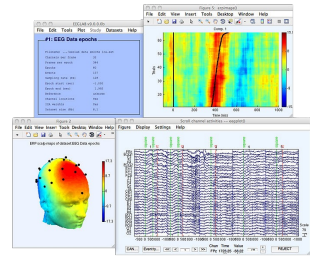
EEGLAB overview

Arnaud Delorme

UC San Diego

EEGLAB History Timeline



1997 — EEG/ICA Toolbox (Salk Institute)

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

2003 — EEGLAB issued to wide audience (Salk Institute) and NIH support

2006 — EEGLAB plug-ins, STUDY structure

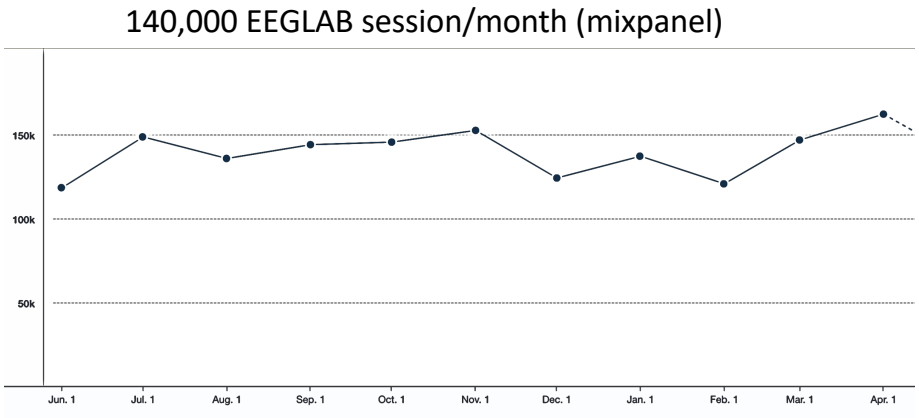
2011 — EEGLAB, the most widely used EEG research environment

2018 — EEGLAB STUDY use single trial and LIMO integration

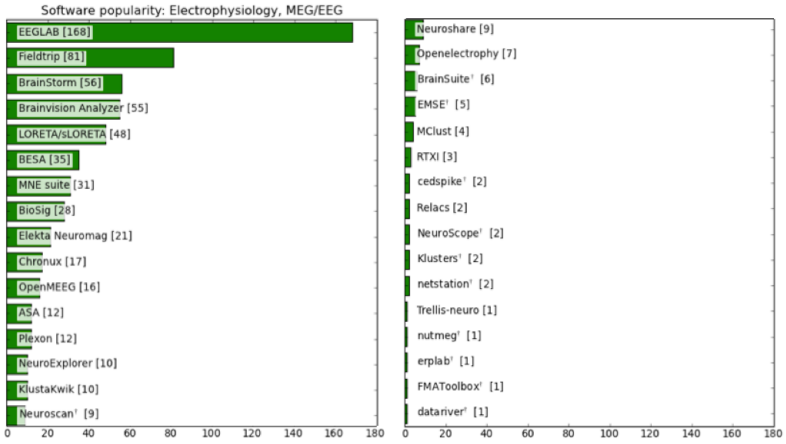
2021 — BIDS integration, big data pipelines, New website

EEGLAB in a few numbers

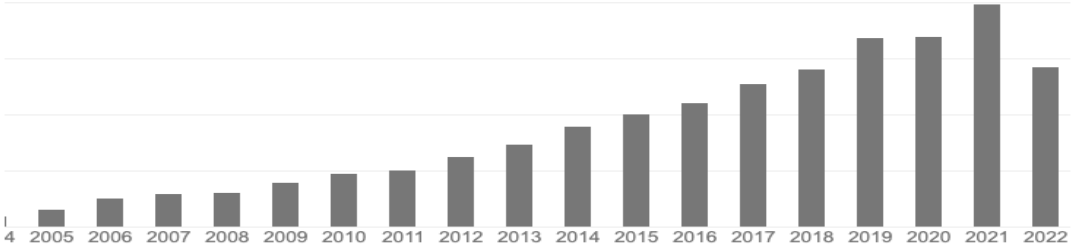
- About 600 functions (150 000 lines of code)
- About 400,000 download over the past 10 years
- 15,500 users on the diffusion list
- Supporting 423 million of dollars of research as of 2022
- NIH funding since 2003
- 143 plugins



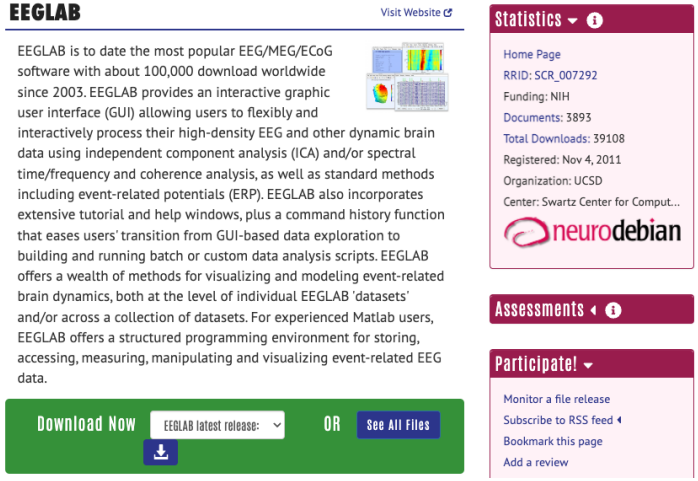
Hanke & Helcencko, 2011, Frontier in Neuroinformatics

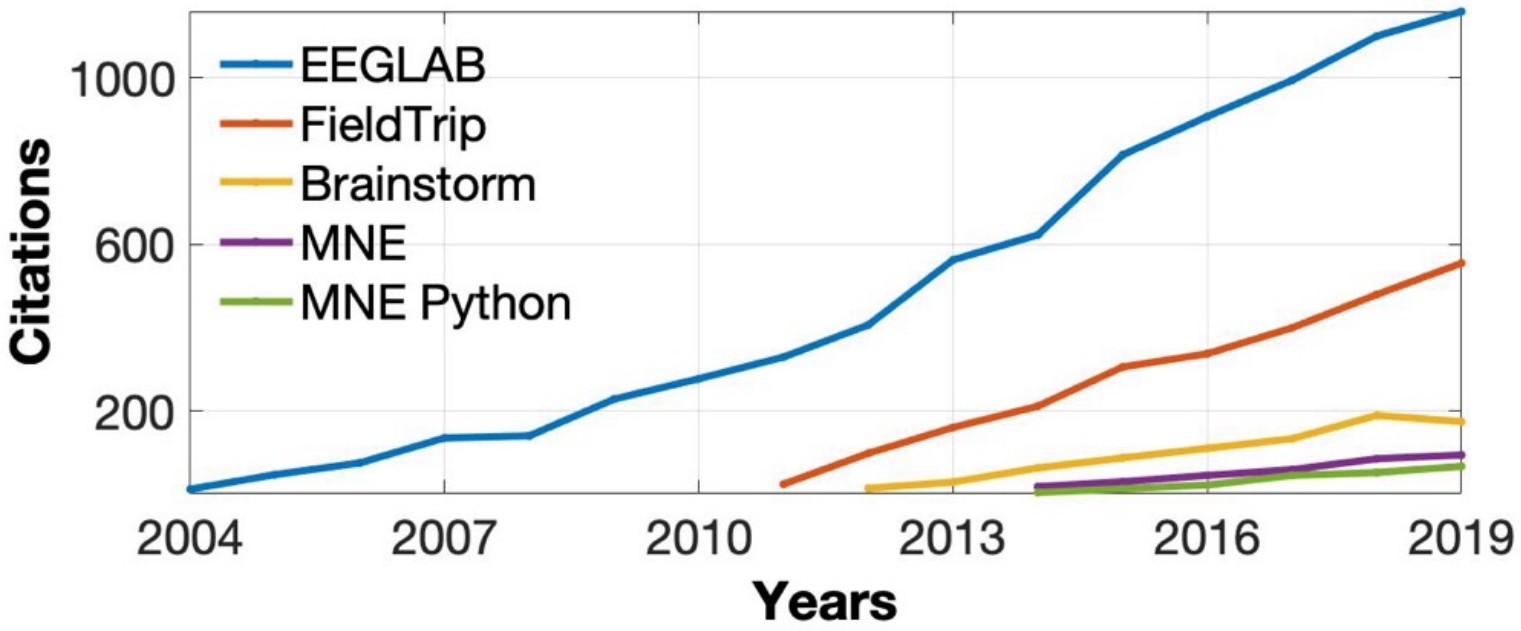


EEGLAB reference article 18,194 citations (September 2022)



Most popular EEG tool on NITRC



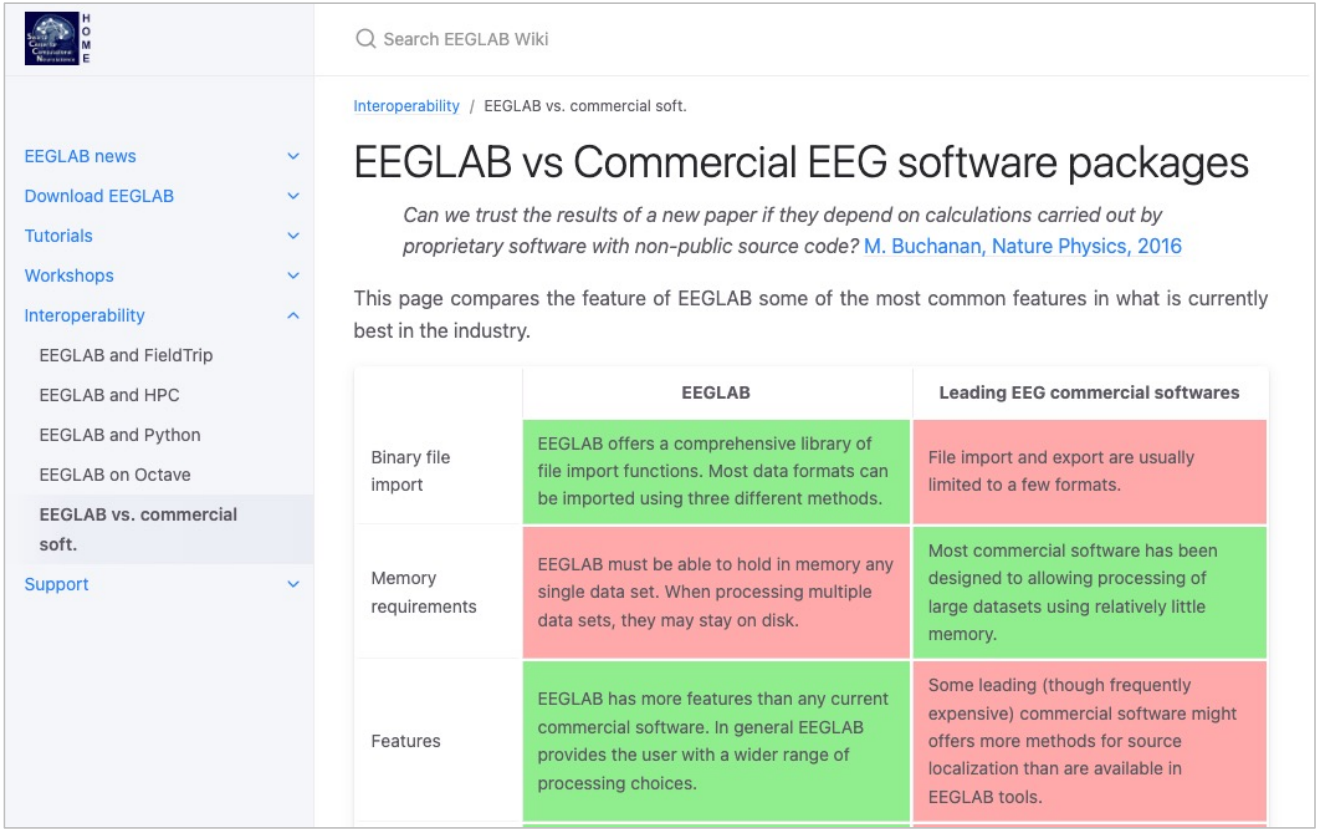

EEGLAB
FieldTrip
Brainstorm
MNE
MNE Python
Citations
1000
600
200
2004
2007
2010
2013
2016
2019
Years

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



HOME

Search EEGLAB Wiki

- EEGLAB news
- Download EEGLAB
- Tutorials
- Workshops
- Interoperability
  - EEGLAB and FieldTrip
  - EEGLAB and HPC
  - EEGLAB and Python
  - EEGLAB on Octave
  - **EEGLAB vs. commercial soft.**
- Support

Interoperability / EEGLAB vs. commercial soft.

