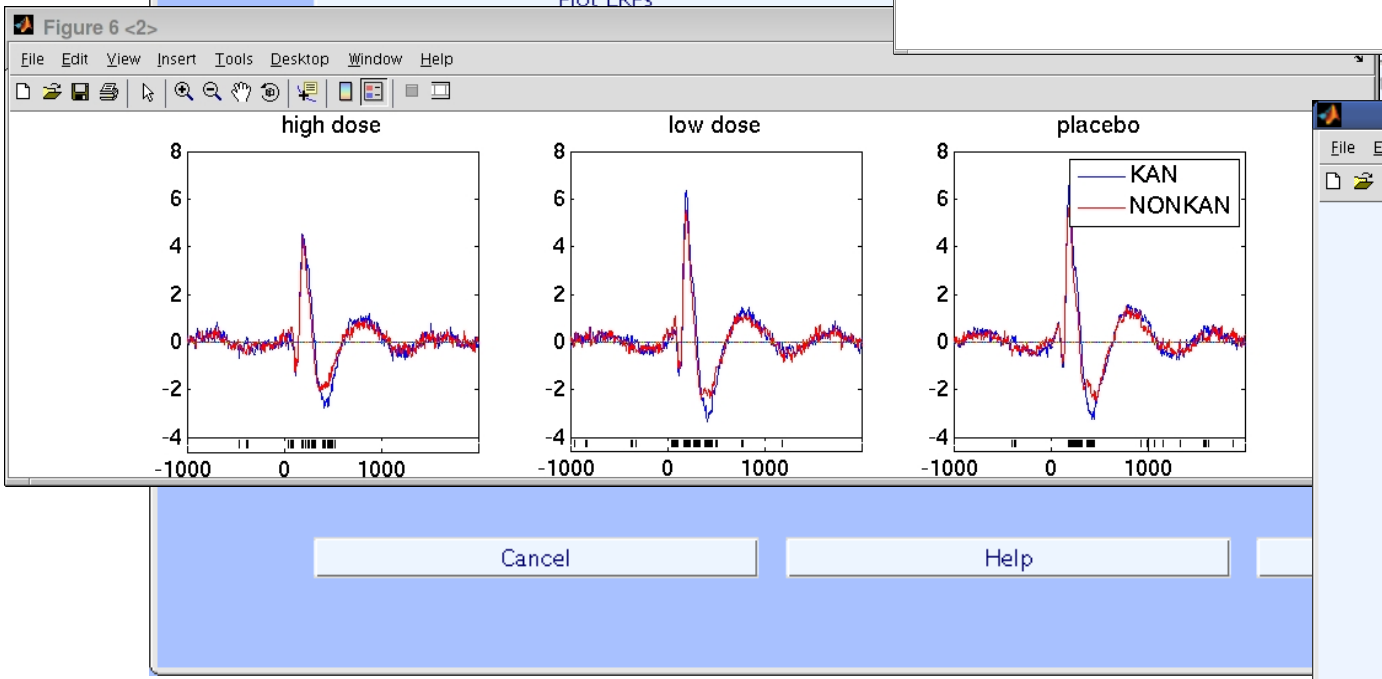


Figure 6 <2>
File Edit View Insert Tools Desktop Window Help
high dose
low dose
placebo
KAN
NONKAN
Cancel
Help

