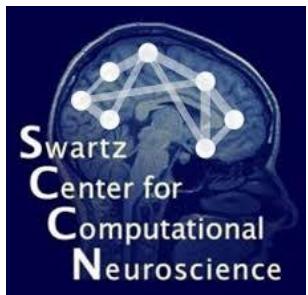


From raw data to robust connectivity analysis

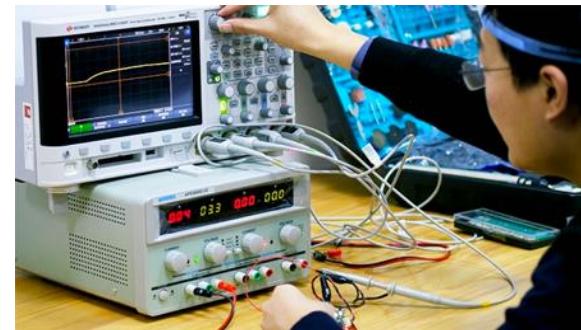
Arnaud Delorme

Swartz Center for Computational Neuroscience, UCSD, La Jolla, CA, USA



Why preprocess data?

Measuring EEG data out of the recording device is like measuring a difference of potential on an oscilloscope.

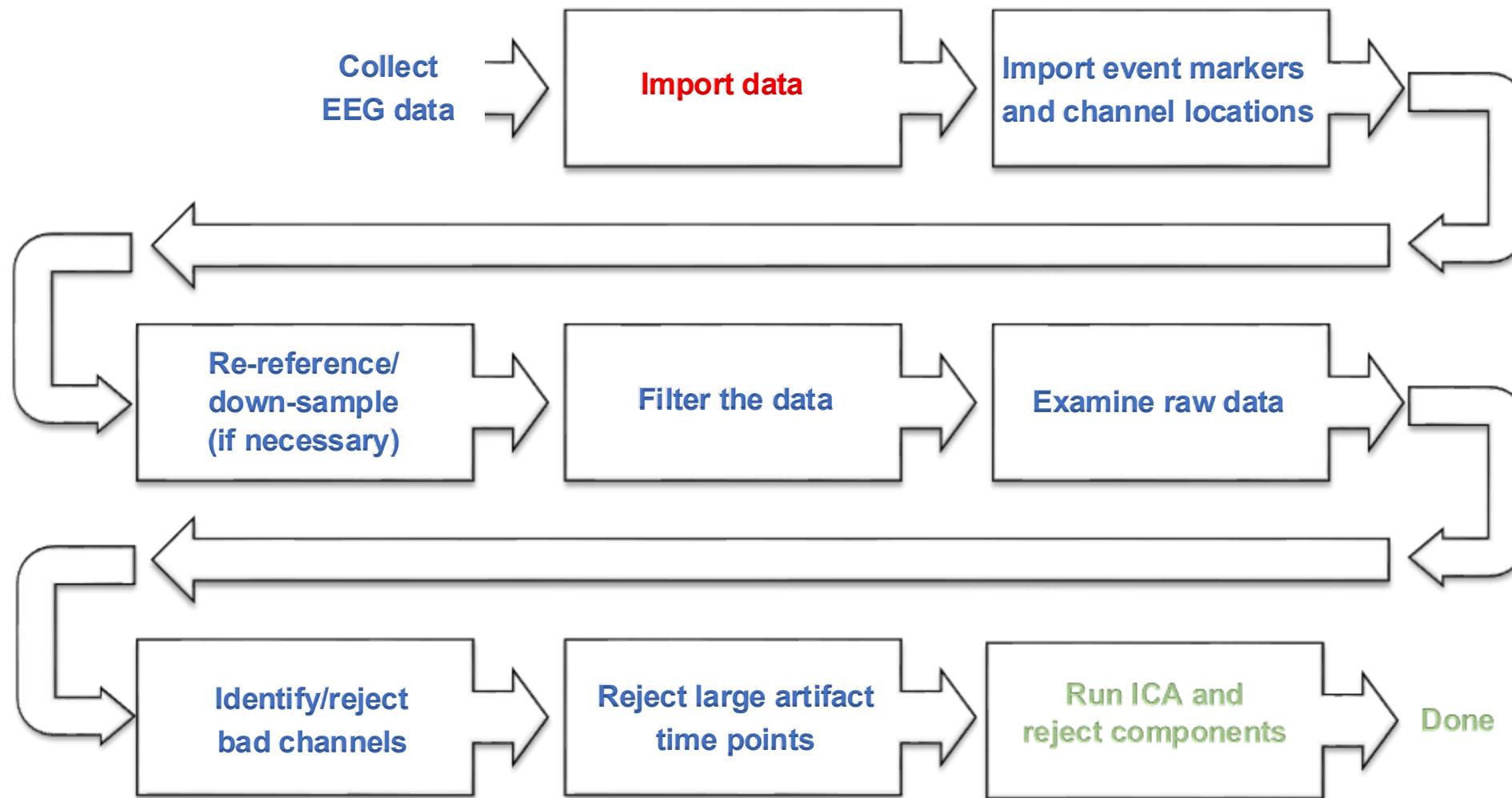


To make sense of the data, we need to:

- ▶ 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 transformations to the data

Pre-processing pipeline



What is BIDS?

BIDS is a way to organize your raw data

- ▶ To improve consistent and complete documentation
- ▶ To facilitate re-use by your future self and others

BIDS is not

- ▶ A new file format
- ▶ A search engine
- ▶ A data sharing tool

SCIENTIFIC DATA

OPEN [The brain imaging data structure, a format for organizing and sharing neuroimaging data](#)

www.nature.com/scientificdata

SCIENTIFIC DATA

OPEN [Comment: MEG-BIDS, the brain imaging data structure extended to magnetoencephalography](#)

Guilmar Niso^{1,2}, Krzysztof J. Gorgolewski³, Elizabeth Bock¹, Teon L. Brooks³, Guillaume Flandin⁴, Alexandre Gramfort^{5,6}, Richard N. Henson⁷, Mainak Jas⁵, Vladimir Litvak⁴, Jeremy T. Moreau¹, Robert Oostenveld^{8,9}, Jan-Mathijs Schoffelen⁸

Received: 14 November 2017 | Accepted: 14 December 2017 | Published online: 14 January 2018

www.nature.com/scientificdata

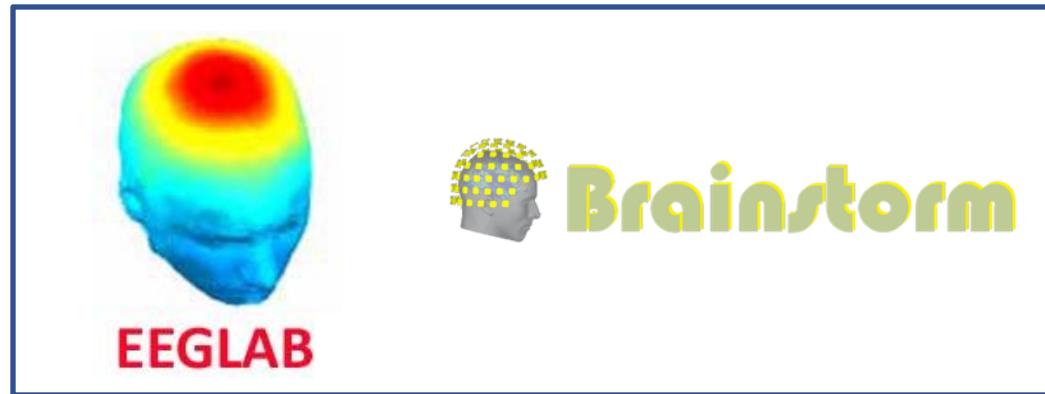
SCIENTIFIC DATA

OPEN [COMMENT](#) [EEG-BIDS, an extension to the brain imaging data structure for electroencephalography](#)

Cyril R. Pernet¹, Stefan Appelhoff², Krzysztof J. Gorgolewski³, Guillaume Flandin⁴, Christophe Phillips⁵, Arnaud Delorme^{6,7} & Robert Oostenveld^{8,9}

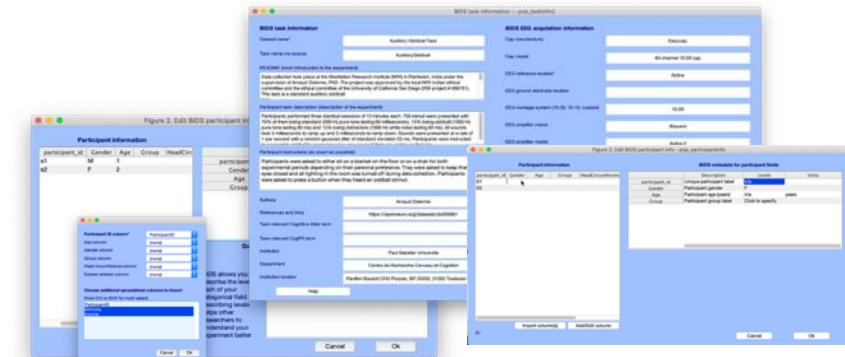
The Brain Imaging Data Structure (BIDS) project is a rapidly evolving effort in the human brain imaging research community to create standards allowing researchers to readily organize and share study data within and between laboratories. Here we present an extension to BIDS for electroencephalography (EEG) data, EEG-BIDS, along with tools and references to a series of public EEG datasets organized using this new standard.

BIDS in popular open-source tools



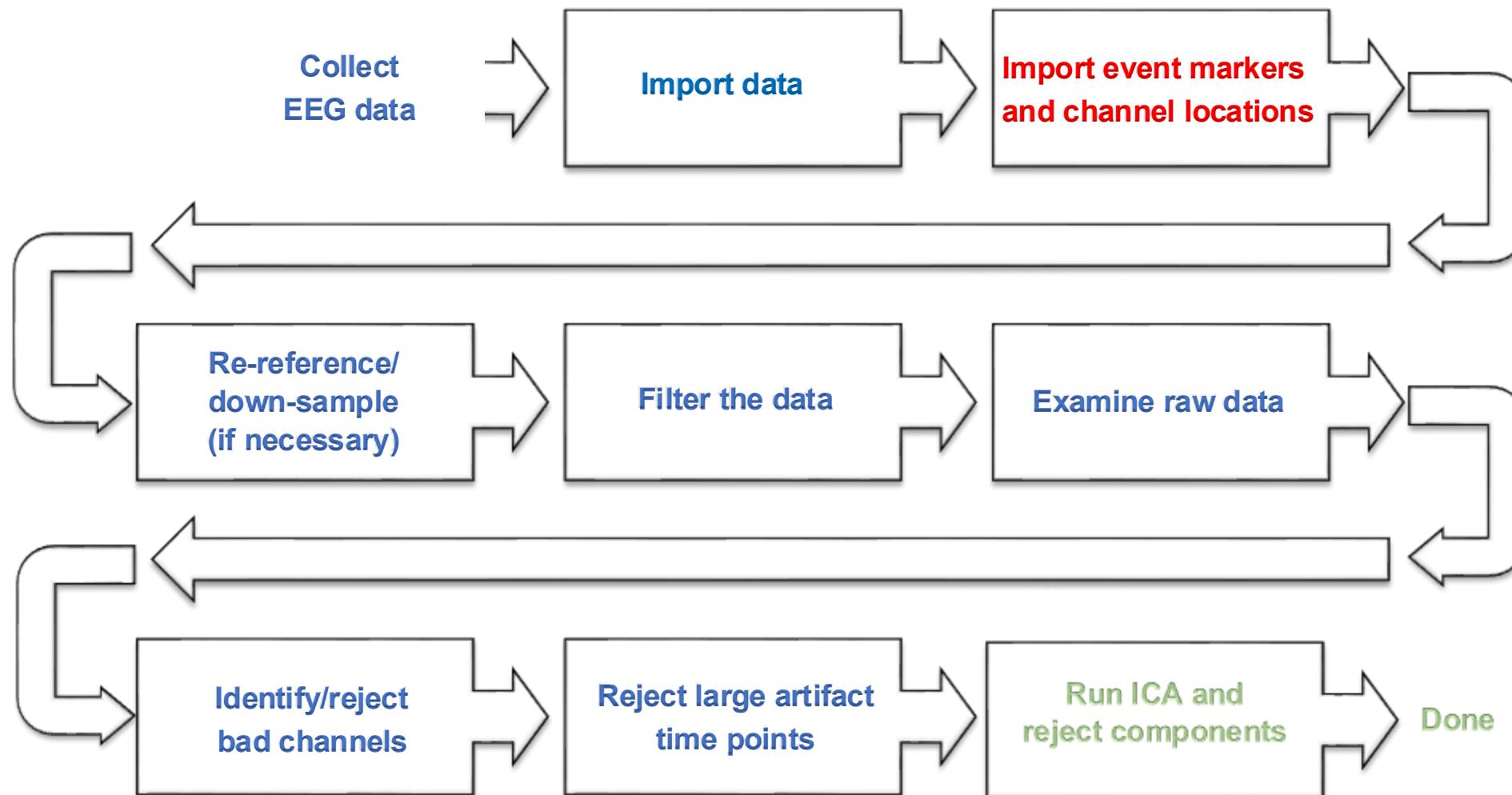
Have dedicated tools for processing group-level data

EEGLAB *bids-matlab-tools* menus and script functions (1450 downloads)



- ▶ All tools can **import** BIDS single subject data (FieldTrip and EEGLAB support BIDS sidecar event files)
- ▶ All tools can **export** BIDS data (GUI available in Brainstorm and EEGLAB)
- ▶ Brainstorm and EEGLAB have dedicated BIDS tools for group analysis

Pre-processing pipeline



Import data events

The screenshot shows the EEGLAB v11.0.5.4b software interface. The main window has a menu bar with File, Edit, Tools, Plot, Study, Datasets, and Help. The 'File' menu is open, showing options like Import data, Import epoch info, Import event info (which is highlighted), Export, Load existing dataset, Save current dataset(s), Save current dataset as, Clear dataset(s), Create study, Load existing study, Save current study, Save current study as, Clear study, Memory and other options, History scripts, and Quit. A tooltip below the 'Import event info' option states: '(Often imported automatically during data import)'. A sub-menu for 'Import event info' is also open, listing From Matlab array or ASCII file, From data channel (which is selected and highlighted in orange), From Presentation .LOG file, From E-Prime ASCII (text) file, and From Neuroscan .ev2 file.