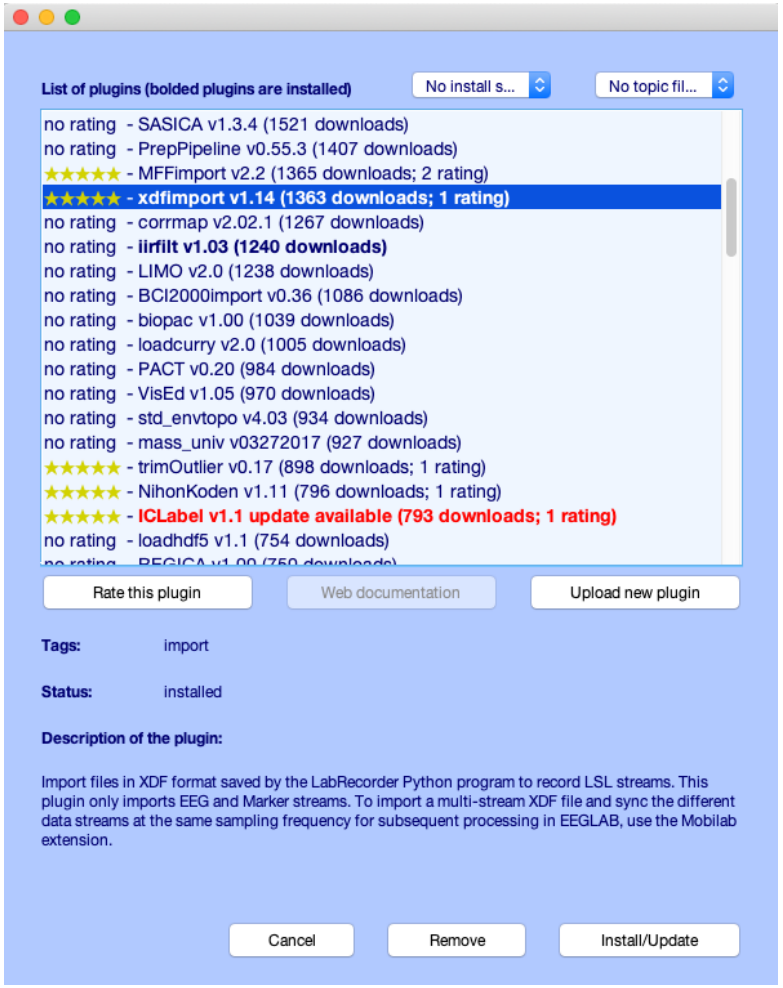
EEGLAB vs Commercial EEG software packages

> *Can we trust the results of a new paper if they depend on calculations carried out by proprietary software with non-public source code?* M. Buchanan, Nature Physics, 2016

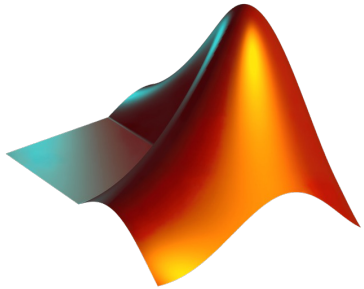
This page compares the feature of EEGLAB some of the most common features in what is currently best in the industry.

	EEGLAB	Leading EEG commercial softwares
Binary file import	EEGLAB offers a comprehensive library of file import functions. Most data formats can be imported using three different methods.	File import and export are usually limited to a few formats.
Memory requirements	EEGLAB must be able to hold in memory any single data set. When processing multiple data sets, they may stay on disk.	Most commercial software has been designed to allowing processing of large datasets using relatively little memory.
Features	EEGLAB has more features than any current commercial software. In general EEGLAB provides the user with a wider range of processing choices.	Some leading (though frequently expensive) commercial software might offers more methods for source localization than are available in EEGLAB tools.

EEGLAB plugin manager



Which MATLAB version?



Download R2020b

R2020b

Download earlier release

- R2010a
- R2009bSP1
- R2009b
- R2009a
- R2008b

Additional MATLAB toolboxes

- Signal processing toolbox
- Statistics toolbox
- Optimization toolbox
- Image processing toolbox

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 commercial license required
- Matlab commercial toolboxes recommended (signal processing, statistics)

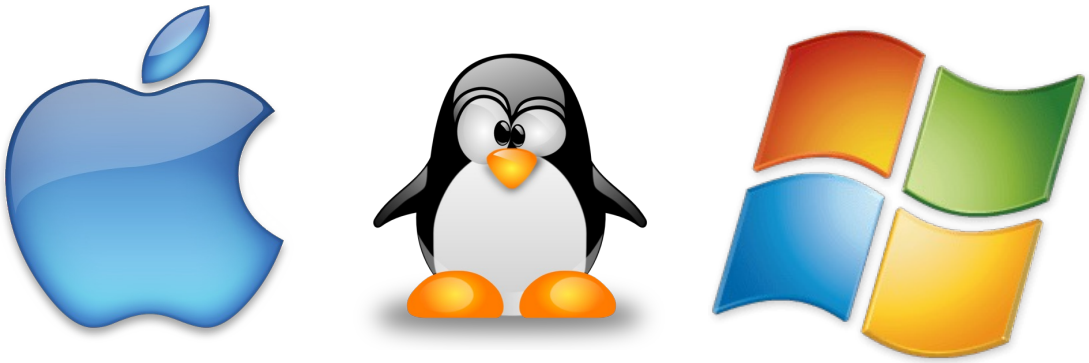
EEGLAB version?

Stable 

Vs.

Dev. 

Which Operating System?