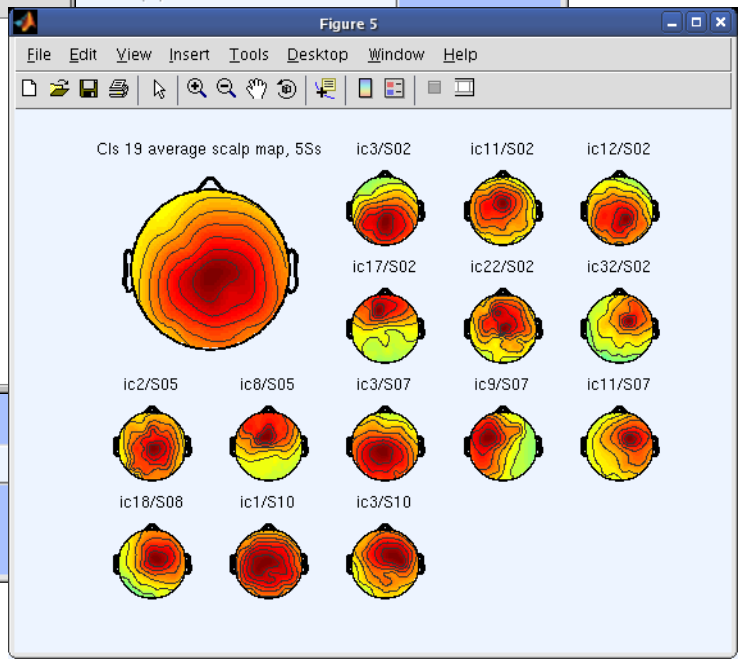


Figure 5
File Edit View Insert Tools Desktop Window Help
Cls 19 average scalp map, 5Ss
ic3/S02
ic11/S02
ic12/S02
ic17/S02
ic22/S02
ic32/S02
ic2/S05
ic8/S05
ic3/S07
ic9/S07
ic11/S07
ic18/S08
ic1/S10
ic3/S10

EEGLAB standard processing pipeline

Single subject

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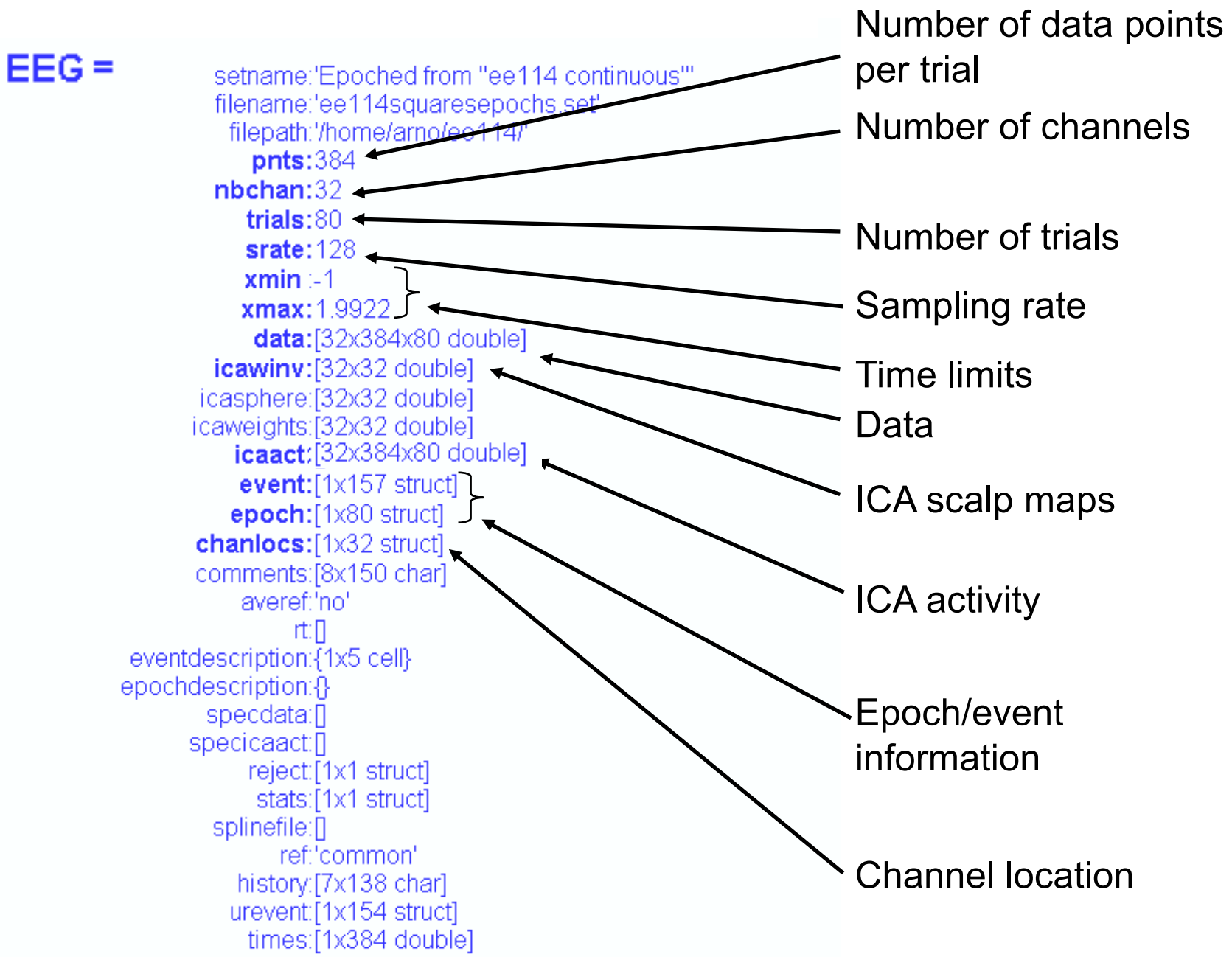
   - Analyze components contribution to spectrum