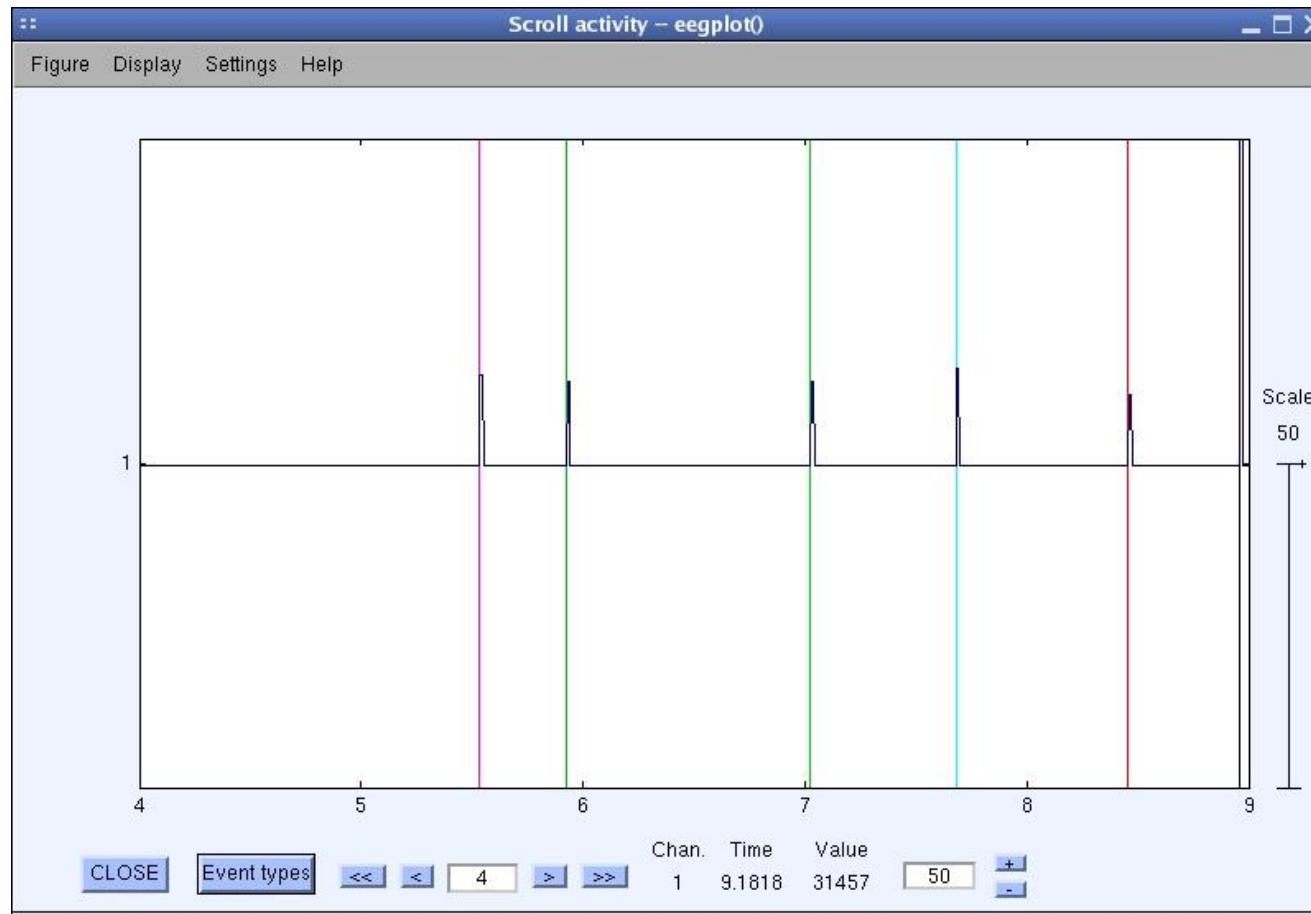
The 'From data channel' option in the sub-menu is circled in orange. An arrow points from this circled option to a list of five bullet points describing import methods:

- 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

A second dialog box titled 'Extract event from channel(s) - pop_chanevent()' is displayed. It contains the following settings:

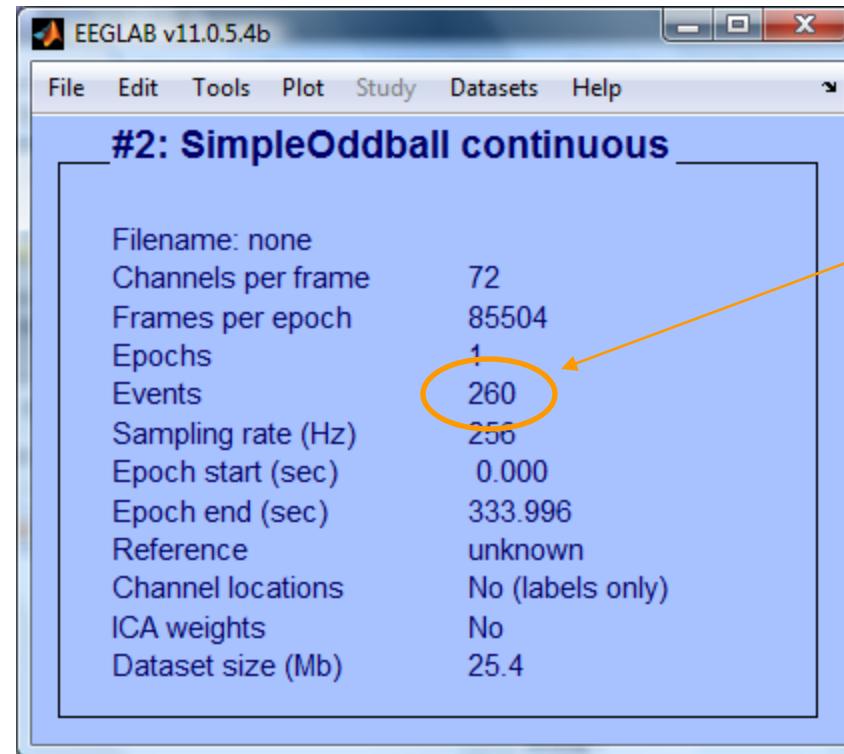
- Event channel(s): 73 (this value is circled in orange)
- Preprocessing transform (data='X'): (empty field)
- Optional. Ex: X>3 (click to select)
- Transitions to extract? (up/down): up (leading)
- Transition length (1=perfect edges): 0
- Assign duration to each events?: (set=yes)
- Delete event channel(s)? (set = yes)
- Delete old events if any?
- All events of same type?

Appearance of an event channel in raw data





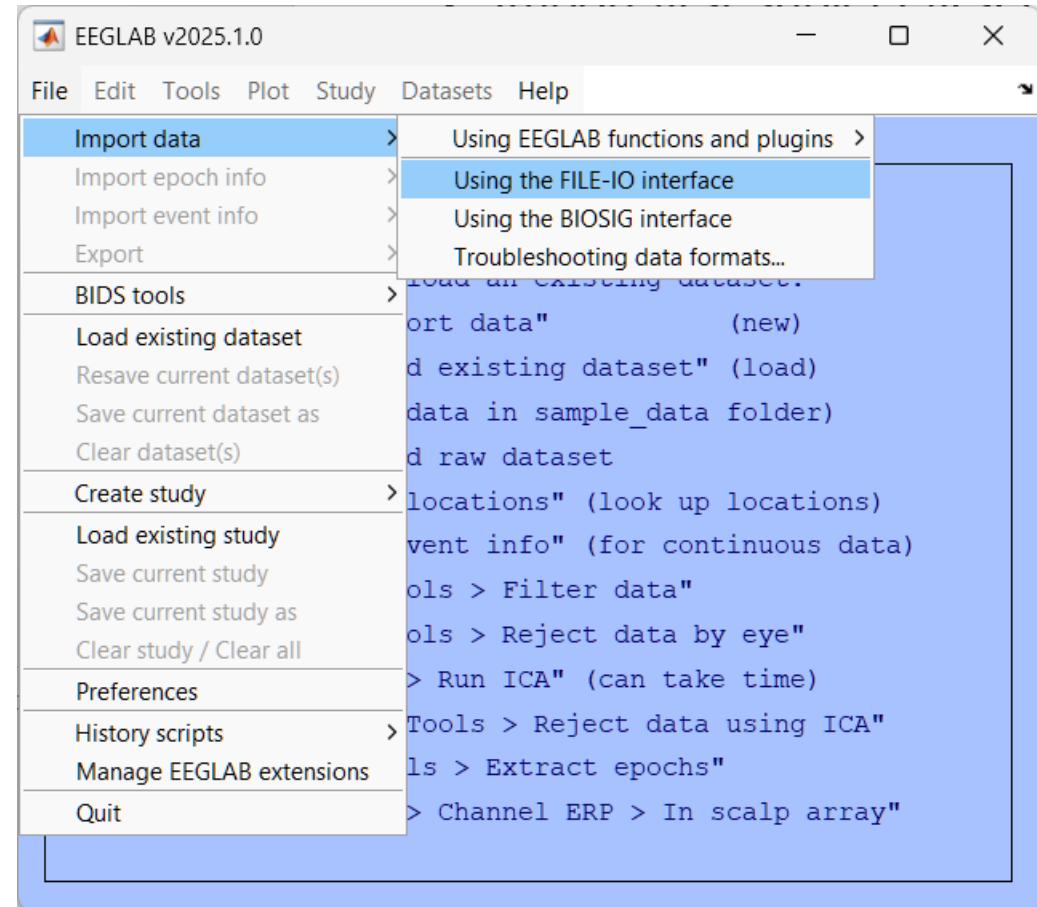
Imported data events



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

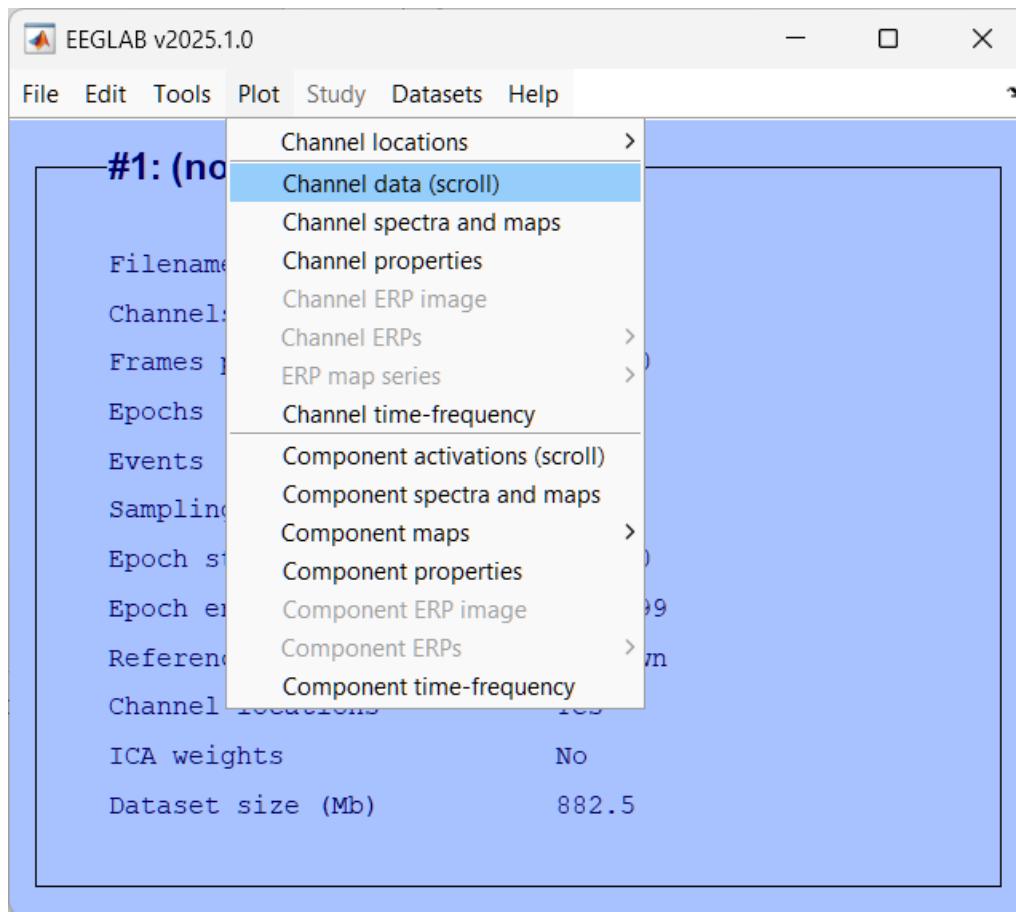
Import data

- Open matlab
- Start eeglab
- Import first subject first run meeg .fif datafile from ds000117 dataset