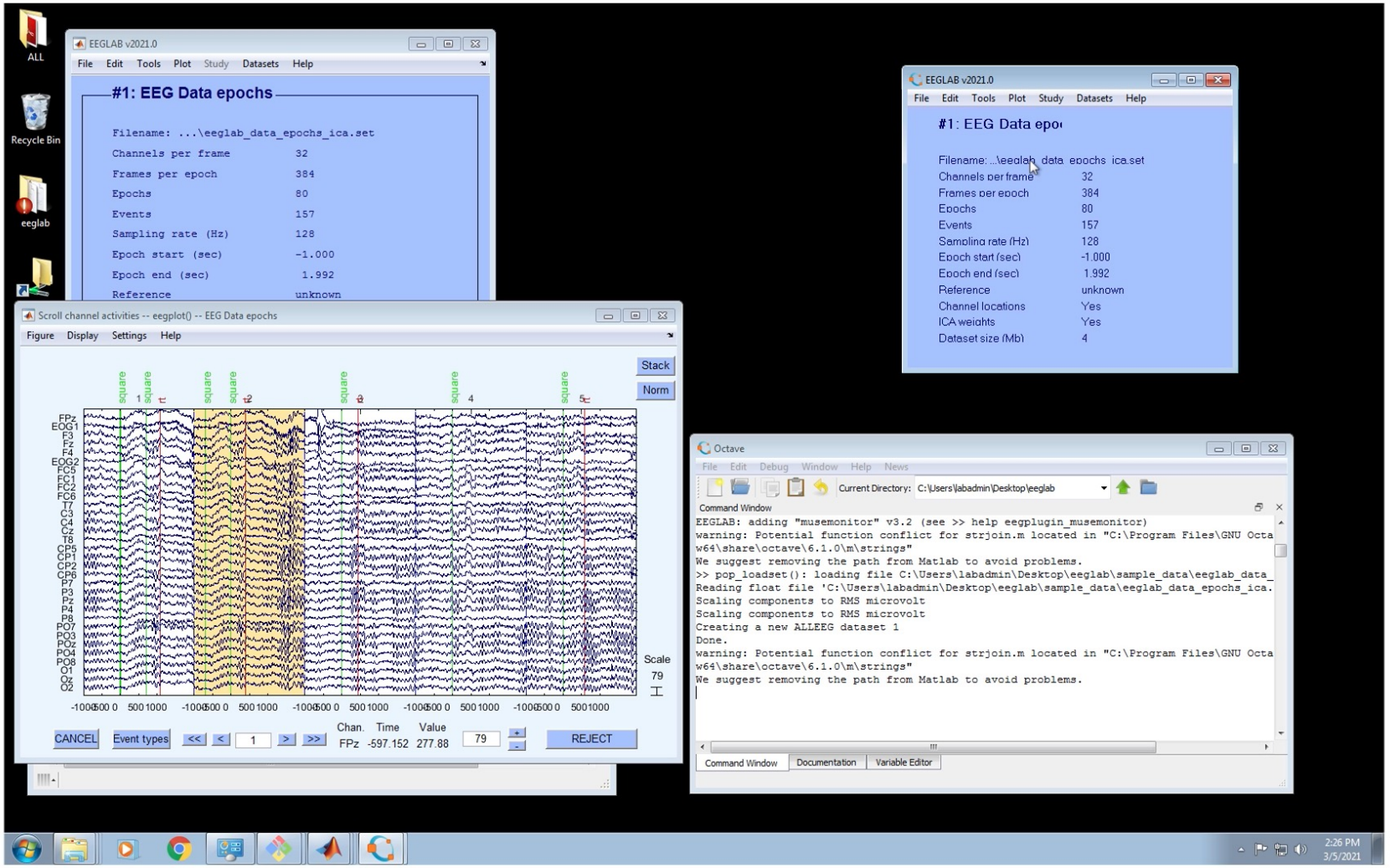


EEGLAB on MATLAB
vs EEGLAB compiled

EEGLAB on Octave

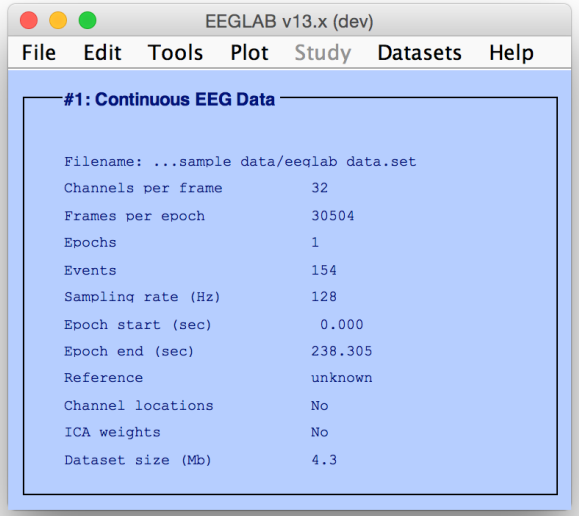
EEGLAB MATLAB

EEGLAB Octave

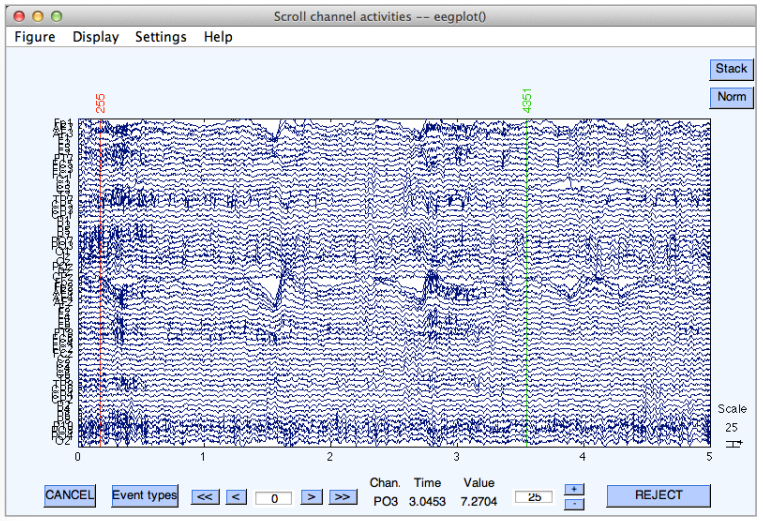


Importing data

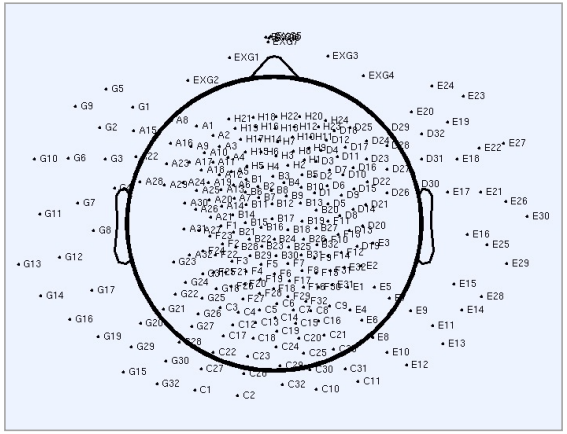
Data info



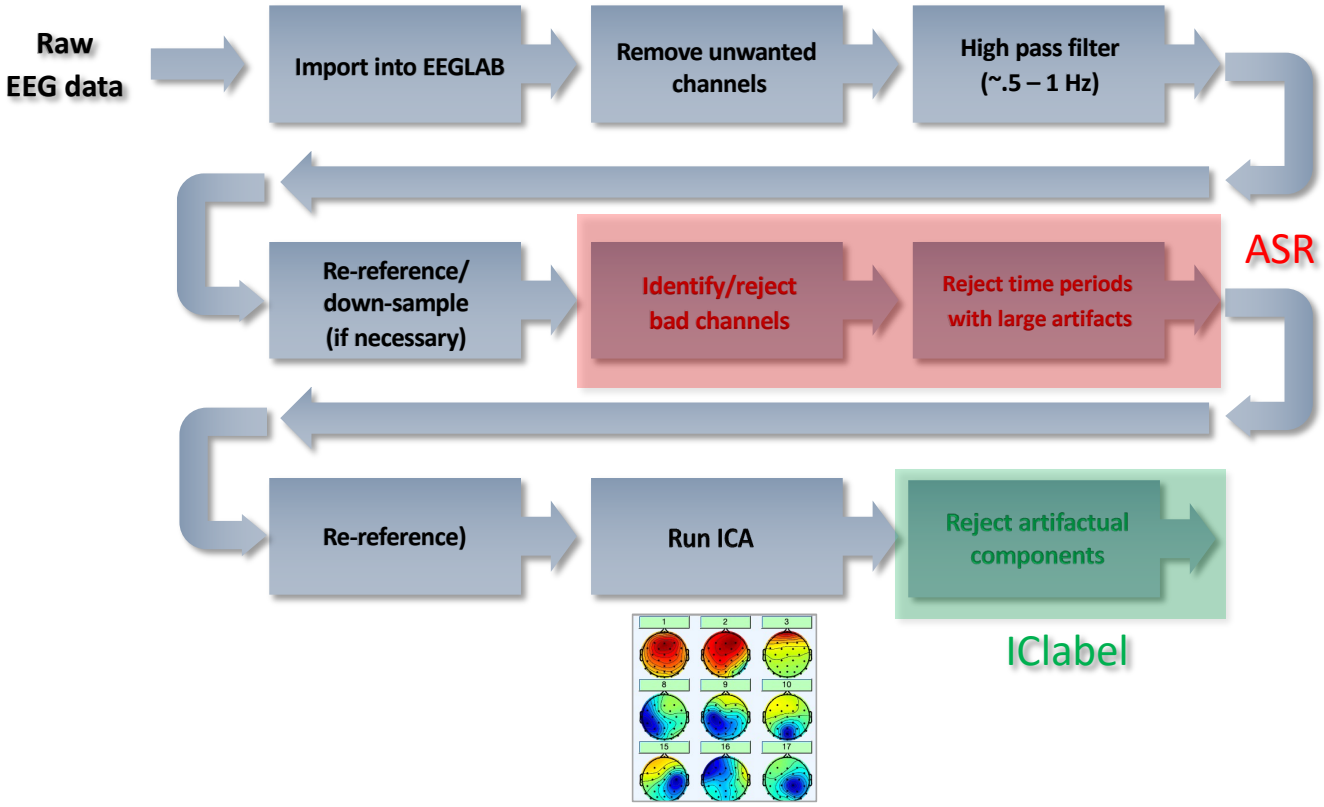
Scrolling data



Channel location



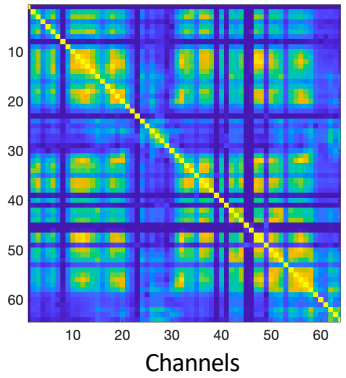
Preprocessing pipeline



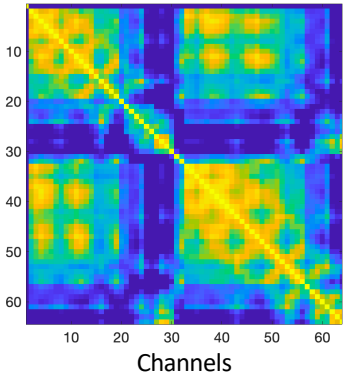
ASR – Artifact Subspace Reconstruction

Pairwise correlation to find bad channels

Bad data



Good data



ASR finds and reconstructs bad portions of data

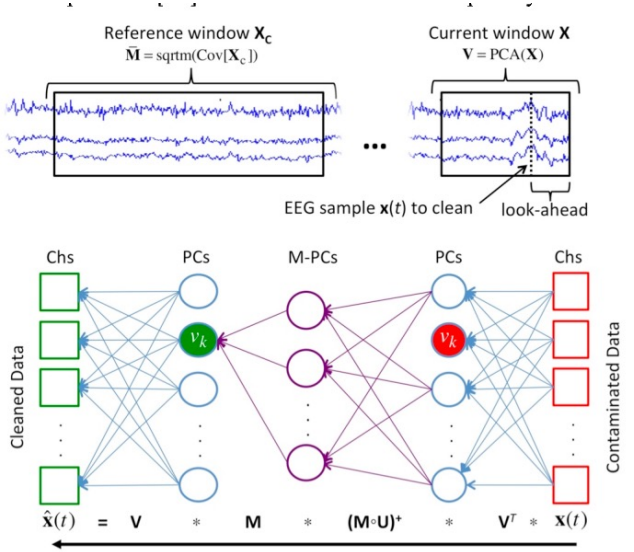
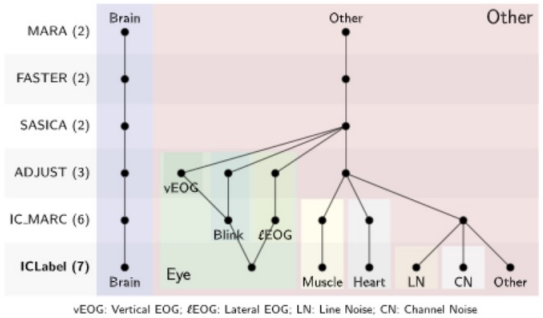


Fig. 3. The Artifact Subspace Reconstruction method. High-variance

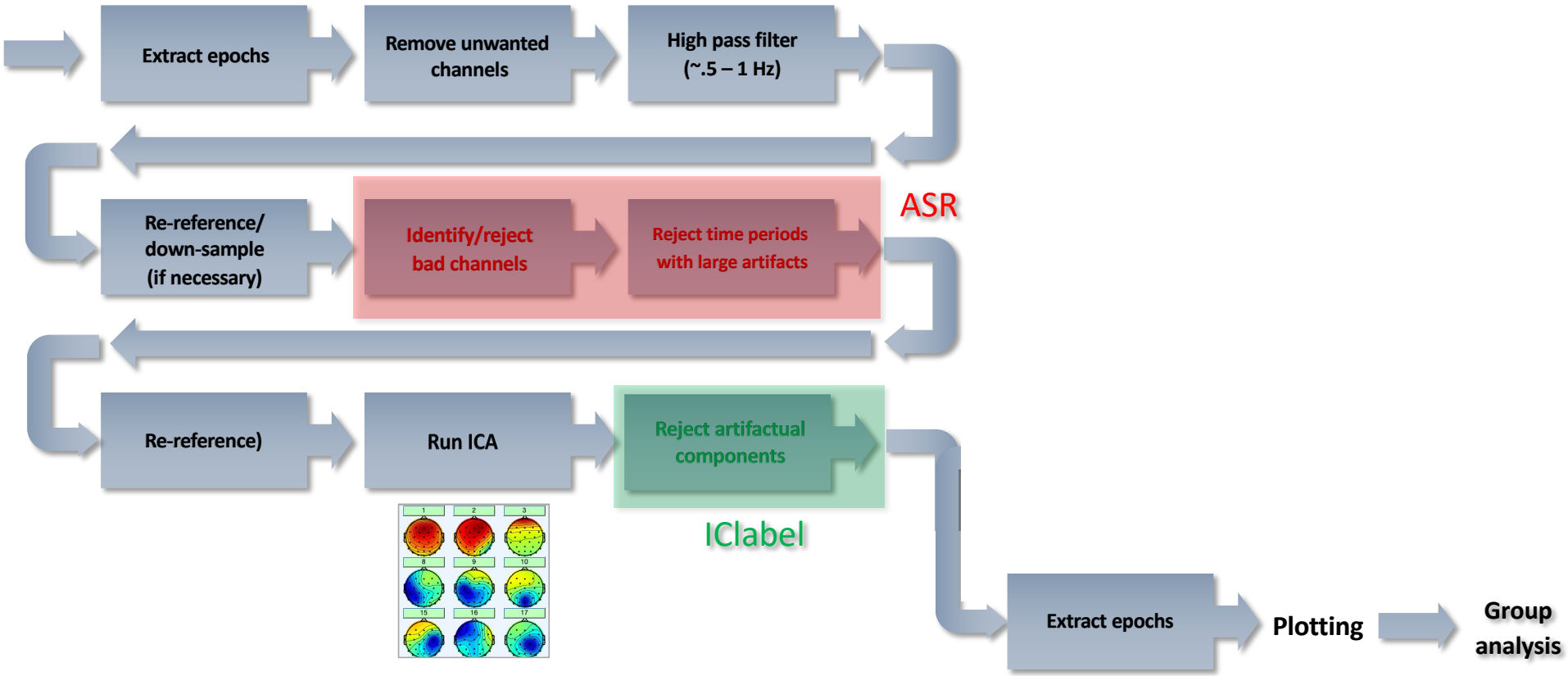
Tim R. Mullen, Christian Kothe, et al.(2015) Real-time neuroimaging and cognitive monitoring using wearable dry EEG. *IEEE Transactions on Biomedical Engineering.* DOI:10.1109/TBME.2015.2481482