Multi-subjects

1. Build study and design
2. Pre-compute measures
3. Cluster components
4. Analyze clusters

Advanced analysis using scripting and EEGLAB command line functions

EEG structure



3 levels of functions

Administrative functions: handle EEG and ALLEEG structures

eeglab(), eeg_checkset(), pop_delset(), …

Pop functions: interactive functions using EEG structure

pop_erpimage(), pop_topoplot(), pop_envtopo(), …

Signal processing functions: perform signal processing

erpimage(), topoplot(), envtopo(), …

Command line tools

(“eegh” Menus write both dataset and global history)

- Automated processing on groups of subjects (possibly on several processors).
- Richer options for plotting and processing functions (time-frequency decompositions, …)
- Custom processing…

EEGLAB Scripting

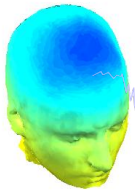
```
% Create Stern STUDY
[ALLEEG EEG CURRENTSET ALLCOM] = eeglab;
pop_editoptions( 'option_storedisk', 1);
subjects = {'S01' 'S02' 'S03' 'S04' 'S05' 'S06' 'S07' 'S08' 'S09' 'S10' 'S11' 'S12'};
filepath = '/Users/arno/temp/STUDY'; % XXXXX Change path here XXXXX
if ~exist(filepath), error('You need to change the path to the STUDY'); end;
commands = {}; % initialize STUDY dataset list

% Loop through all of the subjects in the study to create the dataset
for loopnum = 1:length(subjects) %for each subject
    IgnoreFile   = fullfile(filepath, subjects{loopnum}, 'Ignore.set');
    MemorizeFile = fullfile(filepath, subjects{loopnum}, 'Memorize.set');
    ProbeFile    = fullfile(filepath, subjects{loopnum}, 'Probe.set');
    commands = {commands{:} ...
        {'index' 3*loopnum-2 'load' IgnoreFile   'subject' subjects{loopnum} 'condition' 'Ignore'} ...
        {'index' 3*loopnum-1 'load' MemorizeFile 'subject' subjects{loopnum} 'condition' 'Memorize'} ...
        {'index' 3*loopnum   'load' ProbeFile    'subject' subjects{loopnum} 'condition' 'Probe'}};
end;
% Uncomment the line below to select ICA components with less than 15% residual variance
% commands = {commands{:} {'dipselect', 0.15}};
[STUDY, ALLEEG] = std_editset(STUDY, ALLEEG, 'name','Sternberg','commands',commands,'updatedat','on');

% Update workspace variables and redraw EEGLAB
CURRENTSTUDY = 1; EEG = ALLEEG; CURRENTSET = [1:length(EEG)];
[STUDY, ALLEEG] = std_checkset(STUDY, ALLEEG);
eeglab redraw

[STUDY ALLEEG] = std_precomp(STUDY, ALLEEG, {},'rmicacomps','on','interp','on','recompute','on','erp','on');
STUDY = pop_erpparams(STUDY, 'topotime',[200 300] );
[STUDY erpdata] = std_erpplot(STUDY,ALLEEG,'channels',{'LEYE' 'REYE' 'OZ' 'O2' 'FP1' 'FPZ' 'FP2' 'AF7' ...
            'AF3' 'AFZ' 'AF4' 'AF8' 'F9' 'F7' 'F5' 'F3' 'F1' 'FZ' 'F2' 'F4' 'F6' 'F8' 'F10' 'FT9' ...
            'FT7' 'FC5' 'FC3' 'FC1' 'FCZ' 'FC2' 'FC4' 'FC6' 'FT8' 'FT10' 'T7' 'C5' 'C3' 'C1' 'CZ' ...
            'C2' 'C4' 'C6' 'T8' 'TP9' 'TP7' 'CP5' 'CP3' 'CP1' 'CPZ' 'CP2' 'CP4' 'CP6' 'TP8' 'TP10' ...
            'P7' 'P5' 'P3' 'P1' 'PZ' 'P2' 'P4' 'P6' 'P8' 'PO9' 'PO7' 'PO3' 'POZ' 'PO4' 'PO8' 'PO10' 'O1'});

dlmwrite('erpfile.txt',squeeze(erpdata{1}),'delimiter', '\t', 'precision', 2);
dlmwrite('erpfile.txt',squeeze(erpdata{2}),'-append', 'roffset', 1, 'delimiter', '\t', 'precision', 2);
dlmwrite('erpfile.txt',squeeze(erpdata{2}),'-append', 'roffset', 1, 'delimiter', '\t', 'precision', 2);
```