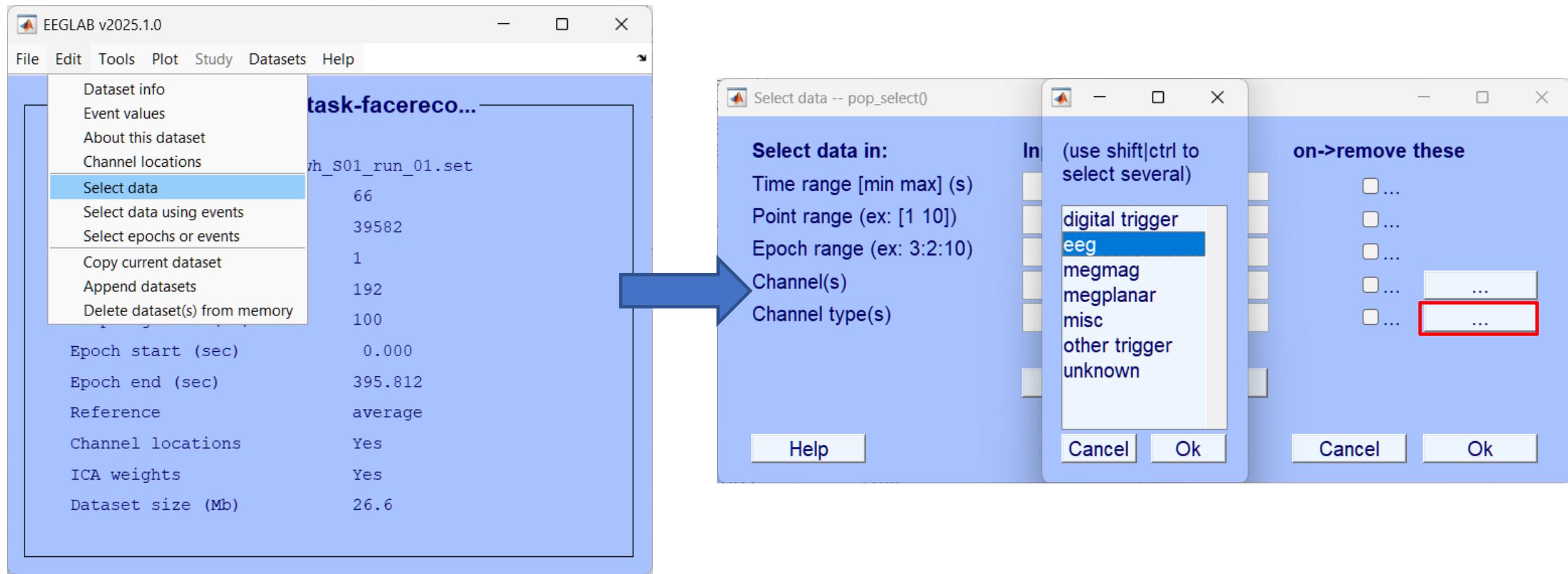


Path : ds000117_pruned\derivatives\meg_derivatives\sub-01\ses-meg\meg\
File : sub-01_ses-meg_task-facerecognition_run-01_proc-sss_meg.fif

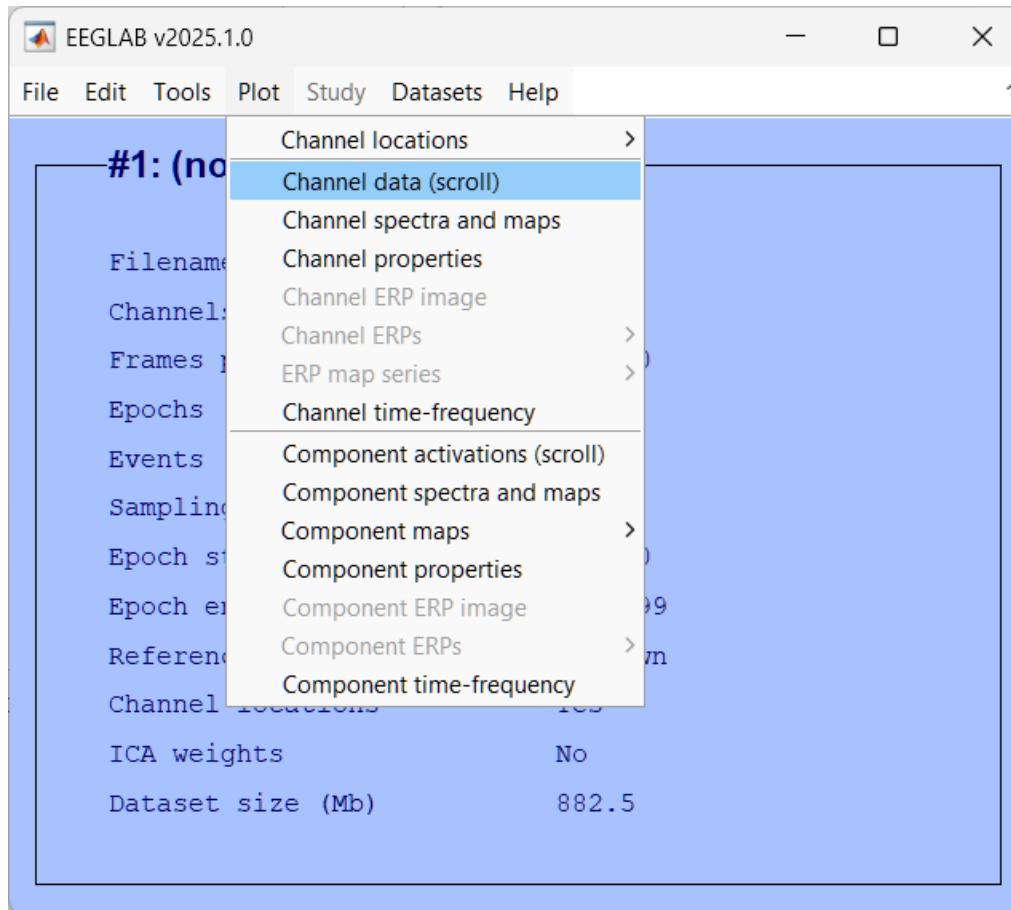
Plot channels timecourse



Select EEG channels



Check again signal timecourse



Hands on: Basic data loading and plotting

- Start EEGLAB
- Import FIF file using menu item **File > Import data > Using File-IO**
ds000117_pruned/derivatives/meg_derivatives/sub-01/ses-meg/meg/sub-01_ses-meg_task-facerecognition_run-06_proc-sss_meg.fif
- Use menu item **Edit > Select data** to select all the channels of type EEG
- Use menu item **Plot > Scroll** data to scroll the data. Use menu **Edit > Channel locations** to inspect channel locations
- **Note:** Because the data was collected in an MEG machine, it is complex and is preprocessed by the script *script_01_import_data.m* including renaming and realigning events. In future lectures, we will use the result of that script. If it has not already been executed for you on that folder, you will need to execute it.



Contents lists available at [ScienceDirect](#)

NeuroImage

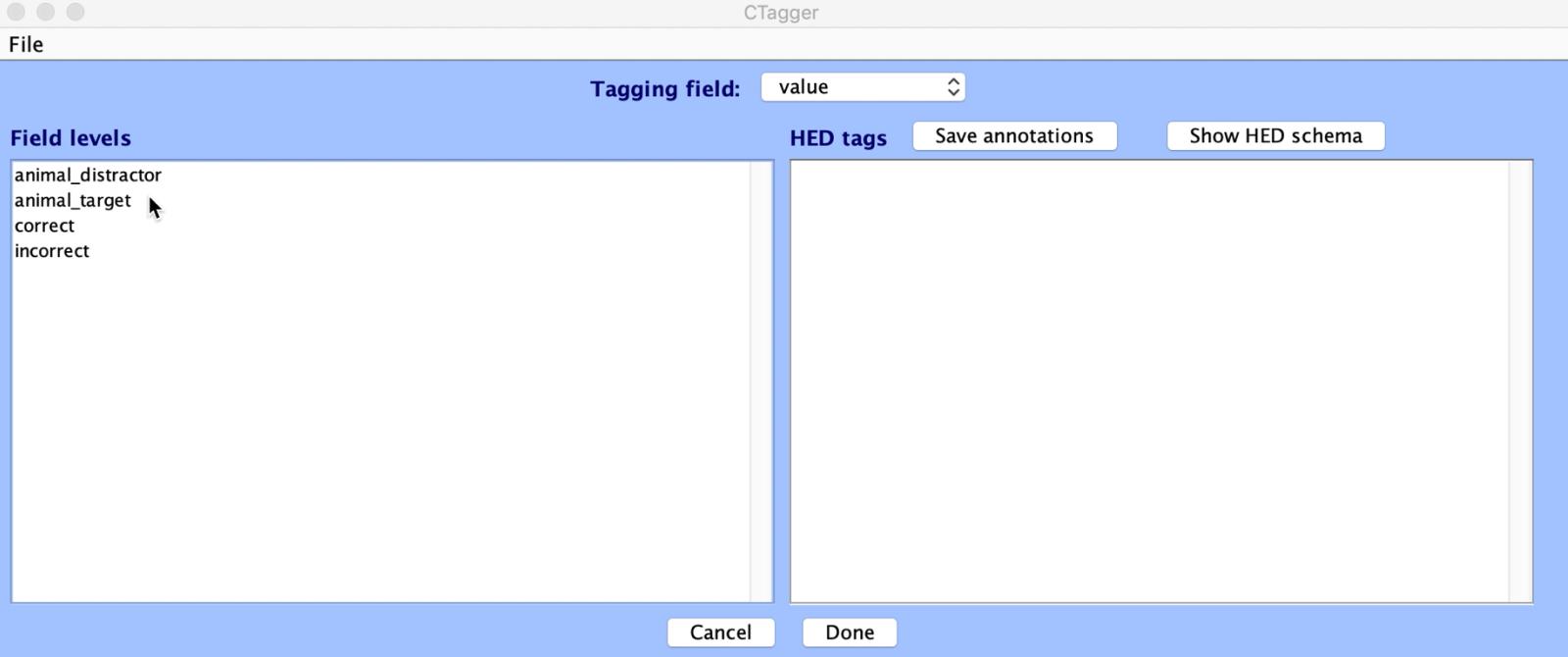
journal homepage: www.elsevier.com/locate/neuroimage



Capturing the nature of events and event context using hierarchical event descriptors (HED)

Kay Robbins^{a,*}, Dung Truong^b, Stefan Appelhoff^c, Arnaud Delorme^{b,d}, Scott Makeig^b





Action							
Speech	Eye close	Grab	Stretch	Groan	Scratch	Switch attention	Walk
Hum	Eye open	Tap	Bend	Control vehicle	Step around	Step over	Step on
Eye saccade	Turn	Lift	Deep breath	Teleoperate	Swallow	Evade	Shrug
Eye fixation	Point	Reach	Laugh	Allow	Turn	Dance	Whistle
Eye blink	Push	Course correction	Sigh	Deny	Flex	Open mouth	Read

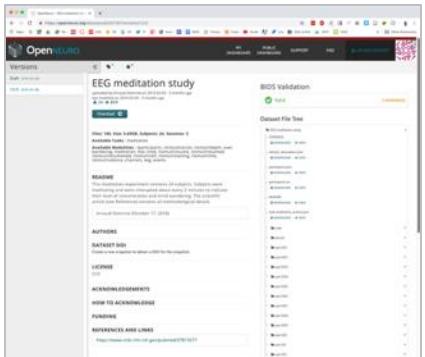
Attribute							
State ID	Location	Auditory	Language	Subliminal	Supraliminal	Liminal	
Social	Object orientation	Visual	Induced		Probability	File	Object control
Repetition	Size	Nonlinguistic	Emotional	Presentation fraction			
Direction	Item count	Semantic	Priming	Path	Association	Extraneous	