ICLabel: Automated ICA component labeling

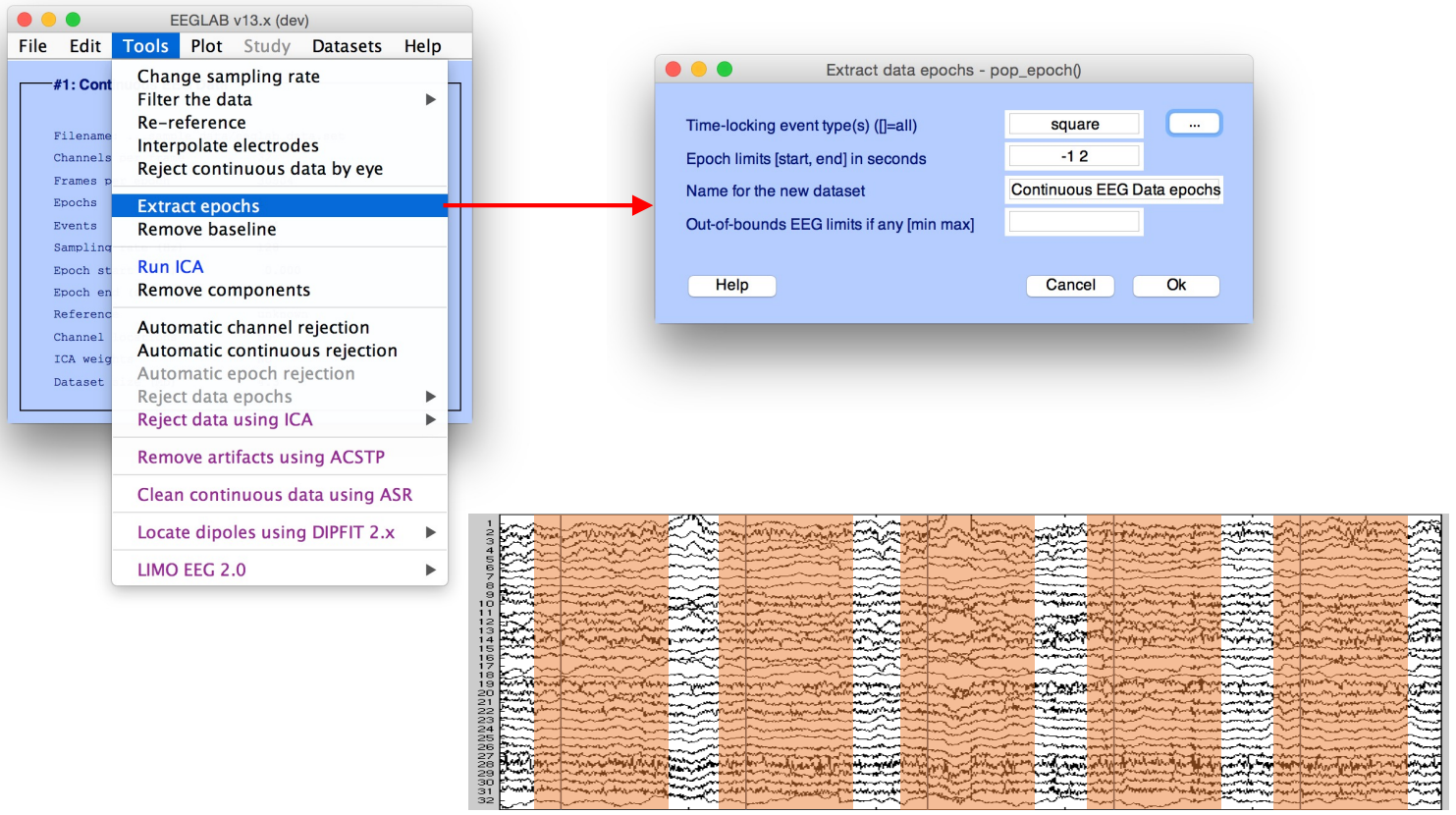


vEOG: Vertical EOG; ℓEOG: Lateral EOG; LN: Line Noise; CN: Channel Noise

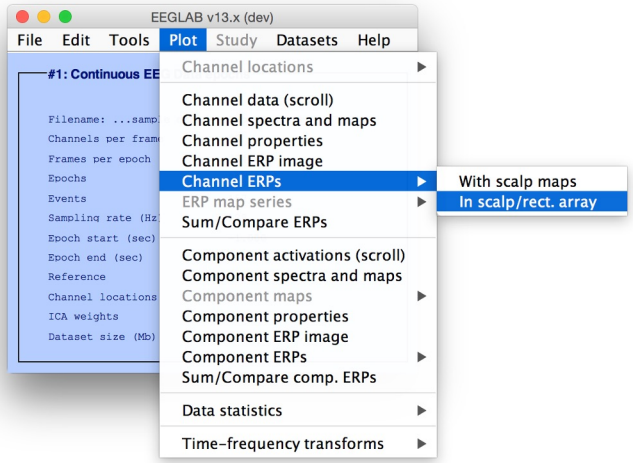
Pion-Tonachini L et al. (2019) ICLabel: An automated electroencephalographic independent component classifier, dataset, and website. Neuroimage, 98:181-197. doi: 10.1016/j.neuroimage.2019.05.026.


Extract epochs
Remove unwanted channels
High pass filter (~.5 – 1 Hz)
Re-reference/ down-sample (if necessary)
Identify/reject bad channels
Reject time periods with large artifacts
ASR
Re-reference)
Run ICA
Reject artifactual components
IClabel
Extract epochs
Plotting
Group analysis