Pros/Cons of Matlab based open source

- Pros
  - Easy to program, highly modular and extendable
  - Not dependent on any platform (64-bit) and highly optimized
  - Large community of users (latest development in signal processing research)
  - Powerful scripting capabilities

- Cons
  - Matlab required for which you have to pay
  - Large memory requirements
  - Matlab bugs, possible version differences, cross-platform compatibility problems
  - Poor graphical interface

EEGLAB articles



Delorme, A., Makeig, S. (2004) EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, 134(1), 9-21.

Makeig, S., Debener, S., Onton, J., Delorme, A. (2004) Mining event related dynamics. *Trends in cognitive Neuroscience*, 8(5), 204-210.

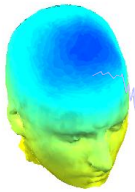
Delorme, A., Mullen, T., Kothe, C., Bigdely-Shamlo, N., Akalin, Z., Vankov, A., Makeig, S. (2011) EEGLAB, MPT, NetSIFT, NFT, BCILAB, and ERICA: New tools for advanced EEG/MEG processing. Computational Intelligence, article ID 130714.

Delorme, A., Kothe, C., Bigdely, N., Vankov, A., Oostenveld, R., Makeig, S. (2010) Matlab Tools for BCI Research? In "human-computer interaction and brain-computer interfaces". Editors : Tan, D. and Nijholt, A. Springer Publishing.

Delorme, A., Makeig, S. (2009) Open Source Programming for Interpreted Language: Graphic Interface and Macro Bridging Interface. 2009 Fifth International Conference on Signal-Image Technology & Internet-Based Systems (SITIS, indexed in IEEE), Nov. 29 2009-Dec. 4 2009, 430-434.

Delorme, A., Palmer, J., Onton, J., Oostenveld, R., Makeig, S. (2012) Independent EEG sources are dipolar.PLoS One, 7(2).

Delorme, A., Miyakoshi., M., Jung, T.P., Makeig, S. (2014) Grand average ERP-image plotting and statistics: A method for comparing variability in event-related single-trial EEG activities across subjects and conditions. J Neurosci Methods. 2014 Oct 22. pii: S0165-0270(14)00363-X. doi: 10.1016/j.jneumeth.2014.10.003



Preliminary Workshop Program (with corresponding PDFs)

Purple lettering = lecture
Orange lettering = tutorial

Tuesday, September 4th 2018

Overview and ICA Theory/Practice

8:30AM – 9:45AM -- Mining event-related brain dynamics I (Scott Makeig)
9:45AM – 10:15AM -- EEGLAB overview (Arnaud Delorme)

-- Coffee Break--

10:30AM – 11:30AM -- ICA theory (Scott Makeig)
11:30AM – 12:30AM -- Data import, Artifact rejection (Arnaud Delorme)

12:30-2:00PM < Lunch -- On your own

ICA and time-frequency

2:00PM – 3:15PM -- ICA decomposition practicum (Arnaud Delorme)

--Coffee Break--

3:30PM – 4:15PM -- Time-frequency decompositions: Theory and practice (Scott Makeig)
4:15PM – 5:15PM -- Source information flow and Granger-Causal modeling tools (Arnaud Delorme)

Wednesday, September 5th 2018

Source Localization

8:30AM – 9:15AM -- Forward and inverse modeling (Scott Makeig)
9:15AM – 10:00AM -- DIPFIT practicum (Arnaud Delorme)

-- Coffee Break--

10:15AM - 11:15AM -- Why cluster ICA components? (Scott Makeig)
11:15AM - 12:00AM -- Robust statistics and correction for multiple comparisons (Arnaud Delorme)
12:00AM - 12:30AM -- Creating a STUDY, STUDY design, and basic plotting (Arnaud Delorme)

12:30AM-2:00PM Lunch -- On your own

Group analysis and ICA clustering in EEGLAB

2:00PM - 3:15PM -- Group analysis using EEGLAB studies: Methods to cluster ICA components (Arnaud Delorme)

-- Coffee Break--

3:30PM – 4:00PM -- Scripting in EEGLAB overview (Arnaud Delorme)
4:00PM – 5:00PM -- Mining event-related brain dynamics II (Scott Makeig)