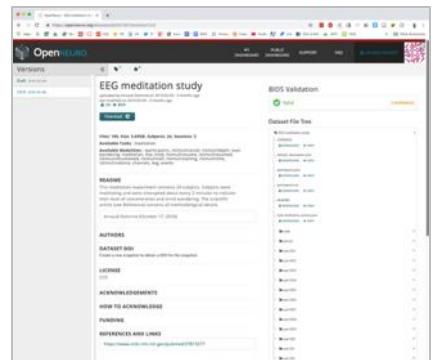
HED is integrated in



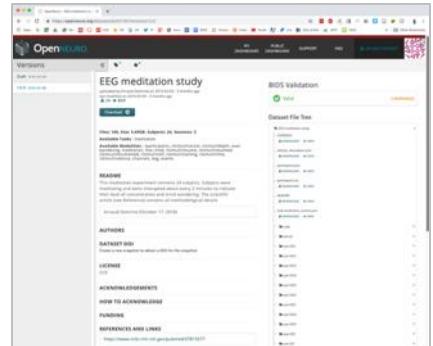
NEMAR BIDS experiment 1



NEMAR BIDS experiment 2



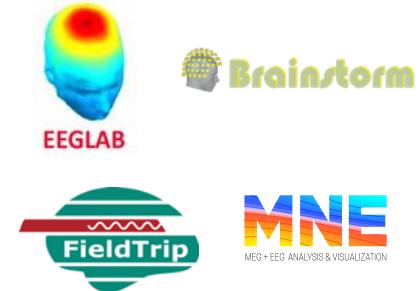
NEMAR BIDS experiment 3



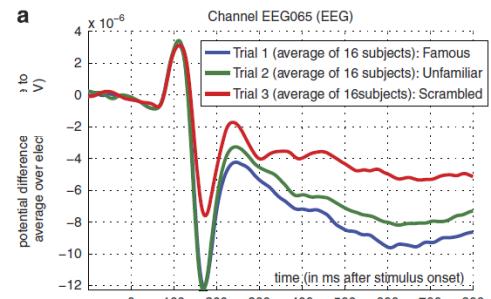
HED event selection



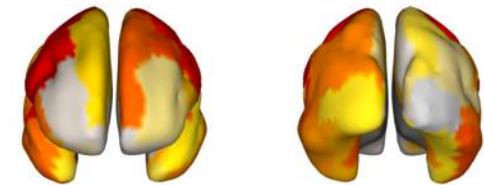
Automated pipelines



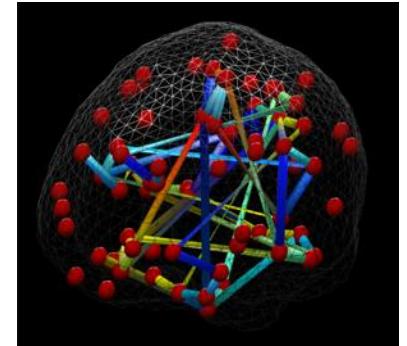
ERPs and ERSPs



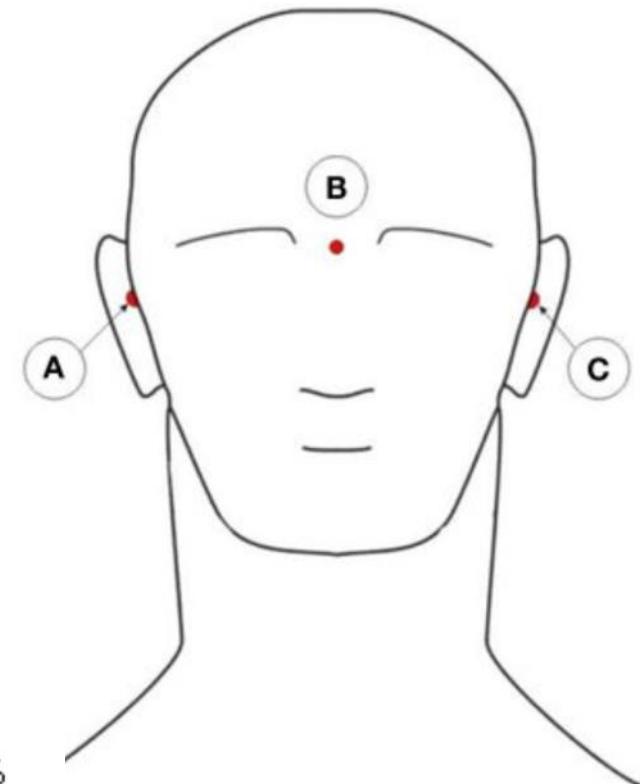
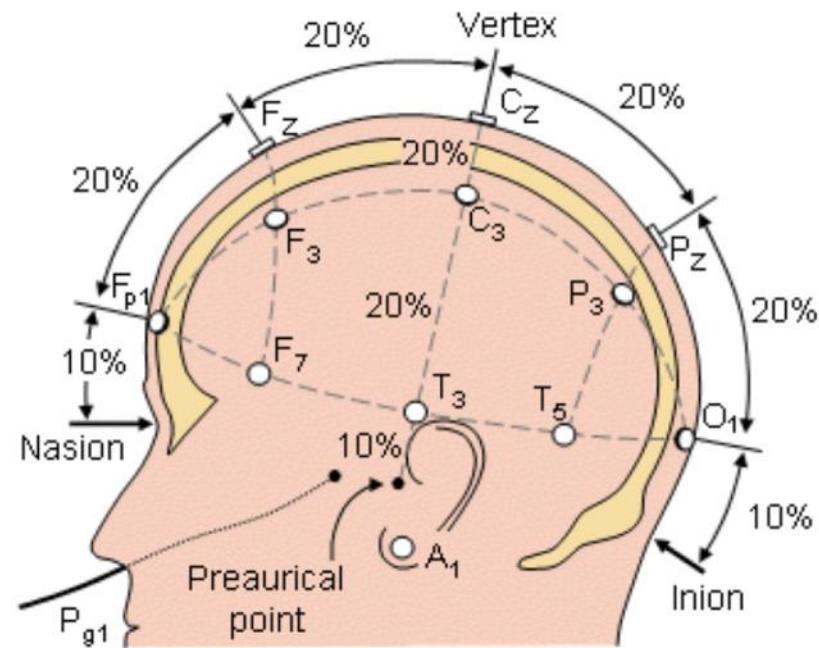
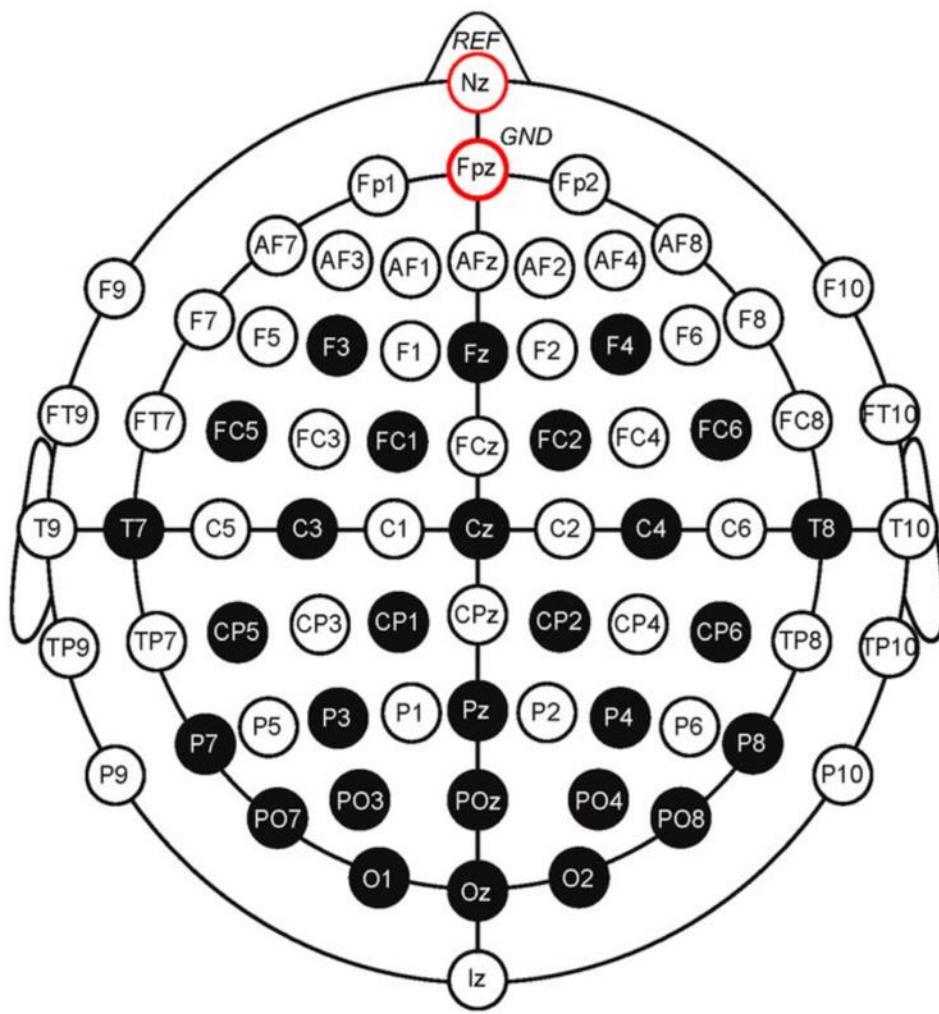
Source localization



Connectivity



Channel labels & locations

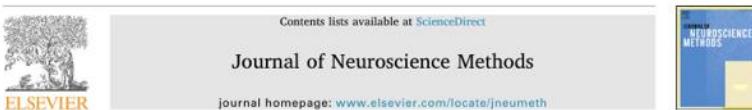


Scanning electrode position will become standard

Get_chanlocs EEGLAB plugin interfacing Fieldtrip's functions



3-D camera mounted on iPad



Using a structured-light 3D scanner to improve EEG source modeling with more accurate electrode positions

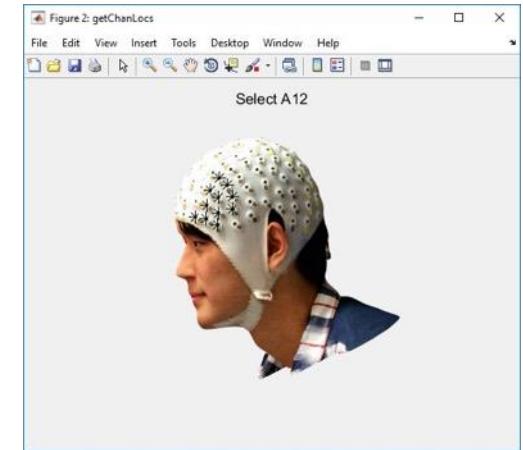
Simon Homölle^{a,b*}, Robert Oostenveld^{a,b}

^a Donders Institute for Brain, Cognition and Behaviour, Radboud University, Kapuzinergang 29, 6525 EH Nijmegen, the Netherlands
^b NurmEG, Karolinska Institutet, Solnavägen 1, 171 77 Solna, Sweden

Smartphone 3-D scanners

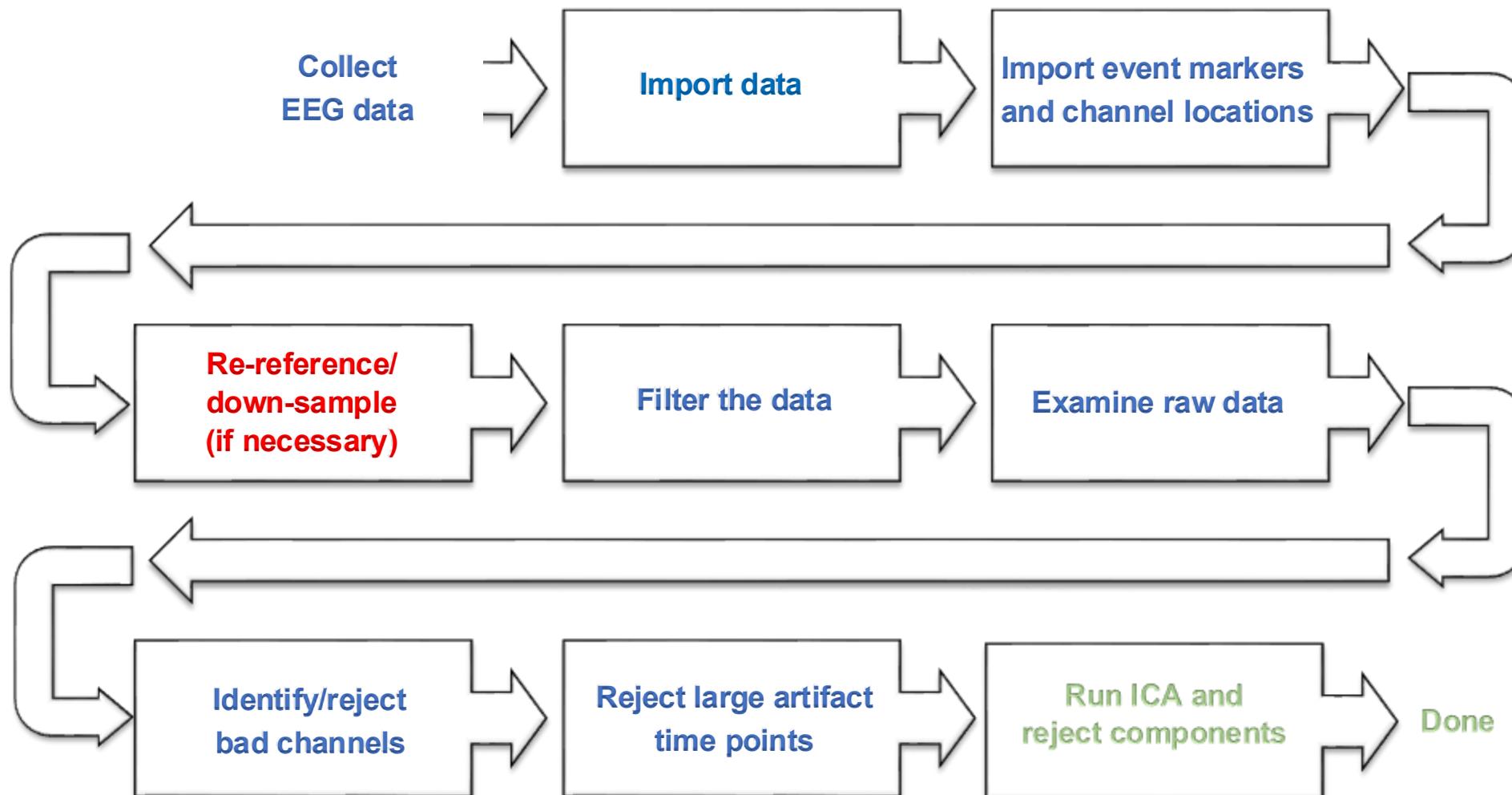


EEGLAB get_chanlocs plugin



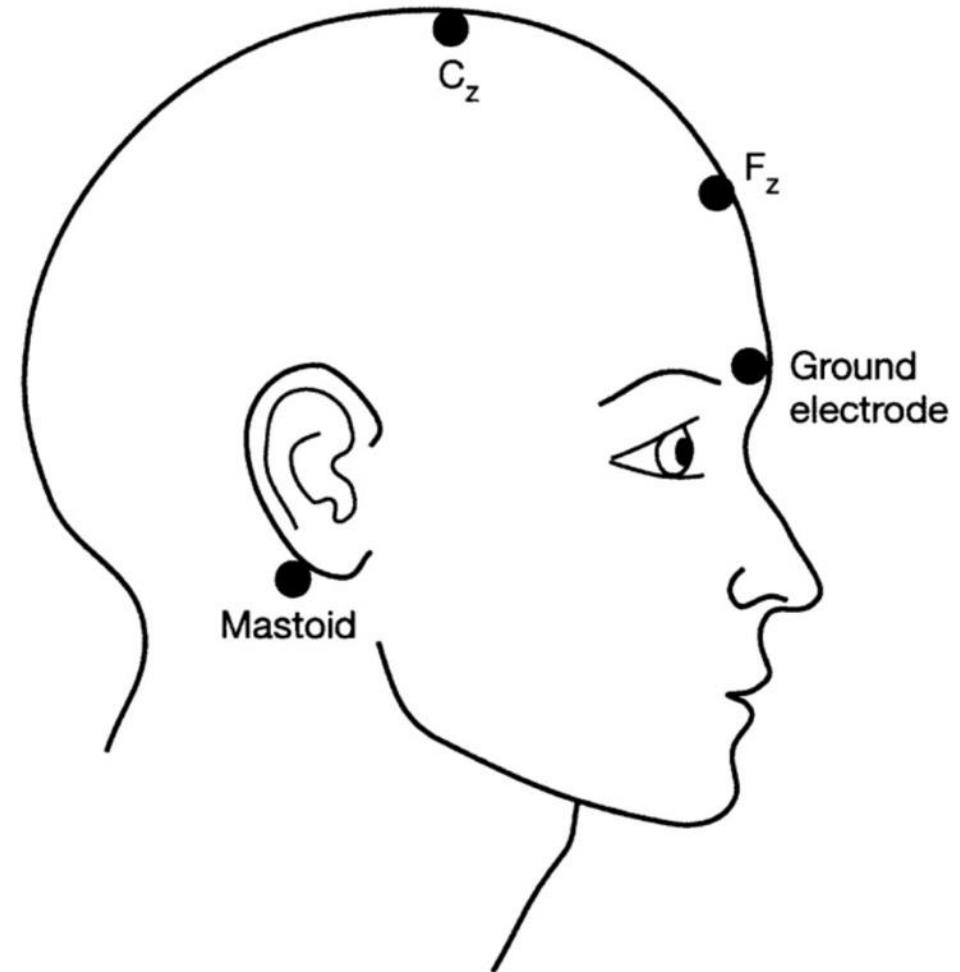
- ▶ The EEGLAB and FieldTrip teams plan to work together to automatically align scans with templates and speed up the manual electrode labeling process (after training, currently 15 minutes per subject for 64 channels)