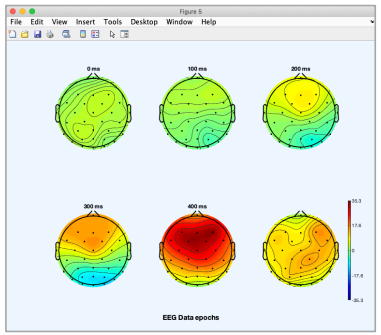
Extract epochs from data



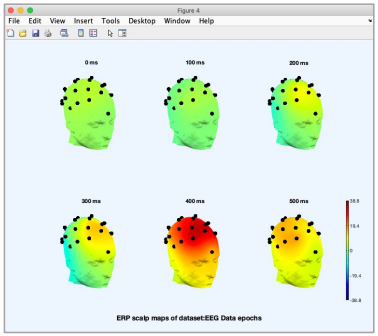
Plot ERPs

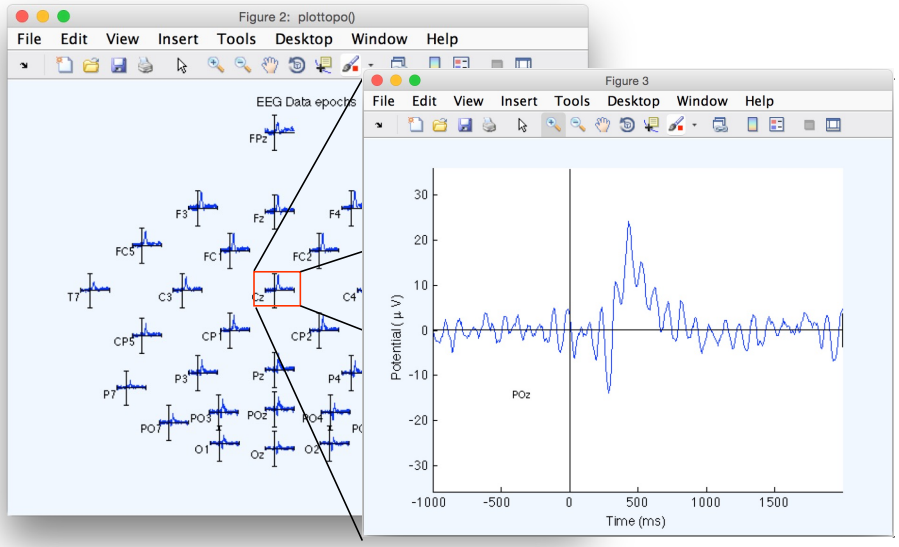


2D

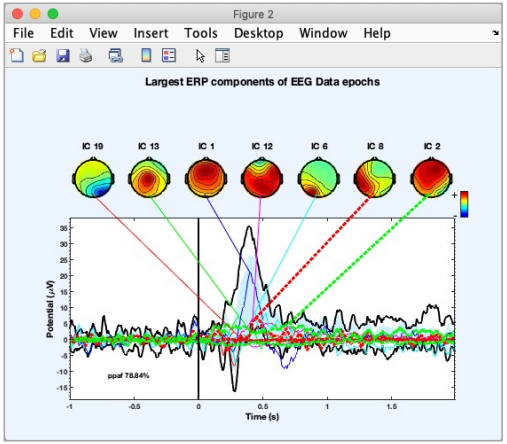


3D

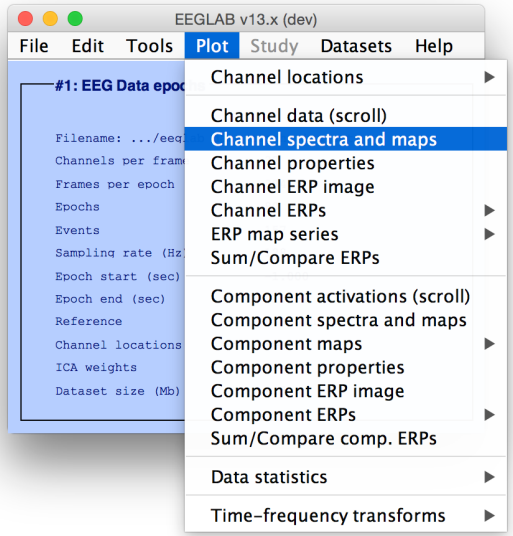


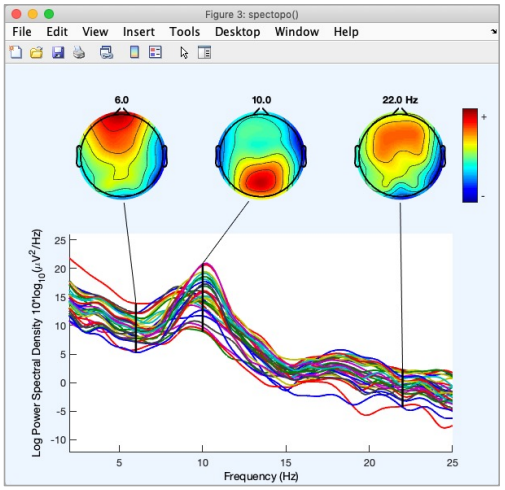


Component contrib. to ERPs

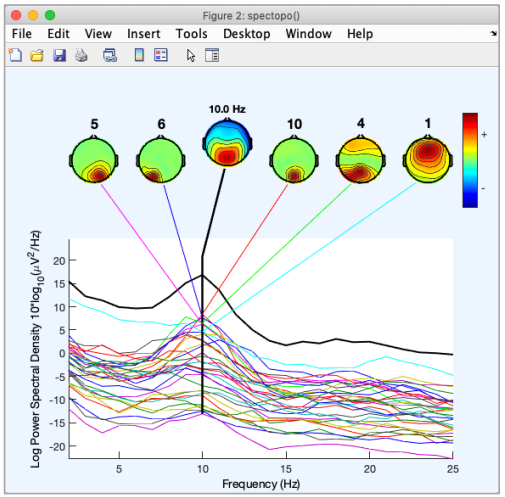


Plot spectrum and maps



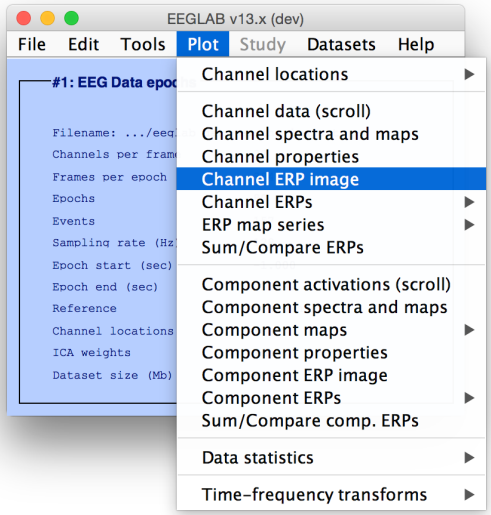


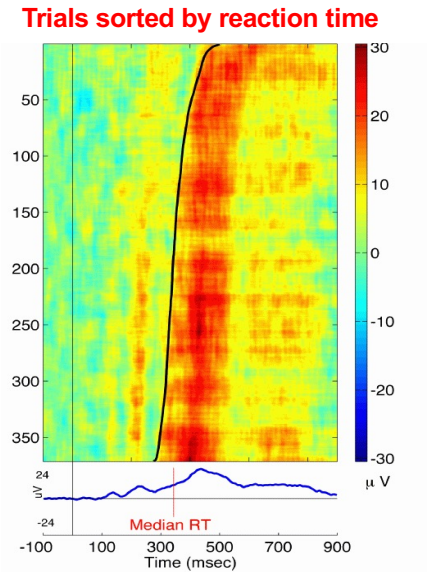
Channel spectrum

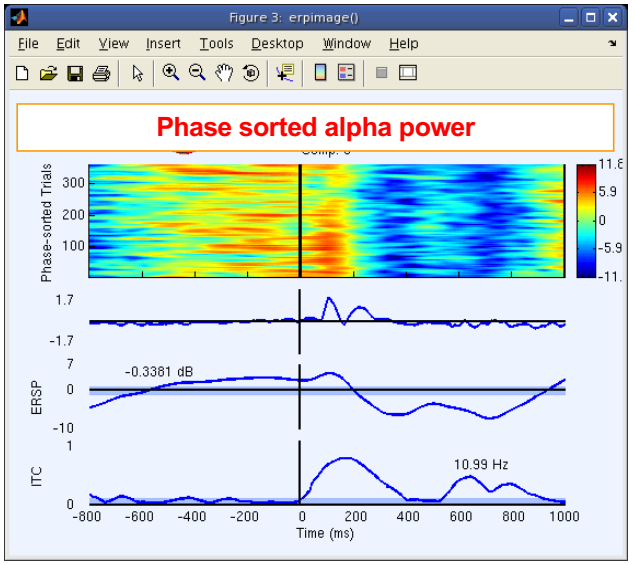


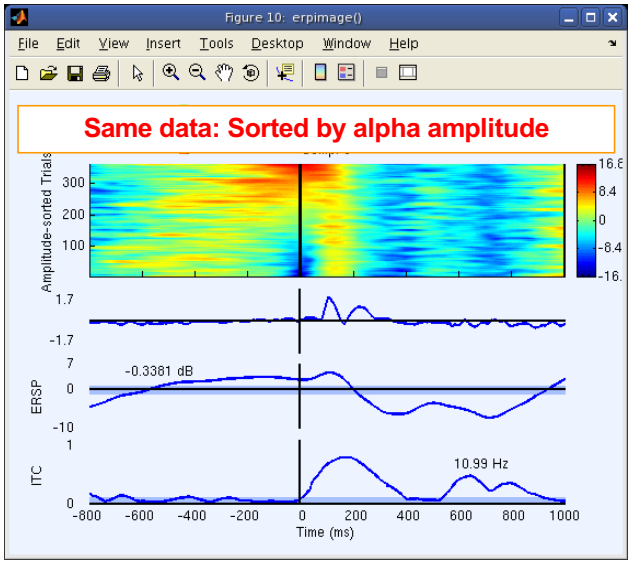
Component contrib. to spectrum

Plot ERPimage

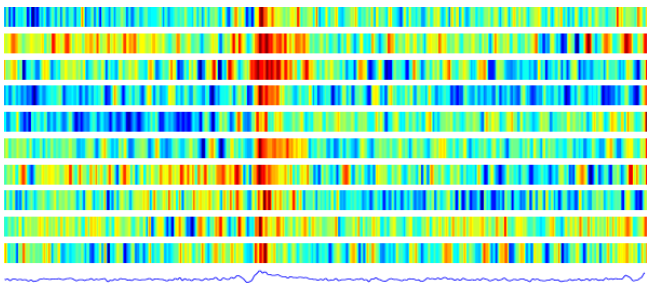




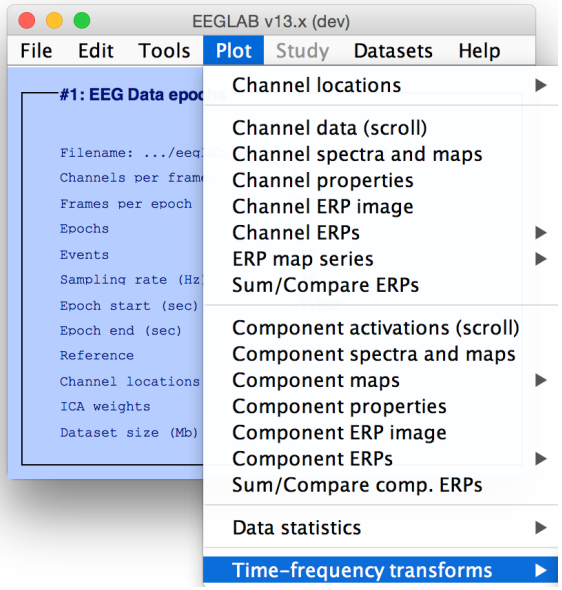


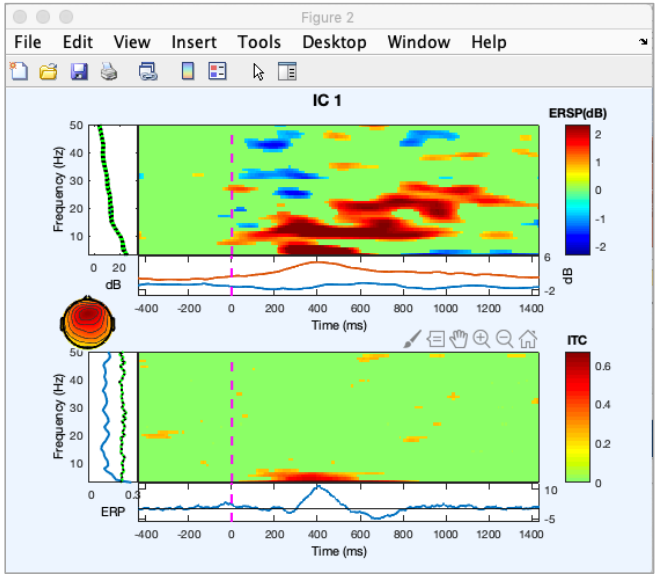


Trial 1:
Trial 2:
.
.
.



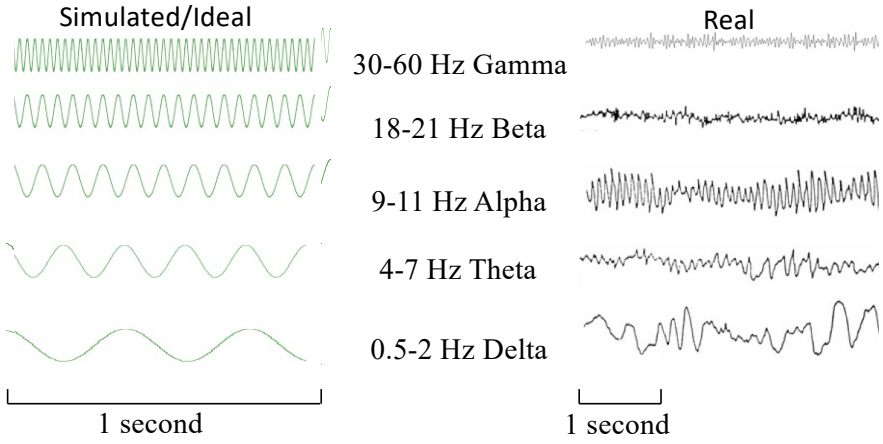
Plot time-frequency decomposition



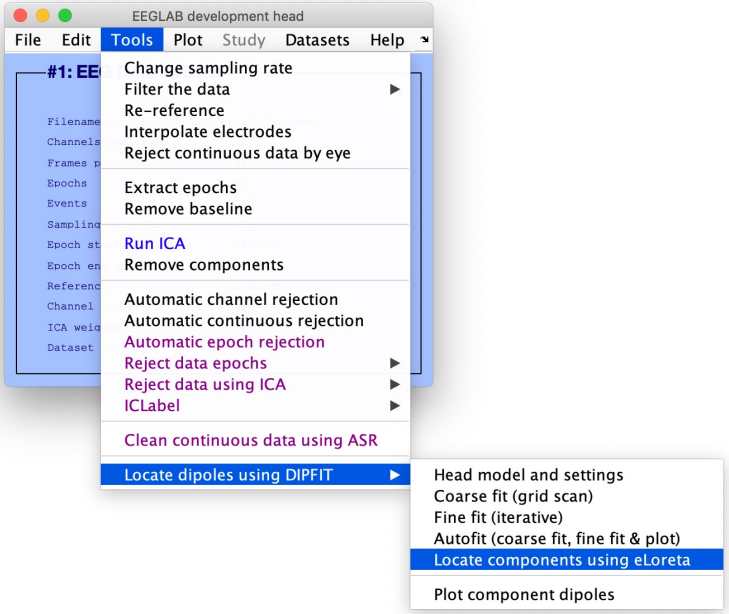


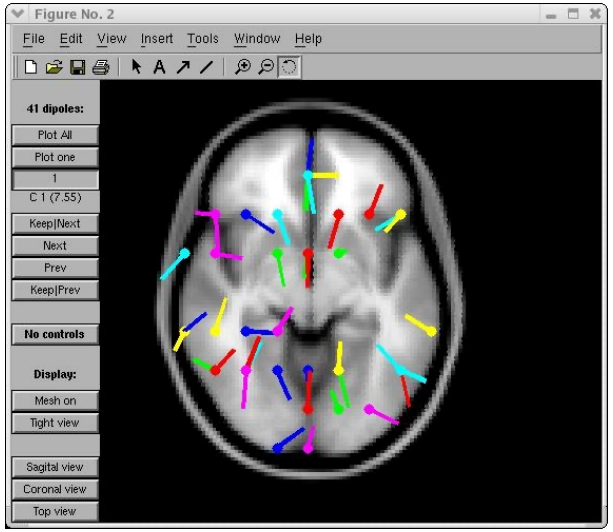
ERSP

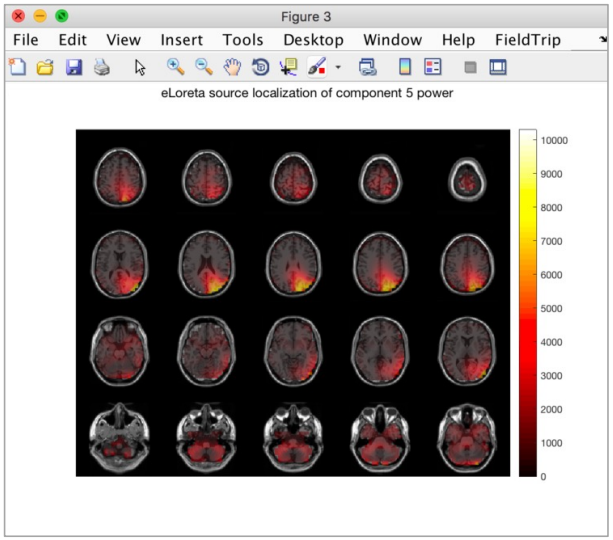
ITC



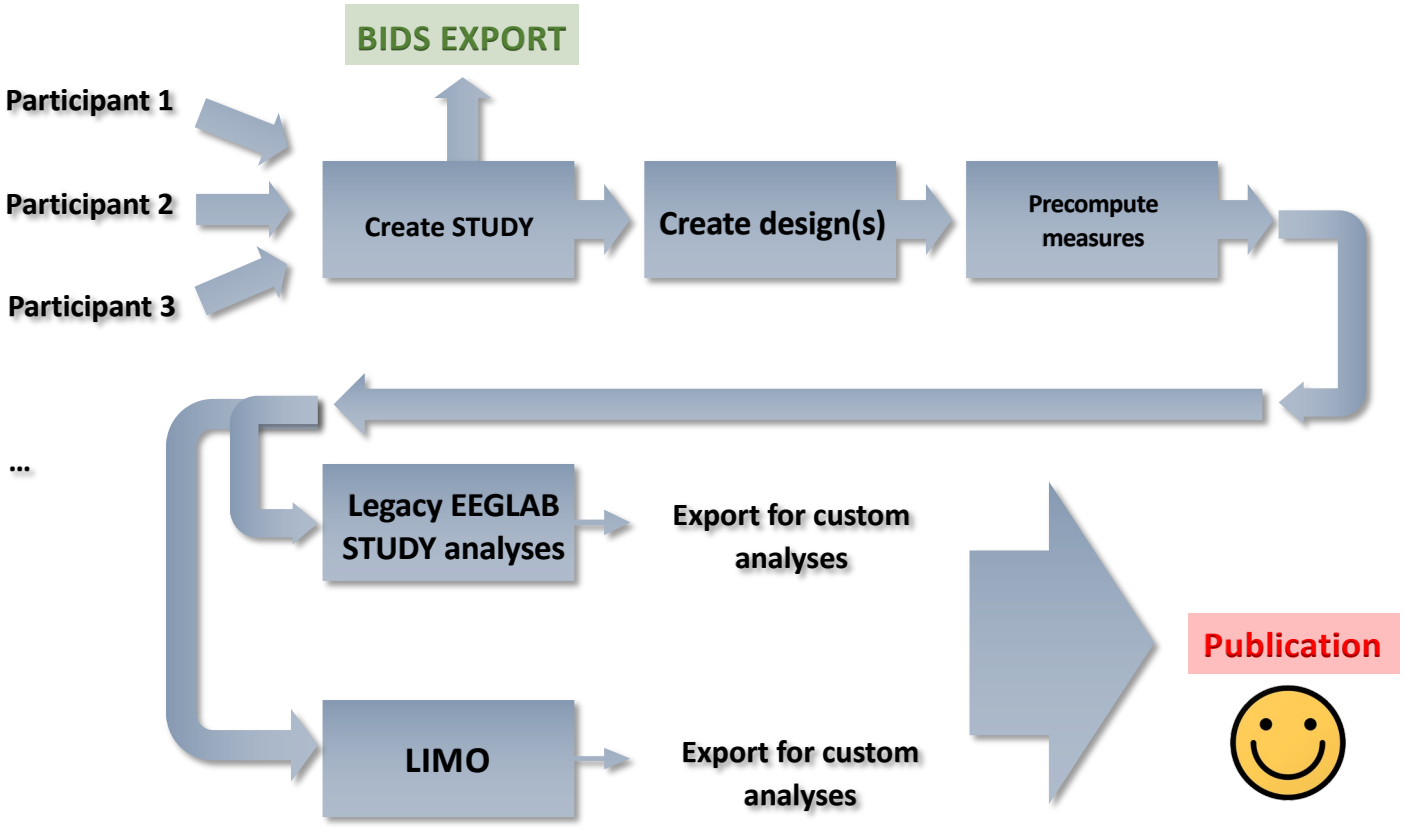
Localizing components







Group analysis pipeline

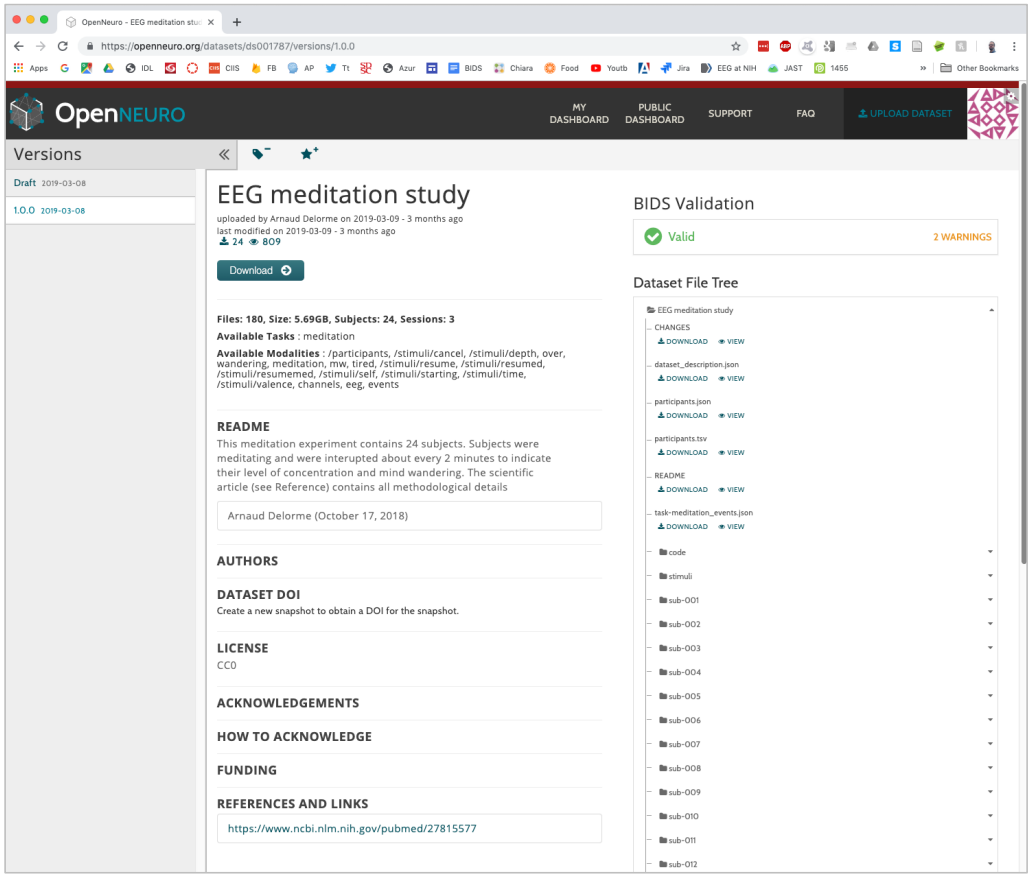


EEGLAB and BIDS

- Export EEGLAB STUDY to BIDS
- Import BIDS to EEGLAB STUDY
- HED support
- Mapping the BIDS architecture

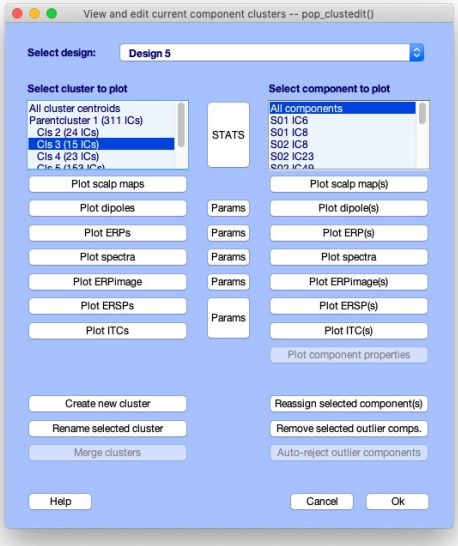
https://github.com/sccn/bids-matlab-tools

OpenNeuro BIDS repository website

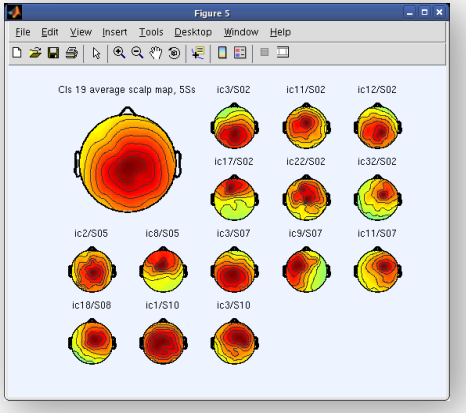


Group analyze channel/component clusters

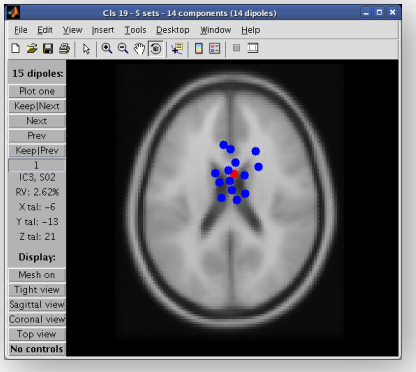
Plotting interface



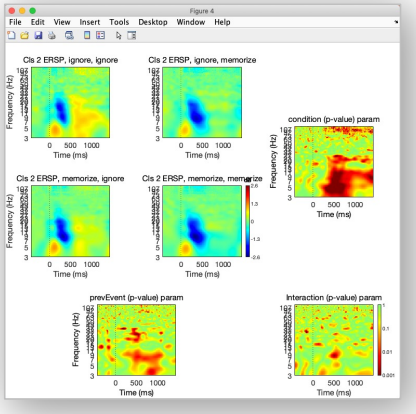
Components making up a cluster



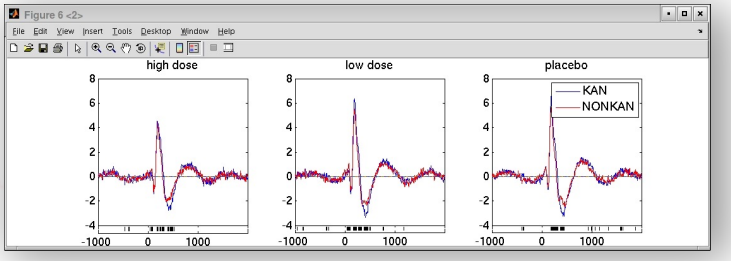
One cluster component dipoles



One cluster ERSPs (2x2 conditions)

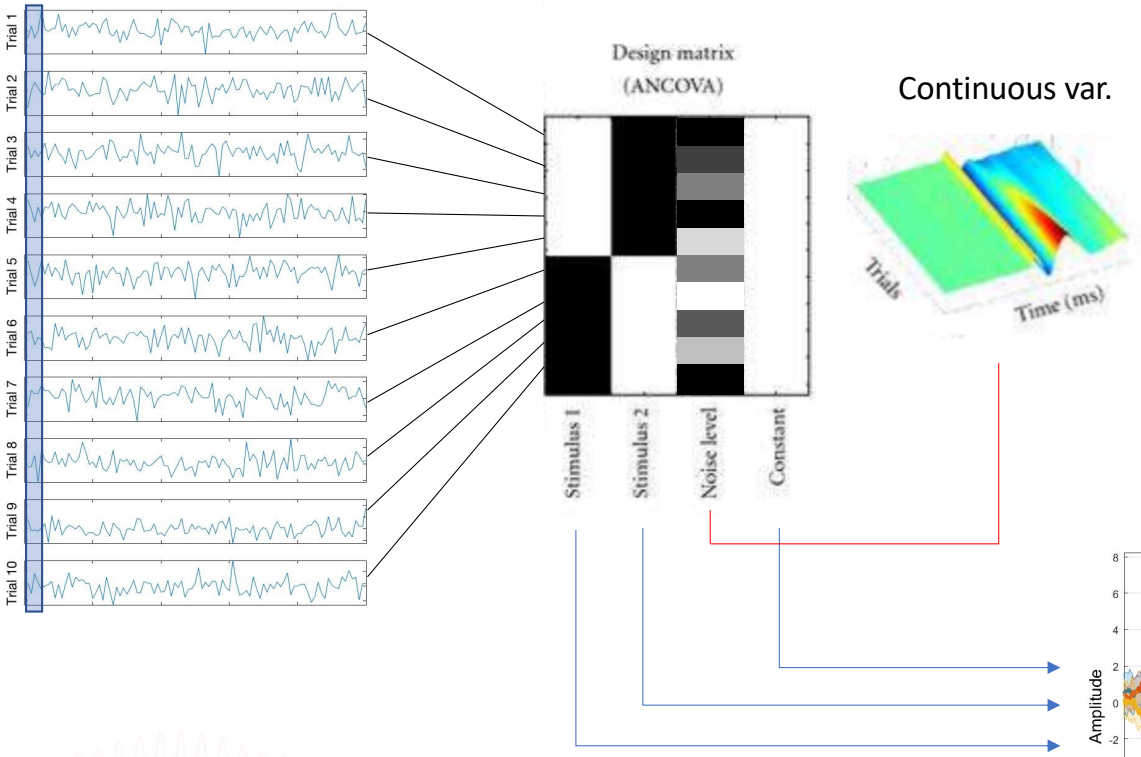


One cluster ERPs (2x3 conditions)



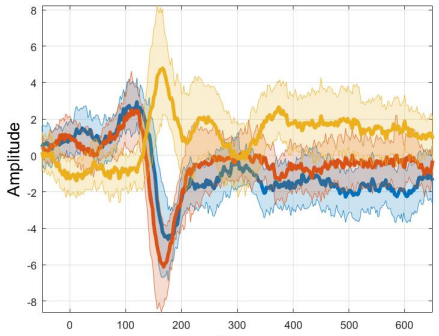
Linear Modeling of EEG data: level 1

Electrode 1

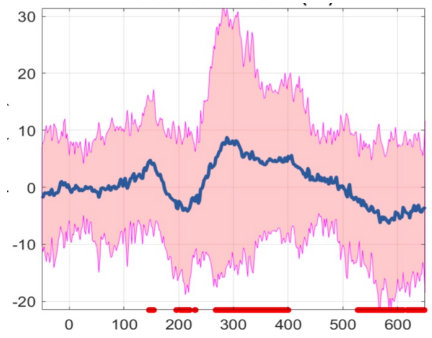


Continuous var.

Categorical var.

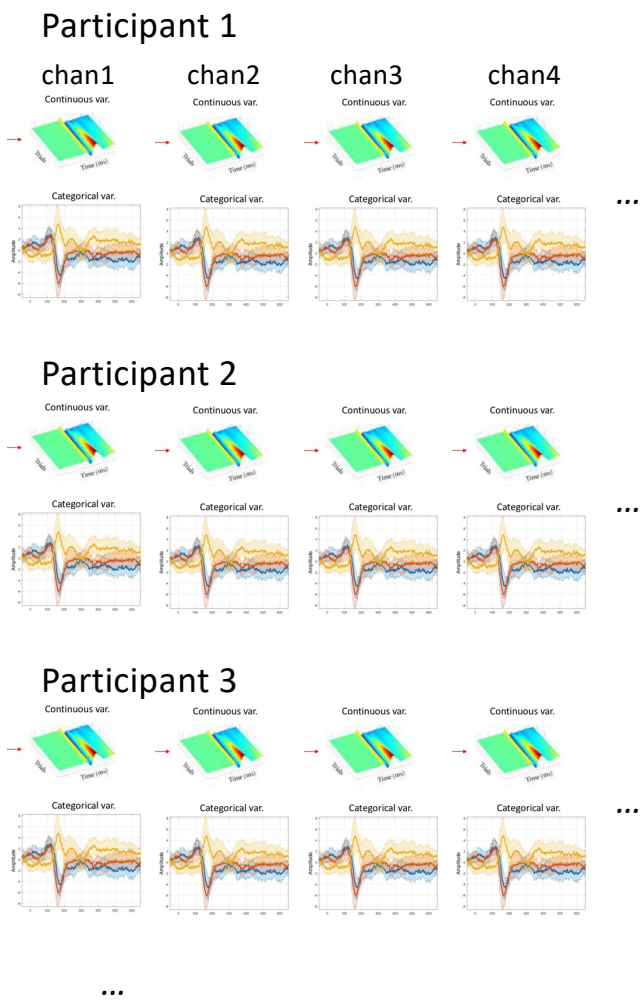


Electrode difference
Between conditions



Significance: bootstrap trials to get confidence interval of βs

Linear Modeling of EEG data: level 2



Level 2

Standard stats.
2nd level-GLM

GLM: ordinary least square (OLS) vs. weighted least square (WLS)

EEGLAB automatically writes scripts for you

- Automated processing pipelines
- Exporting data and results
- Custom processing