Pre-processing pipeline

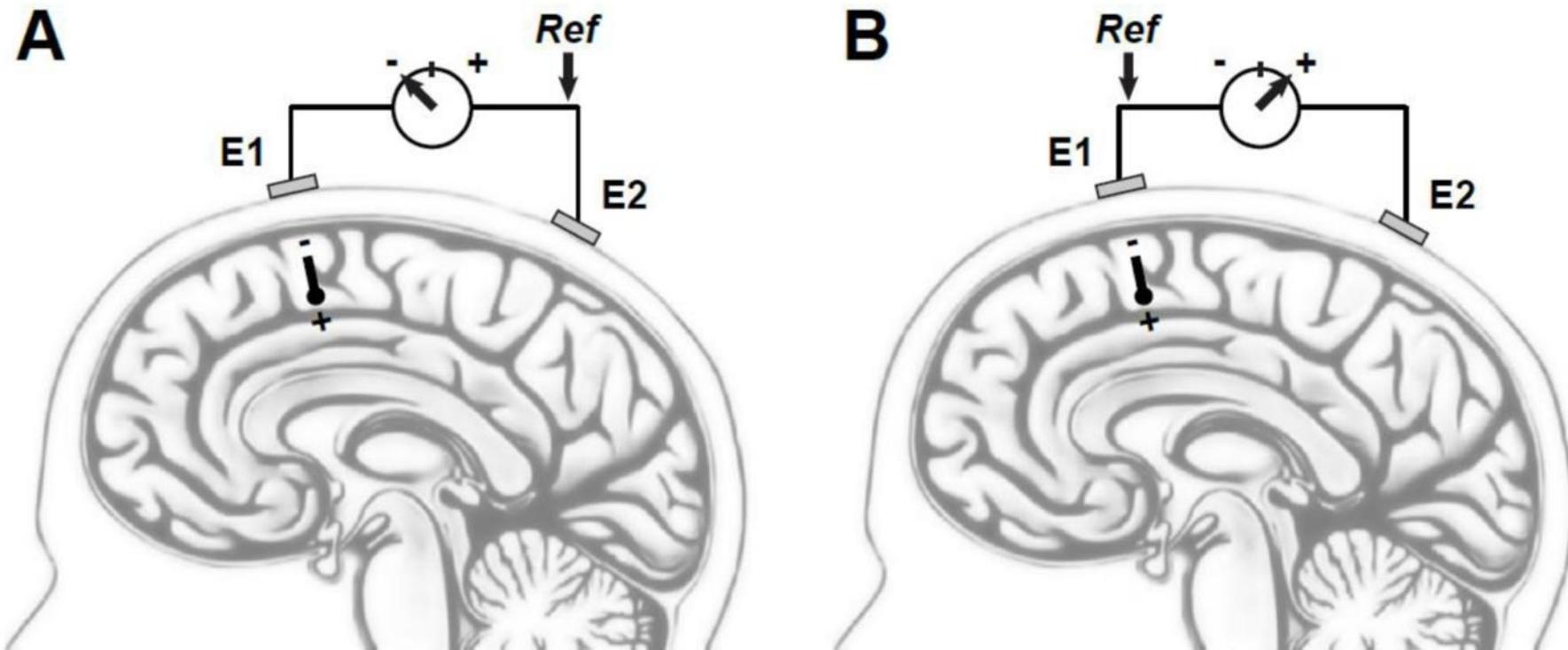


Referencing

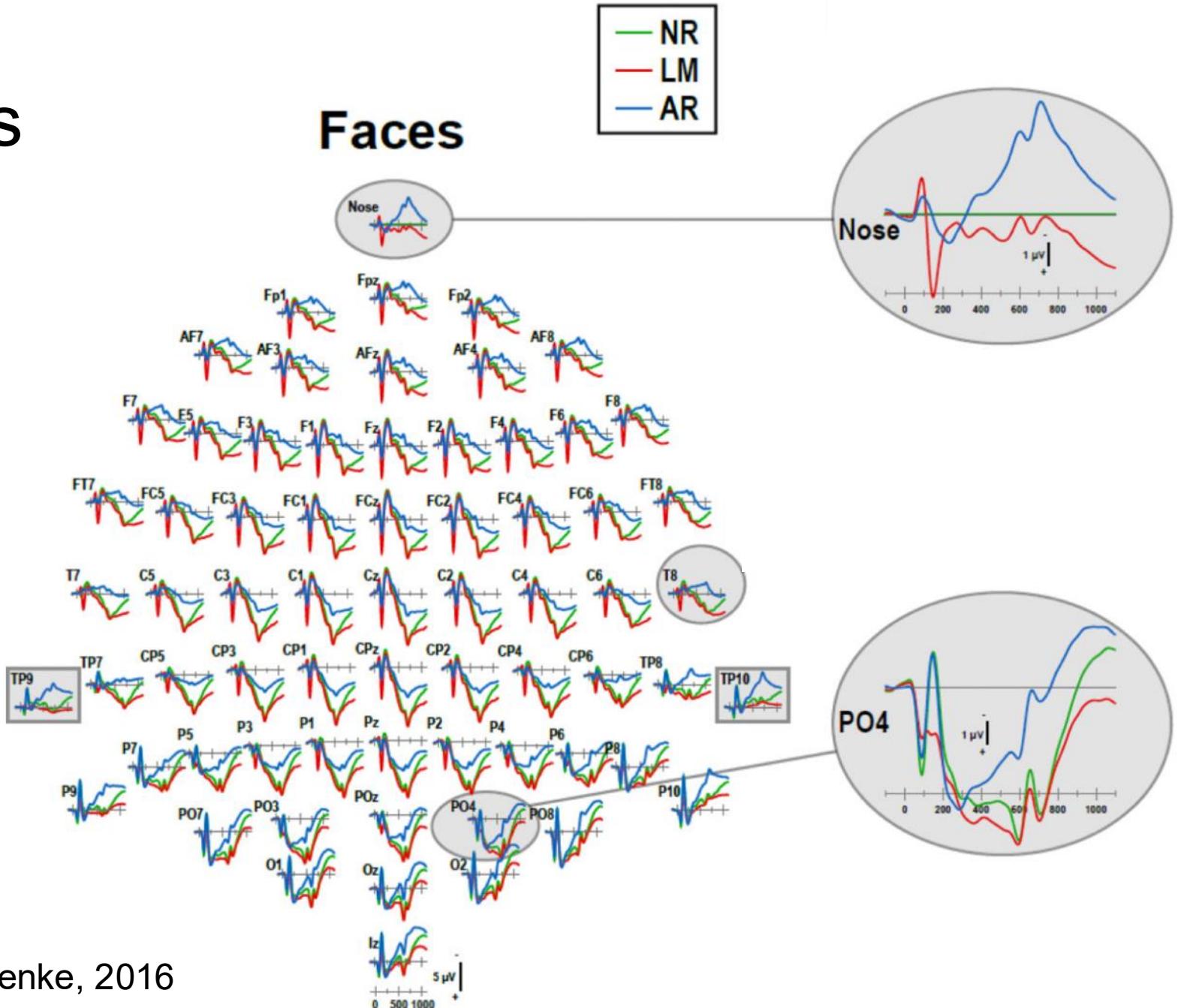
- ▶ Earlobes
- ▶ Nose
- ▶ Average
- ▶ Mastoids
- ▶ Vertex (Cz), scalp electrode
- ▶ Bipolar
- ▶ Infinity reference



The location of the Reference matters



The location of Reference matters



[nature](#) > [scientific reports](#) > [articles](#) > [article](#)

Article | [Open access](#) | Published: 09 February 2023

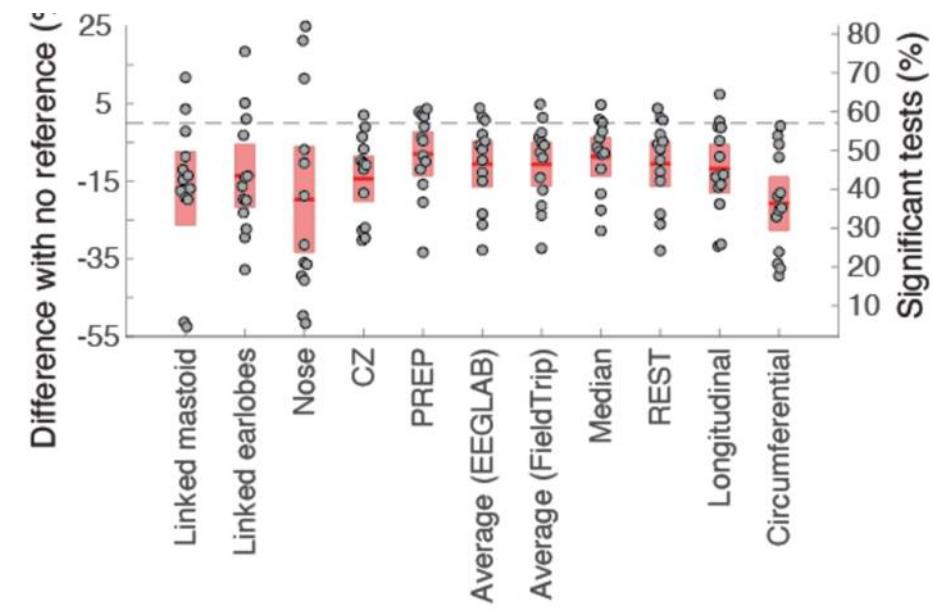
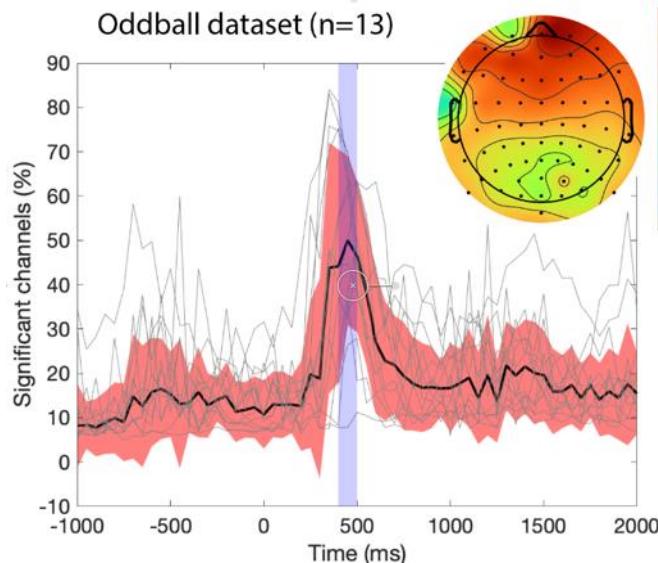
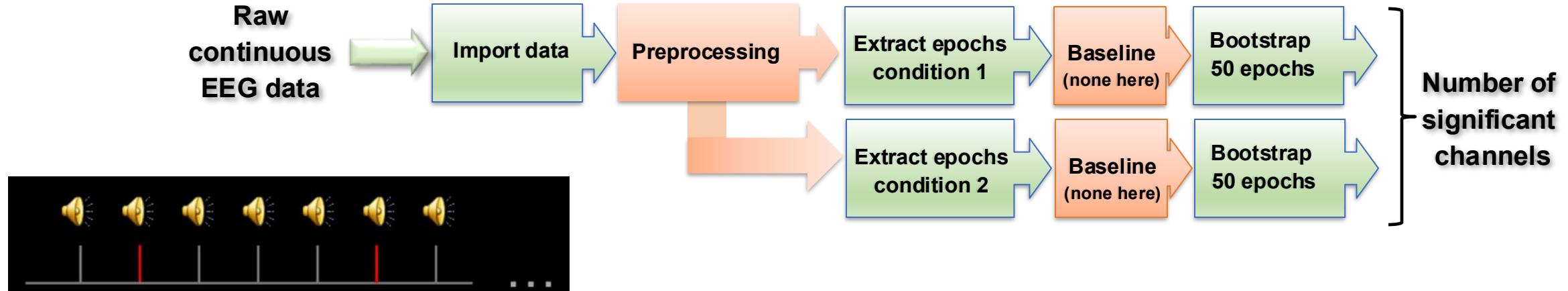
EEG is better left alone

[Arnaud Delorme](#) 

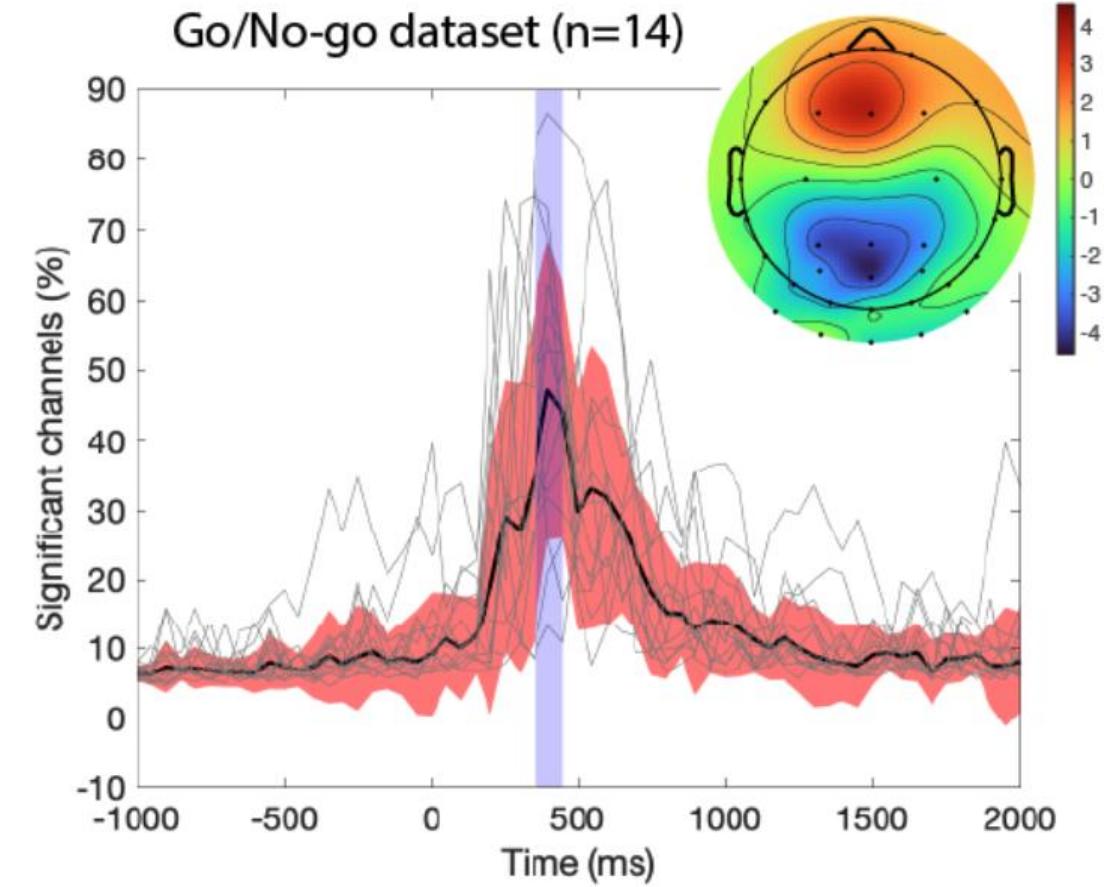
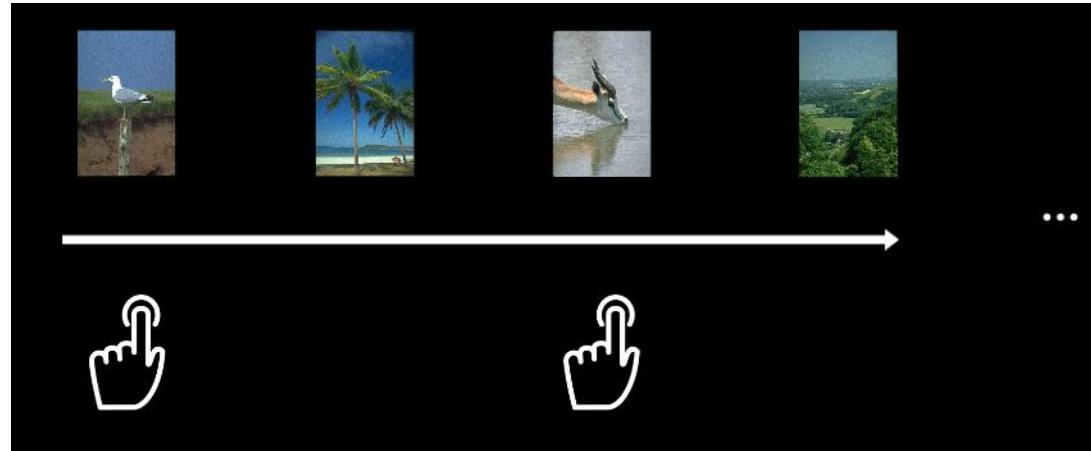
[Scientific Reports](#) 13, Article number: 2372 (2023) | [Cite this article](#)

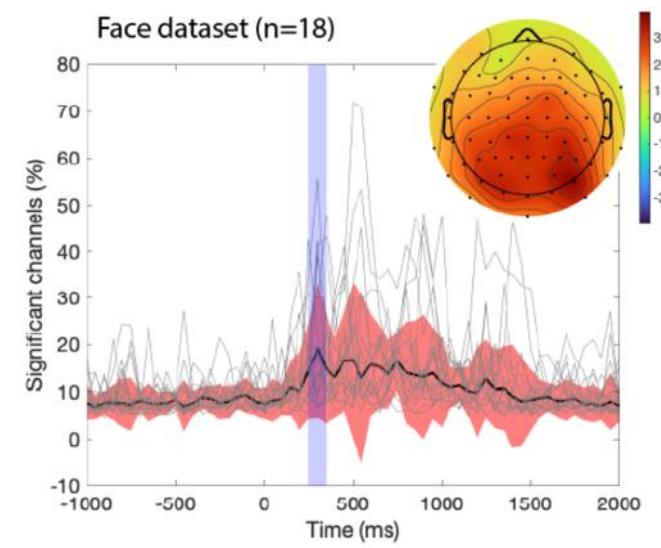
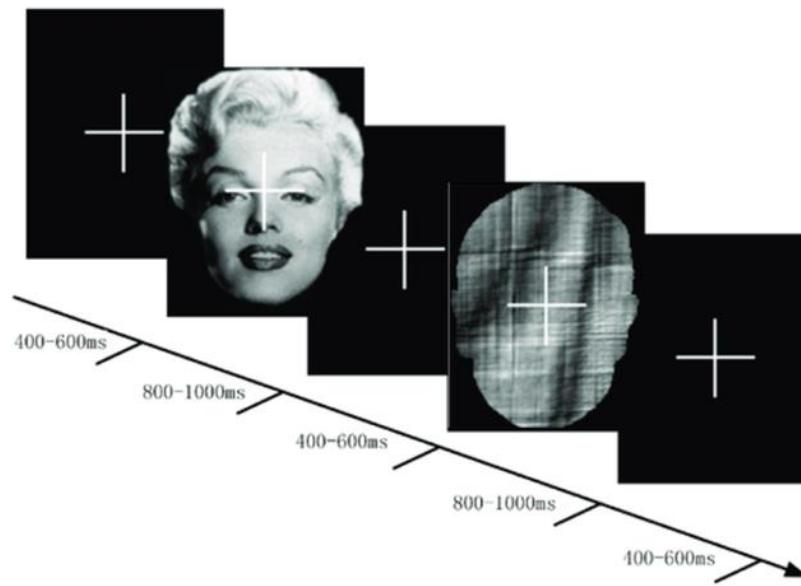
95k Accesses | **183** Citations | **166** Altmetric | [Metrics](#)

Influence of the reference on ERPs



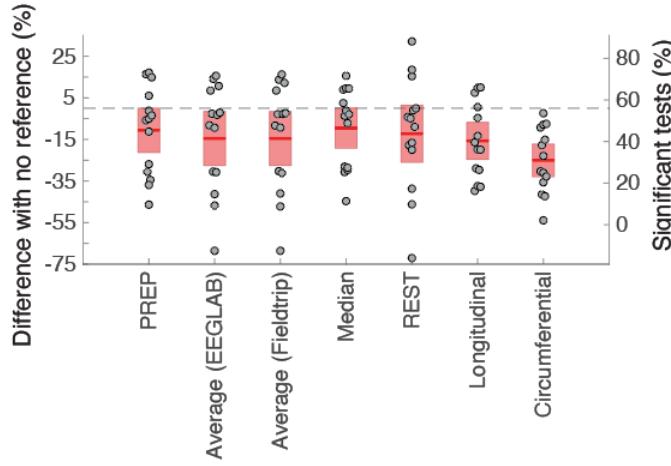
Influence of the reference on ERPs



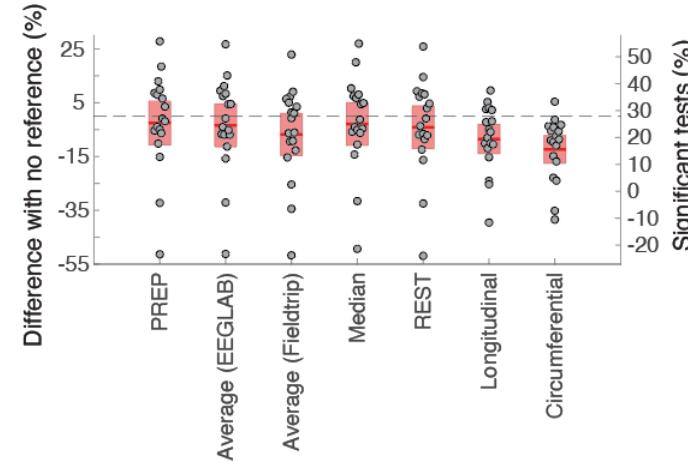


Influence of the reference on ERPs

Animal vs non-animal task
(BIDS 2680)



Face scrambled vs. famous
(dataset used at this workshop)



- ▶ It is unknown why using a reference decreases the number of significant channels when comparing 2 conditions for these 3 datasets
- ▶ No reference wins (REST not superior)

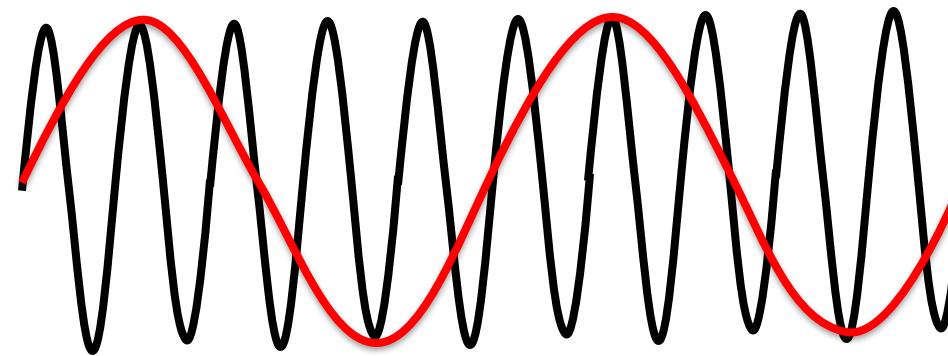
Downsampling data



500 Hz is usually enough

Reasons for lowering sampling rate

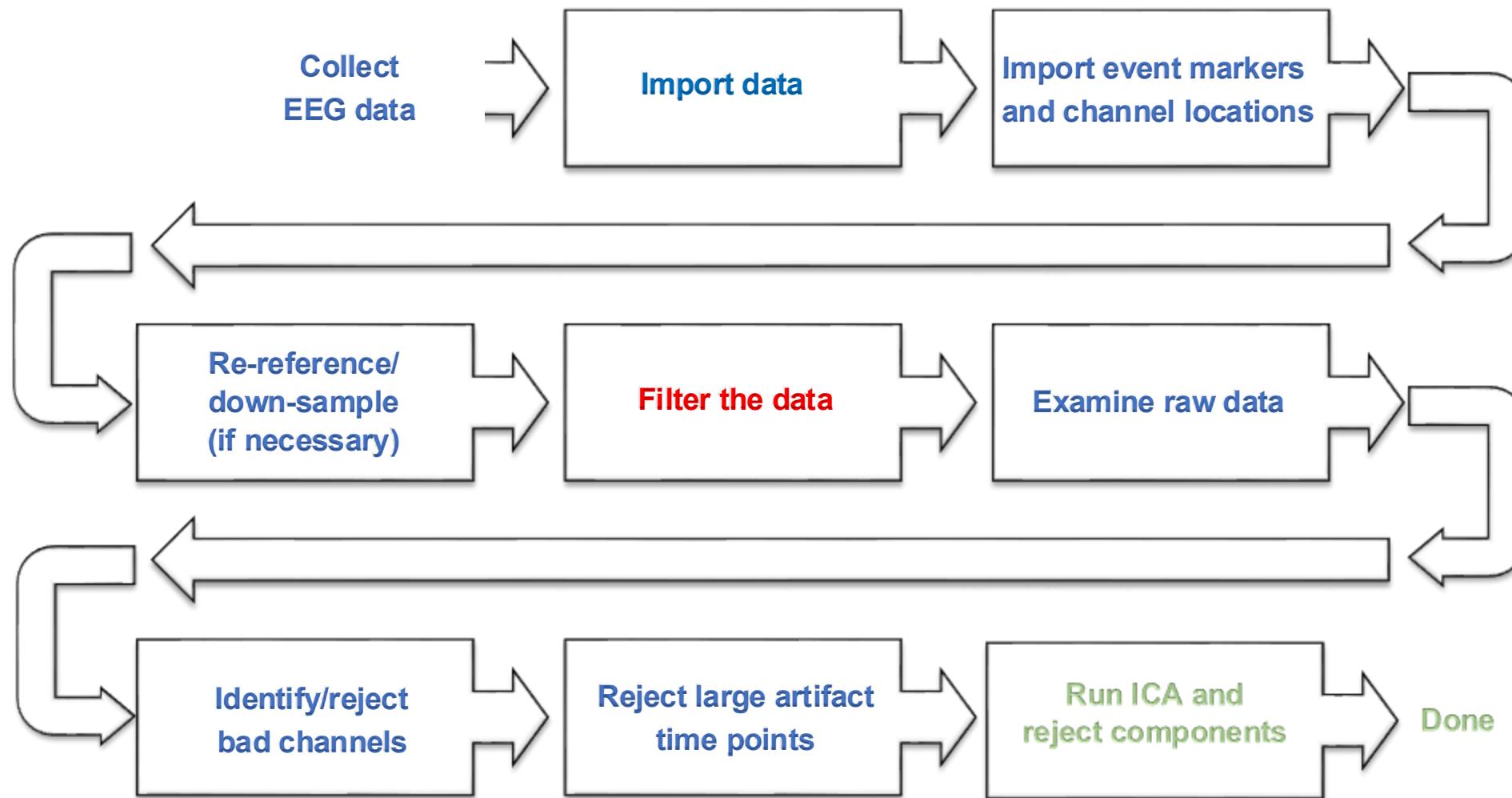
- Reduce time and computational cost
- Most MEEG processes are below 100 Hz. Maybe no need to keep a sample rate at 500Hz (beware of the Nyquist frequency)



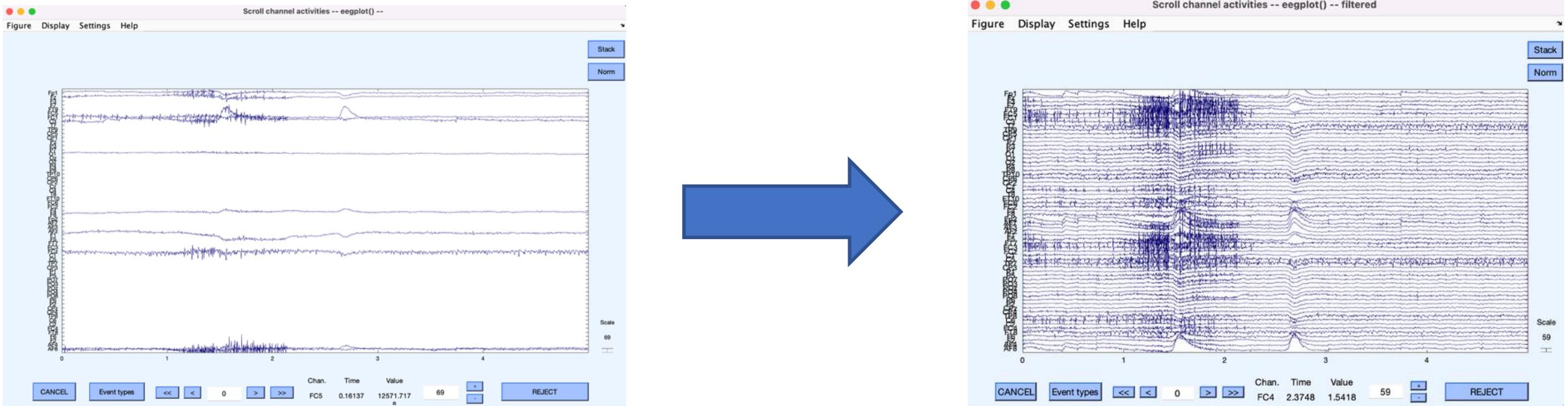
Reasons for NOT lowering sampling rate

- Even with MEEG amplifiers noise, information above 250 Hz (500 Hz sampling rate) might be useful for some algorithm (e.g., Independent Component Analysis)
- Behavioral responses are measured on the order of millisecond – keep MEEG at the same time scale?