- Tight integrations with other tools
  - Fieldtrip back and forth conversion
  - Python integration for Deep Learning

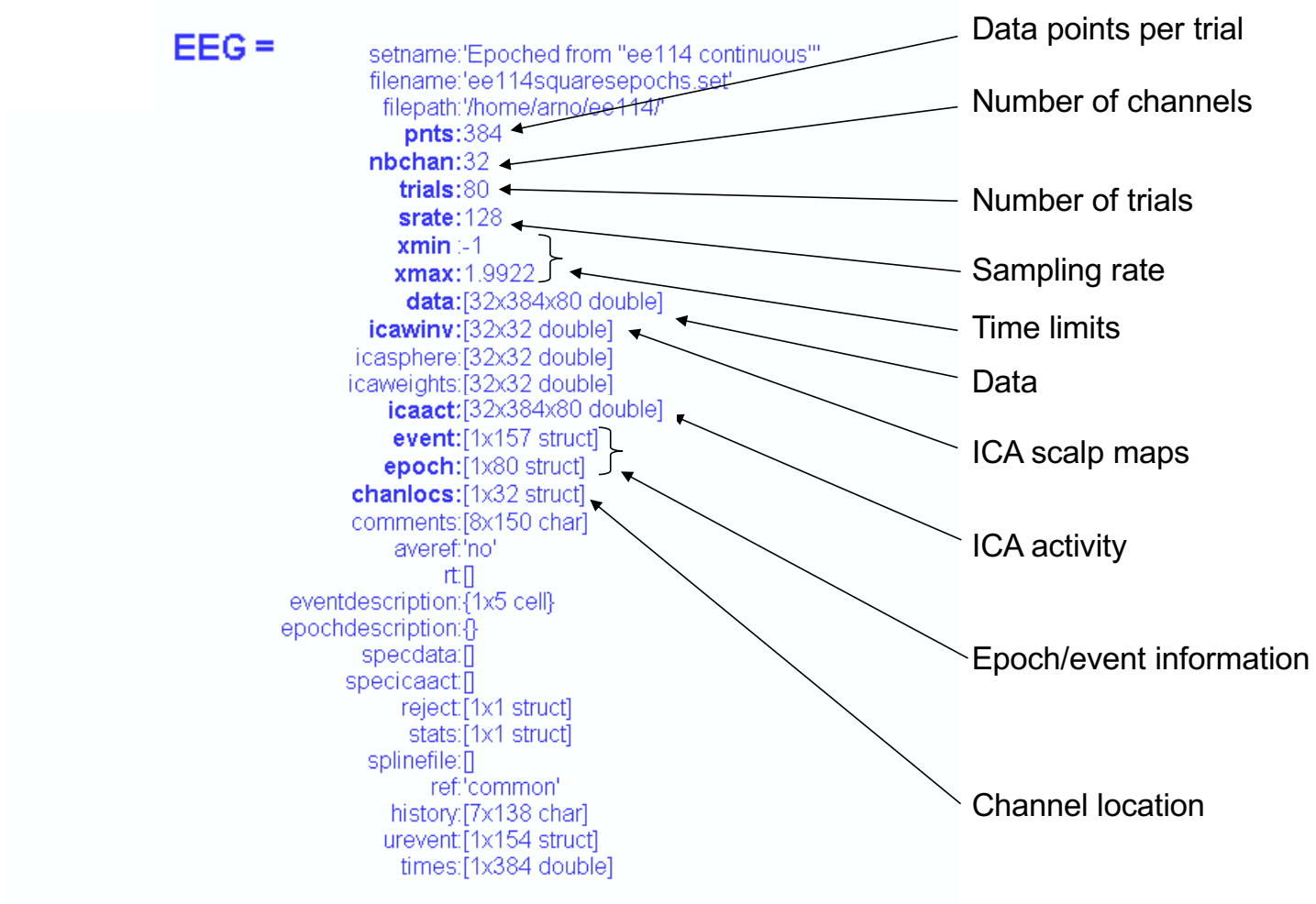
Raw data preprocessing

```
datainfo;
pop_editoptions( 'option_storedisk', 1);
outputEEGFolder = 'preprocessed_data';
if ~exist(outputEEGFolder), mkdir(outputEEGFolder); end;

for iSubj = 1:length(sInfo)

    % load dataset
    EEG = pop_biosig(sInfo(iSubj).file);
    EEG.setname = sInfo(iSubj).name;

    % preprocess data
    chanFile= 'plugins/dipfit2.3/standard_BEM/elec/standard_1005.elc';
    EEG = pop_chanedit(EEG, 'lookup', fullfile(fileparts(which('eeglab.m')), chanFile));
    EEG = pop_iirfilt( EEG, 0.5, 0, [], 0, 0); % high pass filtering
    EEG = pop_iirfilt( EEG, 0, 55, [], 0, 0); % low pass filtering
    EEG = pop_select(EEG, 'nochannel', sInfo(iSubj).bad_channels); % remove bad channels
    EEG = pop_reref( EEG, []); % average reference (optional)
    EEG = eeg_eegrej( EEG, sInfo(iSubj).bad_data); % remove bad portions of data

    % run ICA
    EEG = pop_runica(EEG, 'icatype', 'sobi');

    % tag bad components
    EEG = pop_findmatchingrejcomps(EEG,'matchcomps',sInfo(iSubj).bad_comps,'corrthresh',0.92);

    % extract data epochs
    EEG = pop_epoch(EEG, { 2 4 } , [-1 2]);

    % save dataset
    EEG.saved = 'no';
    EEG = pop_saveset( EEG, 'filepath', outputEEGFolder, 'filename', [ sInfo(iSubj).name '.set' ]);
end
```

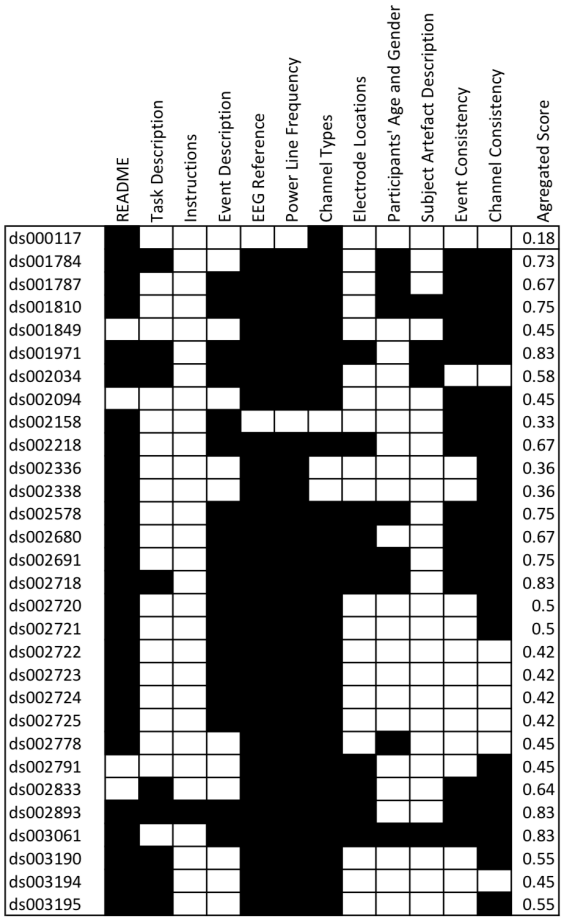
Group level analysis

```
datainfo;
pop_editoptions( 'option_storedisk', 1);
outputEEGFolder = 'preprocessed_data';
studyCommand    = {};

% generate STUDY commands
for iSubject = 1:length(sInfo)
    fileName  = fullfile(outputEEGFolder, [ sInfo(iSubject).name '.set' ]);
    studyCommand = [ studyCommand { 'index' iSubject 'load' fileName 'subject' ...
            sInfo(iSubject).name } ];
end;

% create data
[STUDY ALLEEG] = std_editset( [], [], 'name', 'test', 'commands', studyCommand, ...
        'updatedat','off', 'filename', 'test.study', 'resave', 'on');
STUDY = std_makedesign(STUDY, ALLEEG, 1, 'name','STUDY.design 1','delfiles','off', ...
'defaultdesign','off','variable1','type','values1',{'2' '4' });


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

% precompute and plot data
allchanlocs = eeg_mergelocs(ALLEEG.chanlocs);
[STUDY ALLEEG] = std_precomp(STUDY, ALLEEG, {},'interp','on','recompute','on','erp', 'on');
STUDY = pop_statparams(STUDY, 'condstats','on','singletrials','on','mode','fieldtrip', ...
'fieldtripmethod','montecarlo','fieldtripmcorrect','cluster');
[STUDY erp] = std_erpplot(STUDY,ALLEEG, 'channels',{allchanlocs.labels}, 'topotime',[300 400]);
print results.eps -depsc
```

The EEGLAB main structure is simple



BIDS meta-data analysis



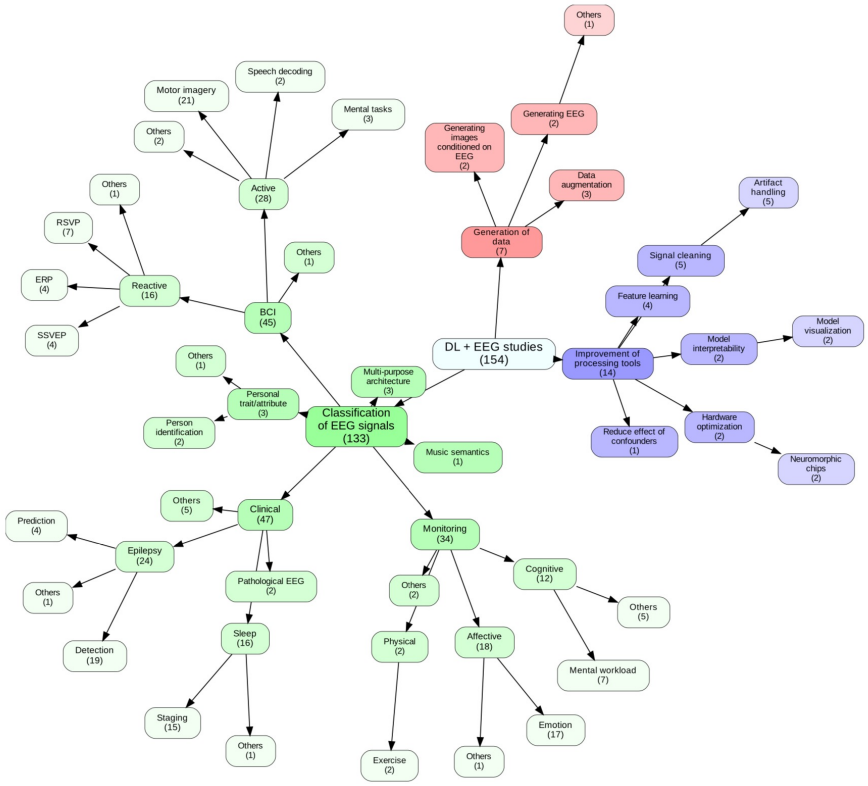
	README	Task Description	Instructions	Event Description	EEG Reference	Power Line Frequency	Channel Types	Electrode Locations	Participants' Age and Gender	Subject Artefact Description	Event Consistency	Channel Consistency	Agregated Score
ds000117	■						■						0.18
ds001784	■	■			■	■	■		■		■	■	0.73
ds001787	■				■	■	■		■		■	■	0.67
ds001810	■				■	■	■		■		■	■	0.75
ds001849					■	■	■				■	■	0.45
ds001971	■	■			■	■	■	■		■	■	■	0.83
ds002034	■	■			■	■	■			■			0.58
ds002094					■	■	■				■	■	0.45
ds002158	■			■							■	■	0.33
ds002218	■			■	■	■	■	■			■	■	0.67
ds002336	■				■	■						■	0.36
ds002338	■				■	■						■	0.36
ds002578	■			■	■	■	■	■	■		■	■	0.75
ds002680	■			■	■	■	■	■			■	■	0.67
ds002691	■			■	■	■	■	■	■		■	■	0.75
ds002718	■	■		■	■	■	■	■	■		■	■	0.83
ds002720	■			■	■	■	■					■	0.5
ds002721	■			■	■	■	■					■	0.5
ds002722	■			■	■	■	■						0.42
ds002723	■			■	■	■	■						0.42
ds002724	■			■	■	■	■						0.42
ds002725	■			■	■	■	■						0.42
ds002778	■				■	■	■		■				0.45
ds002791					■	■	■	■			■	■	0.45
ds002833		■			■	■	■	■				■	0.64
ds002893	■	■	■	■	■	■	■	■			■	■	0.83
ds003061	■			■	■	■	■	■	■	■	■	■	0.83
ds003190	■	■			■	■	■					■	0.55
ds003194	■	■			■	■	■						0.45
ds003195	■	■			■	■	■					■	0.55