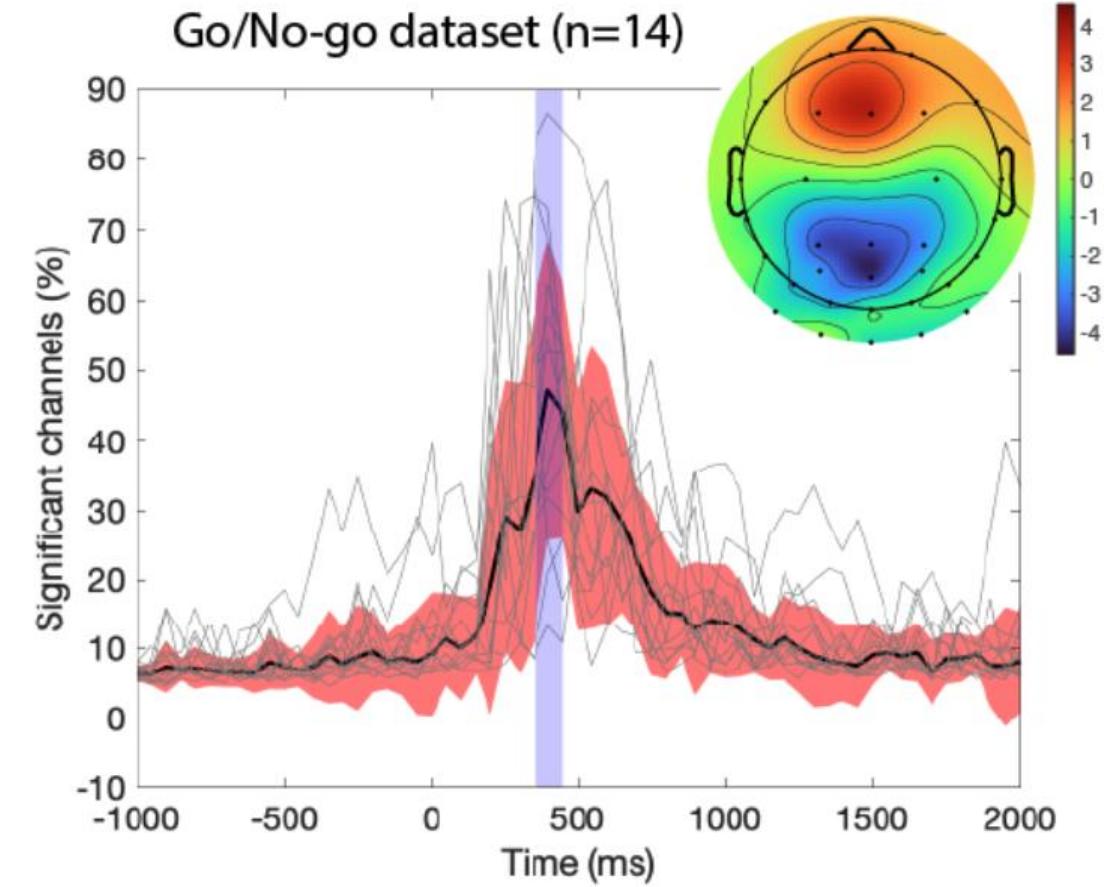
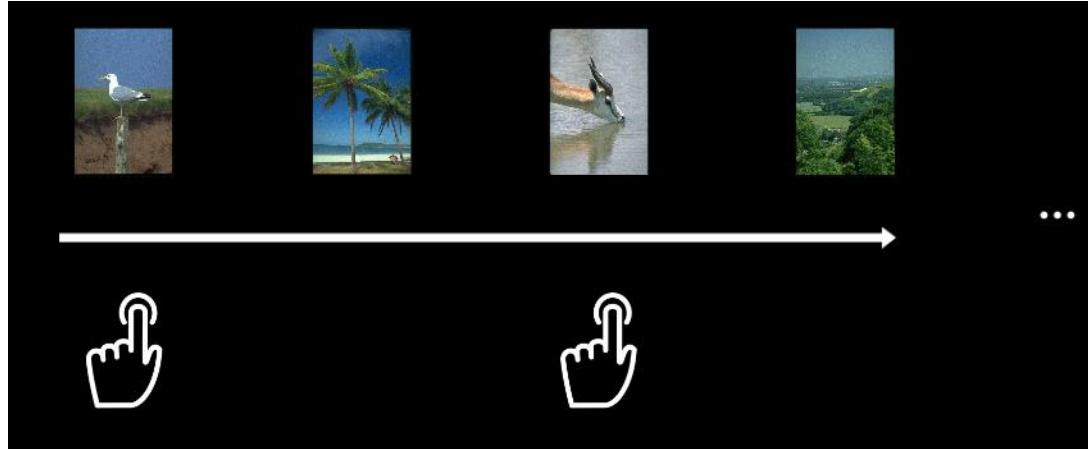
Pre-processing pipeline



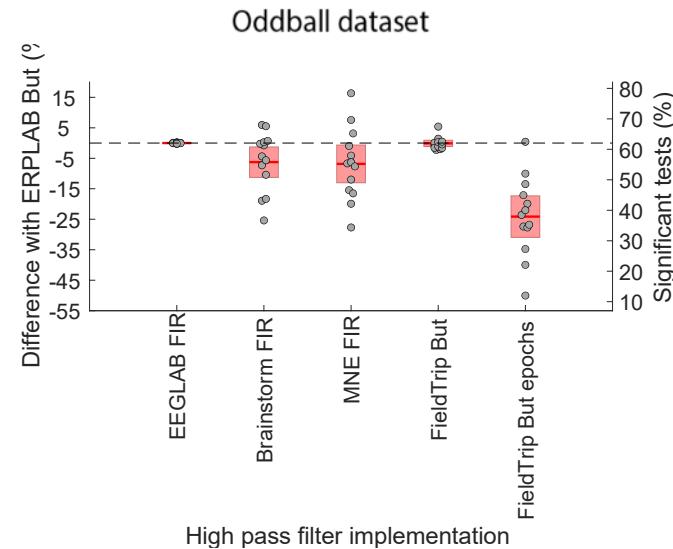
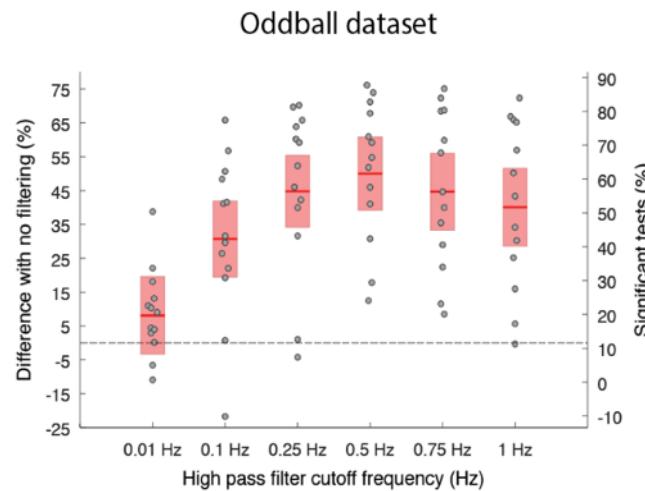
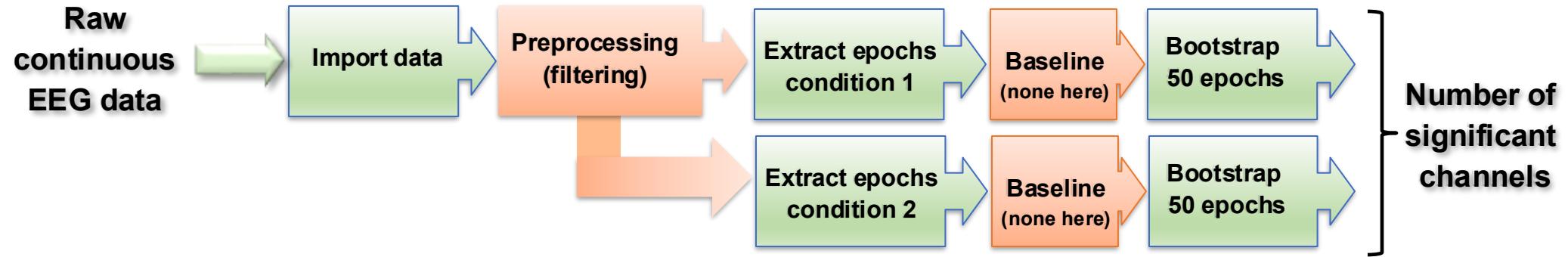
Highpass filter the data