BIDS data analysis

Dataset	n	Flat	Chan.	Good chan.	Good data	Brain ICs
ds000117	84	-	74	89 - 90	68 - 78	28 - 32
ds001784	30	-	60	85 - 92	63 - 77	5 - 11
ds001787	40	-	64	93 - 95	85 - 90	24 - 30
ds001810	263	-	64	78 - 80	71 - 74	35 - 37
ds001849	120	-	30	86 - 88	66 - 70	41 - 45
ds001971	273	-	112*	91 - 95	81 - 84	8 - 10
ds002034	167	21	62	95 - 98	47 - 52	29 - 33
ds002094	43	-	30	88 - 93	66 - 77	37 - 45
ds002158	8	-	63	80 - 86	19 - 66	11 - 23
ds002218	18	-	32	94 - 97	66 - 78	35 - 46
ds002336	54	1	63	81 - 83	74 - 89	33 - 39
ds002338	85	-	63	74 - 77	87 - 95	24 - 28
ds002578	2	-	18	78 - 89	96 - 97	46 - 60
ds002680	350	-	19	92 - 93	81 - 84	53 - 56
ds002691	20	-	32	93 - 97	82 - 87	30 - 40
ds002718	18	-	74	95 - 96	58 - 76	20 - 28
ds002720	165	-	19	93 - 95	68 - 72	52 - 56
ds002721	185	-	19	95 - 96	67 - 72	45 - 49
ds002722	94	-	32	92 - 95	63 - 70	36 - 39
ds002723	44	-	32	95 - 97	66 - 76	36 - 40
ds002724	96	-	32	94 - 96	72 - 77	35 - 39
ds002725	105	-	31	90 - 94	80 - 85	53 - 58
ds002778	46	-	32	90 - 95	68 - 78	41 - 48
ds002791	92	-	256	90 - 92	62 - 70	6 - 7
ds002833	80	-	256	91 - 94	82 - 88	6 - 8
ds002893	55	12	36	89 - 93	76 - 83	29 - 37
ds003061	39	-	64	84 - 89	86 - 92	22 - 28
ds003190	384	2	8	81 - 83	89 - 91	74 - 78
ds003194	29	-	19	93 - 97	90 - 95	72 - 79
ds003195	20	-	19	90 - 97	89 - 94	65 - 76

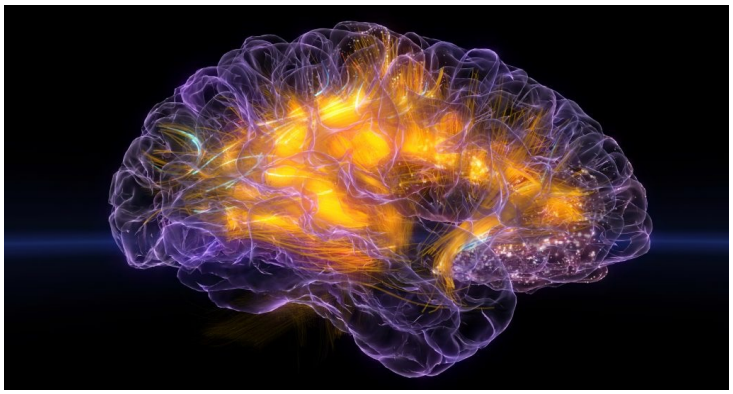
Delorme, A., Truong, D., Martinez- Cancino, R., Pernet, C., Sivagnanam, S., Yoshimoto, K., Poldrack, R., Majumdar, A., Makeig, S. (2020) Tools for Importing and Evaluating BIDS-EEG Formatted Data. 2021 10th International IEEE/EMBS Conference on Neural Engineering (NER), 2021, pp. 210-213, doi: 10.1109/NER49283.2021.9441399

BIDS-DL

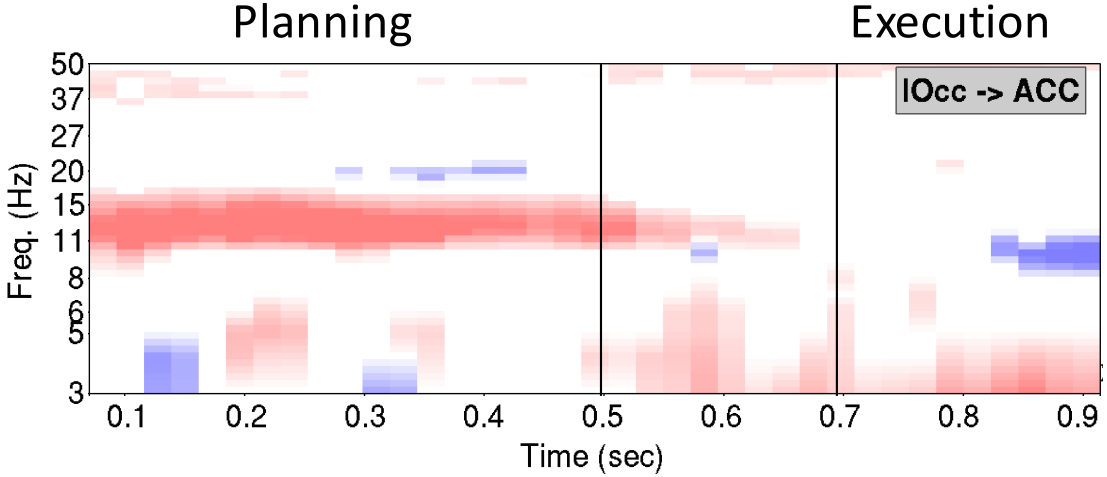


Roy Y, Banville H, Albuquerque I, Gramfort A, Falk TH, Faubert J. Deep learning-based electroencephalography analysis: a systematic review. J Neural Eng. 2019 Aug 14;16(5):051001. doi: 10.1088/1741-2552/ab260c. PMID: 31151119.

Brain connectivity in SIFT/EEGLAB

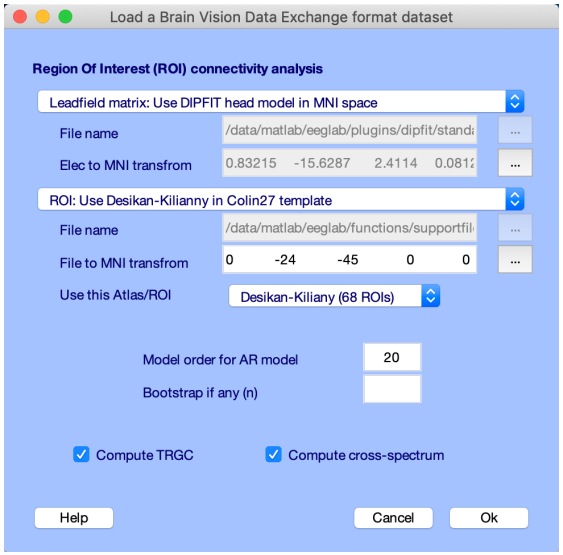


Occipital -> ACC

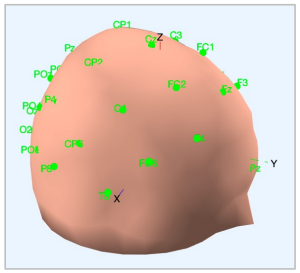


John R. Iversen, Alejandro Ojeda, Tim Mullen, Markus Plank, Joseph Snider, Gert Cauwenberghs, Howard Poizner (2014) EMBC Conference, Osaka, Japan.

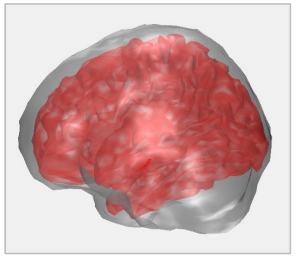
New EEGLAB ROI connectivity plugin



Align electrodes with scalp model

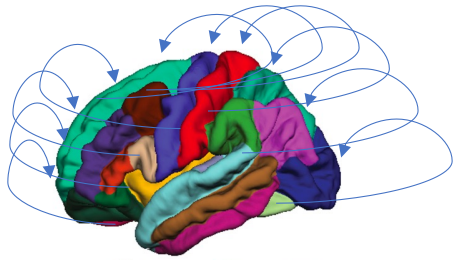


Align atlas with cortex model



Distributed source modeling

Group voxels in regions and compute connectivity

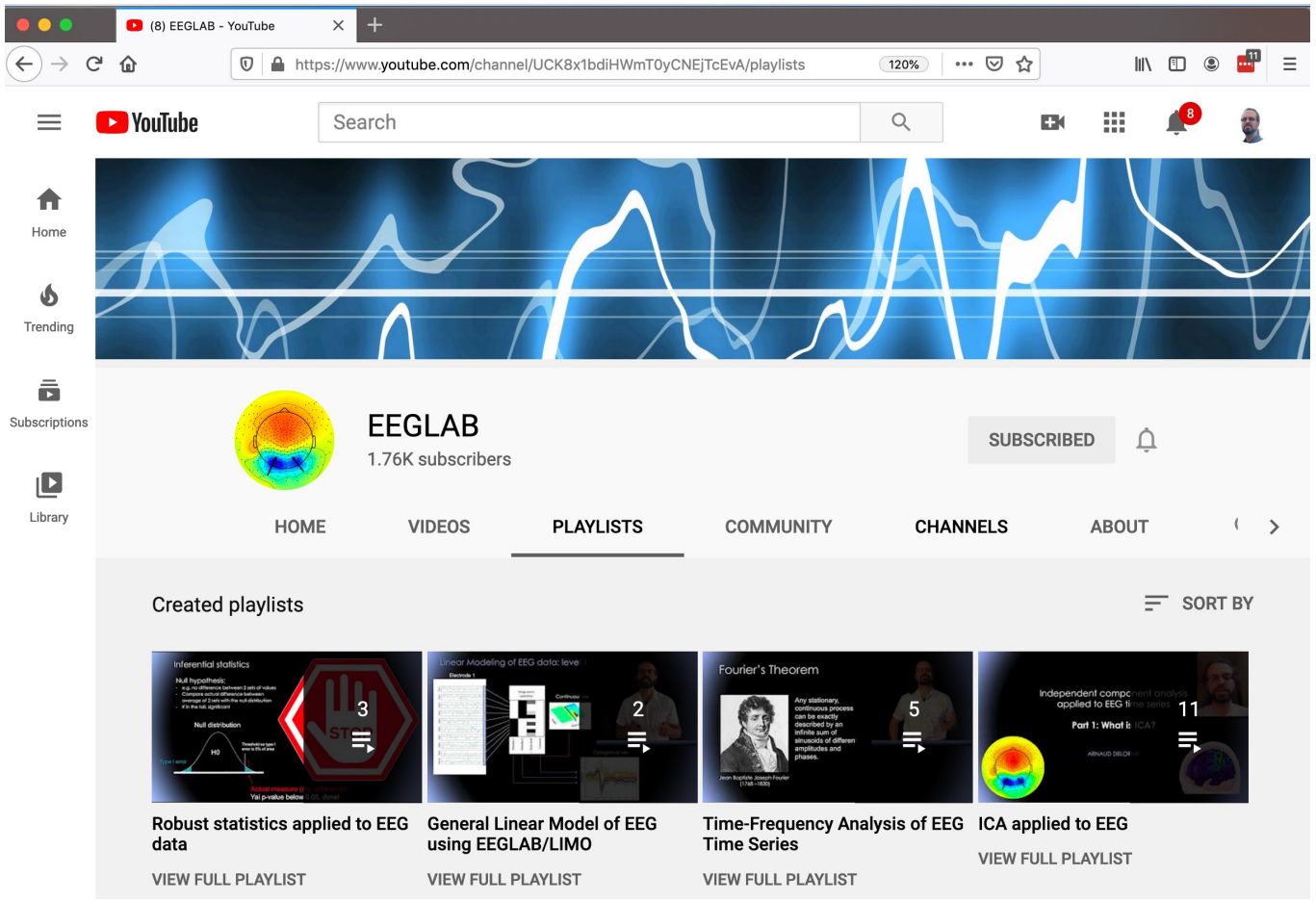


Measures TRGC, GC, TRPDC, PDC, TRDTF, DTF and CS

https://github.com/arnodelorme/roiconnect

Haufe, S., Nikulin, V. V., Miller, K. R., & Nolte, G. (2013). A critical assessment of connectivity measures for EEG data: a simulation study. Neuroimage, 64, 120-133.

EEGLAB Youtube Channel



EEGLAB reference 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