Influence of HP filtering on ERPs

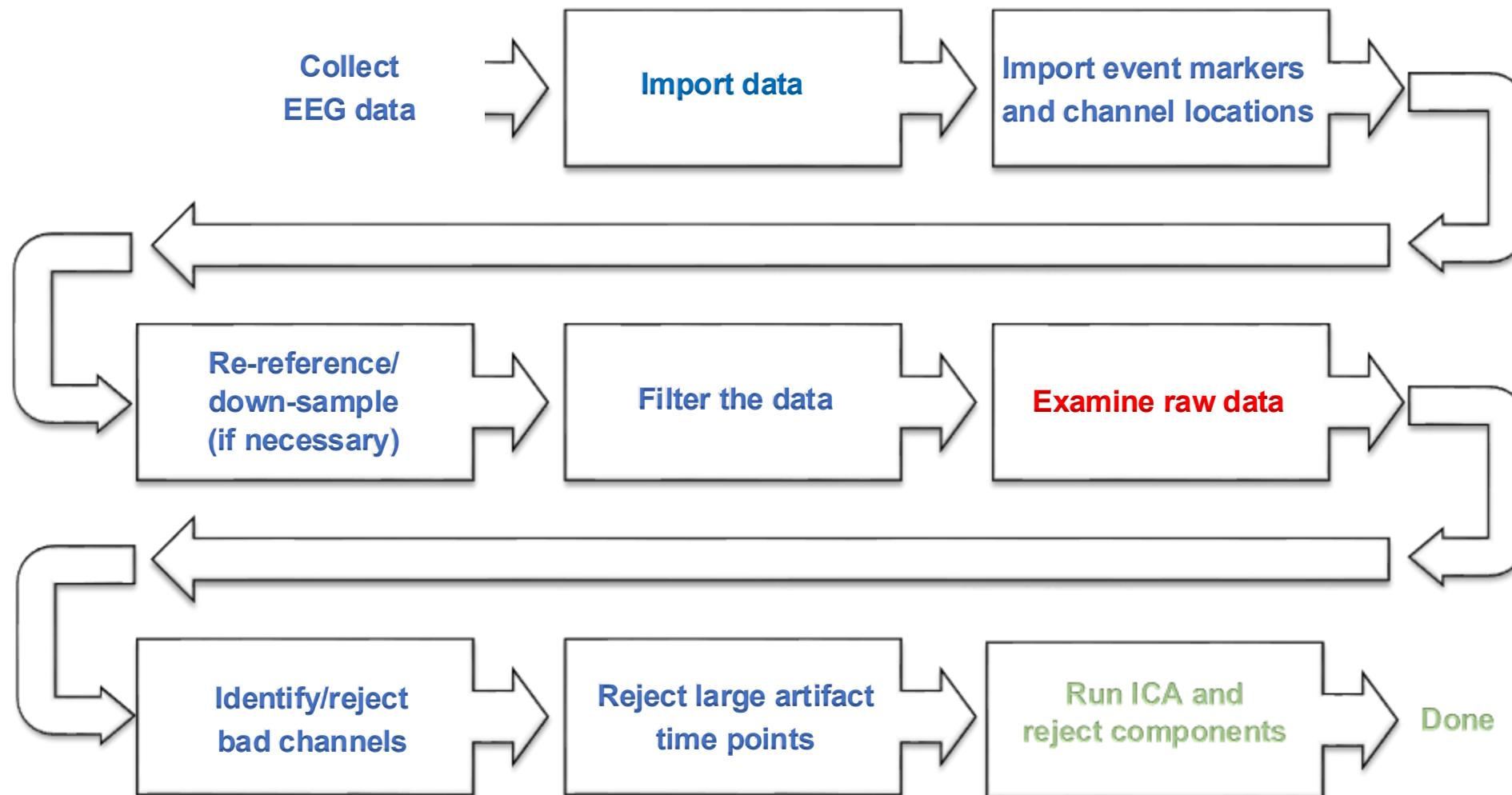


Influence of HP filtering on ERPs



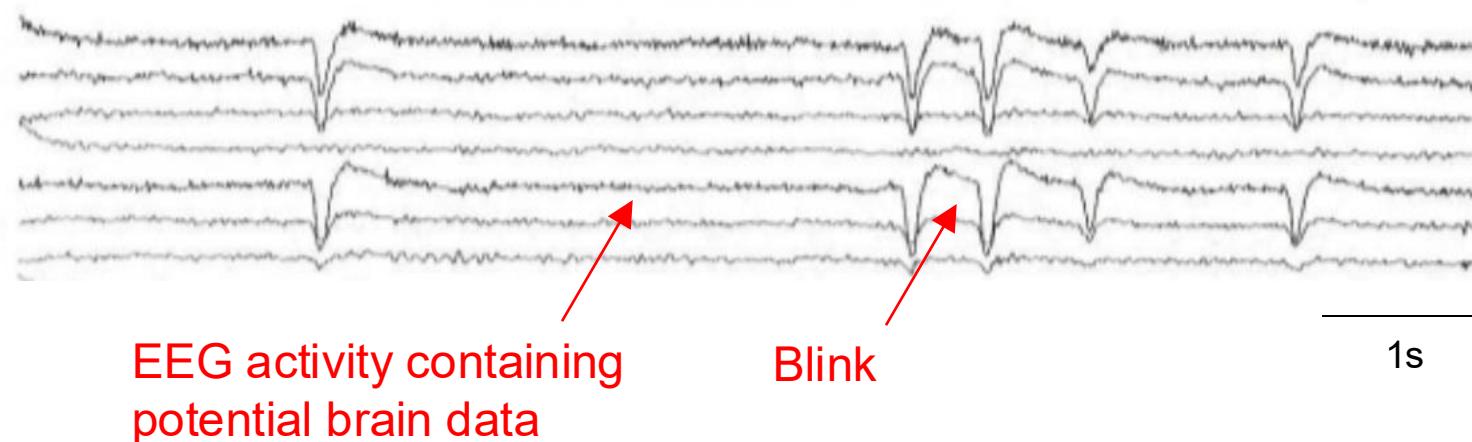
- ▶ The frequency cutoff is important
- ▶ Usually 0.5Hz is a good value
- ▶ The type of filter FIR or IIR is not critical
- ▶ Raw data should be filtered not epochs (e.g., FieldTrip preprocessing)

Pre-processing pipeline



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

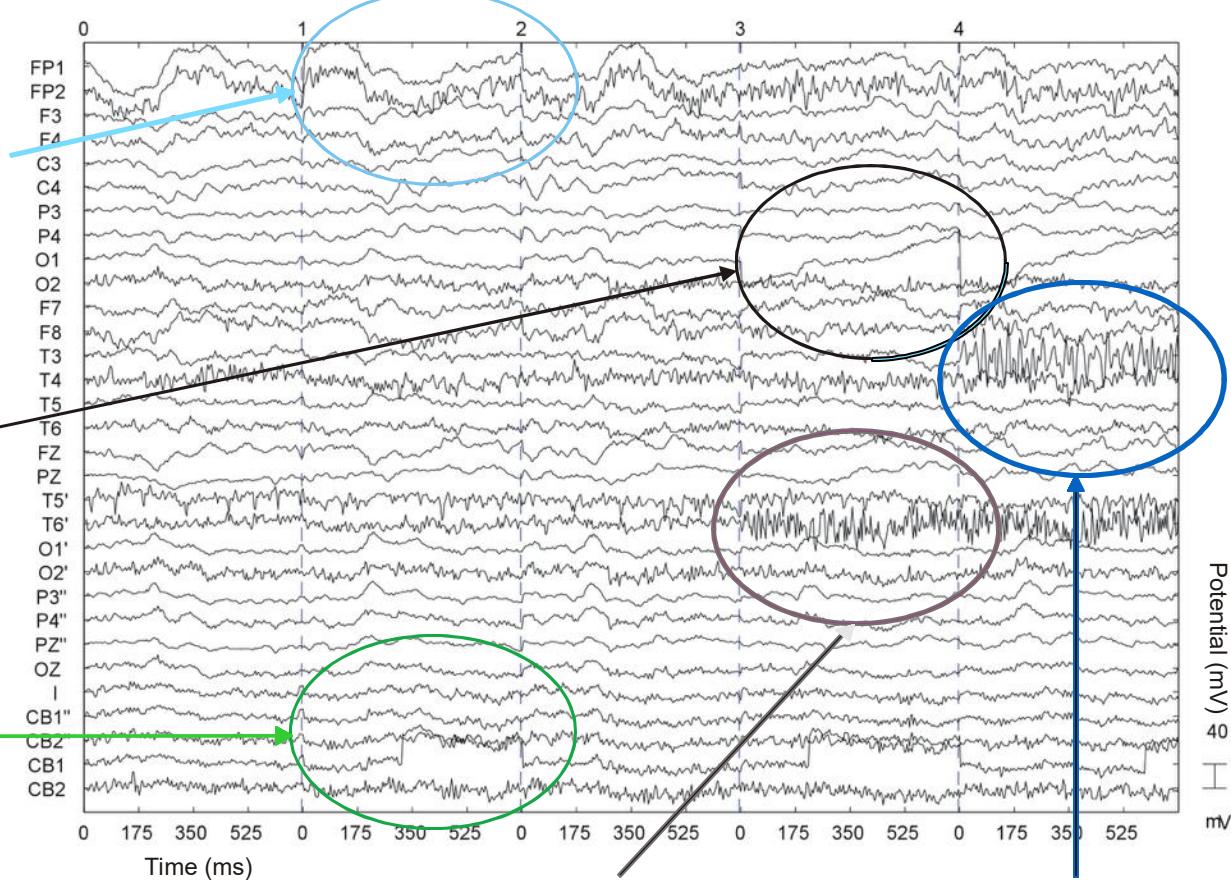
2 - Low frequency event (eye movements)

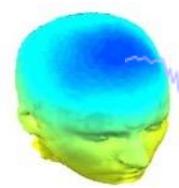
5 - Linear trend

3 - Discontinuity

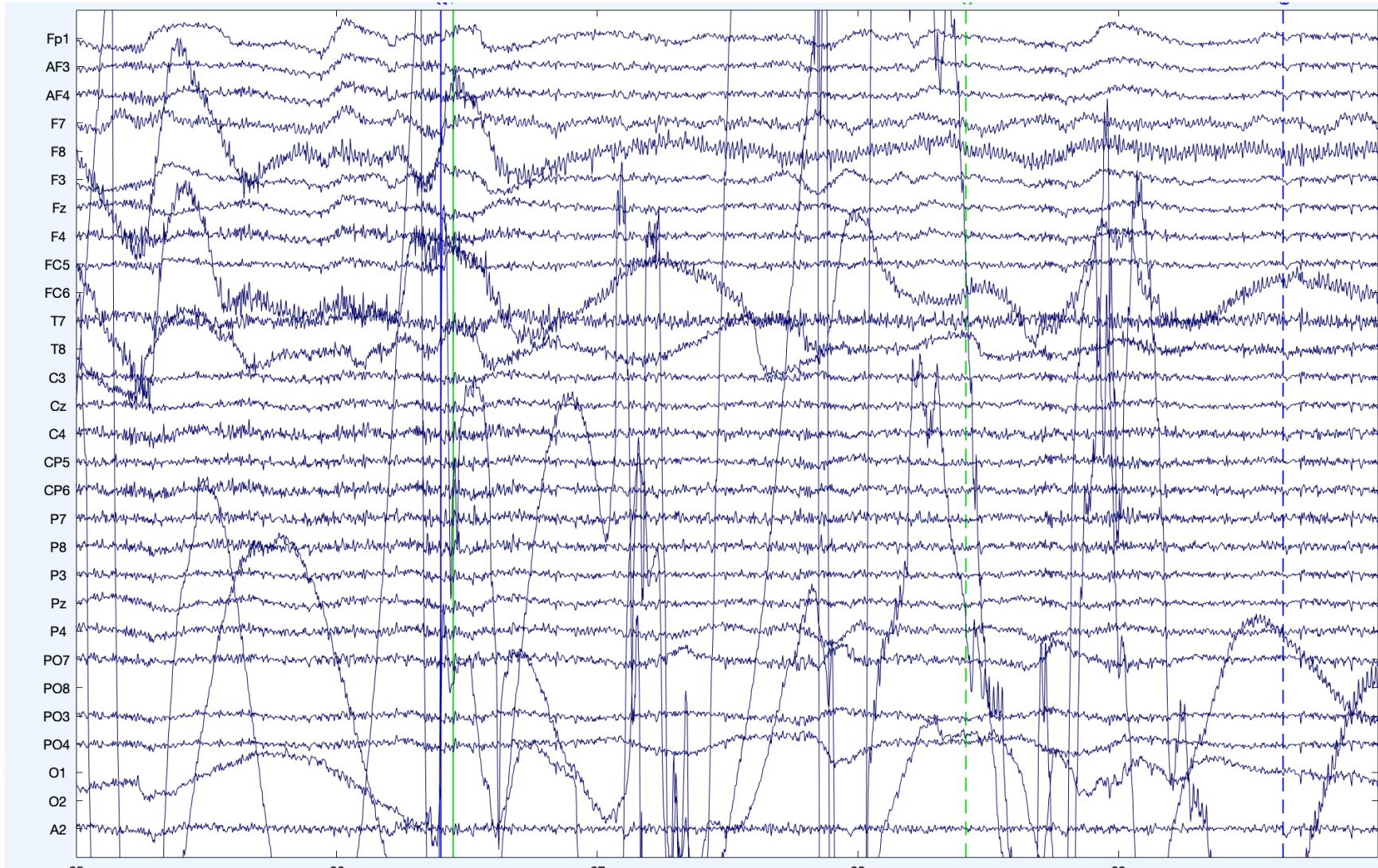
4 - High noise

1 - Transient high frequency event (muscle)



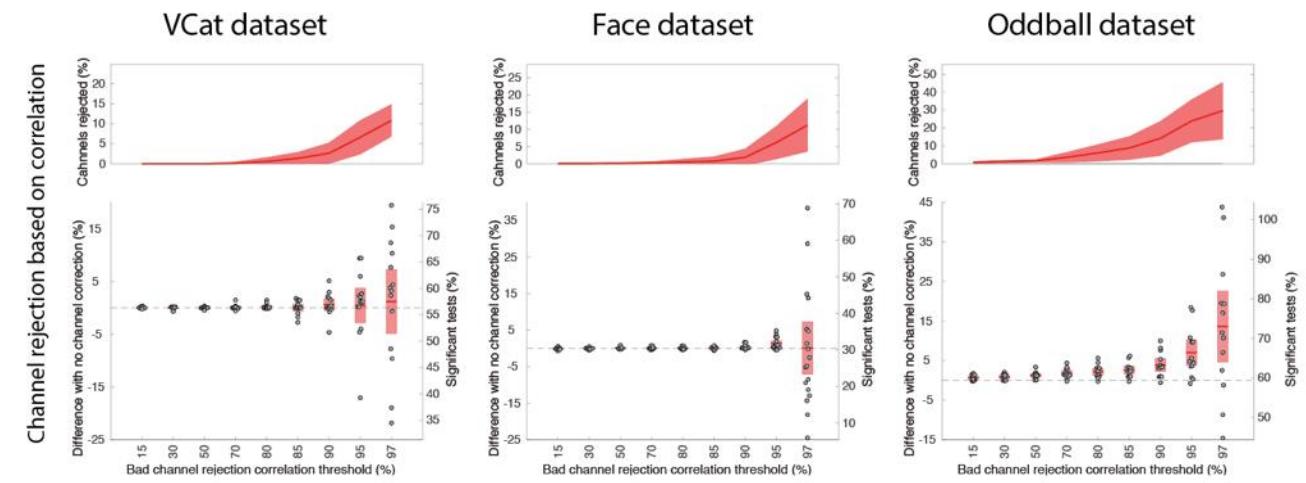
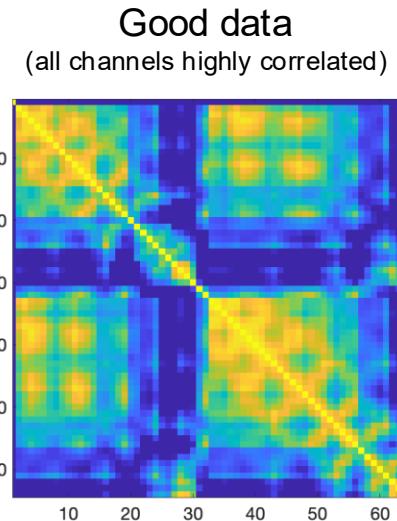
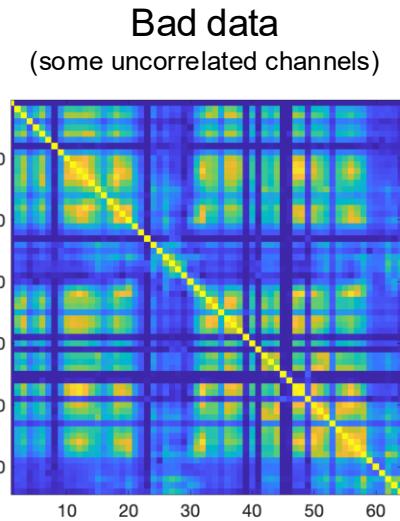


Looking for bad channels



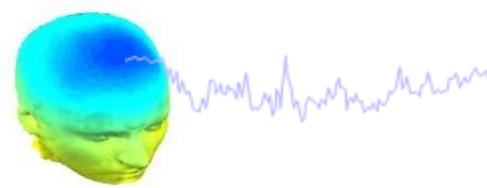


Pairwise correlation to find bad channels

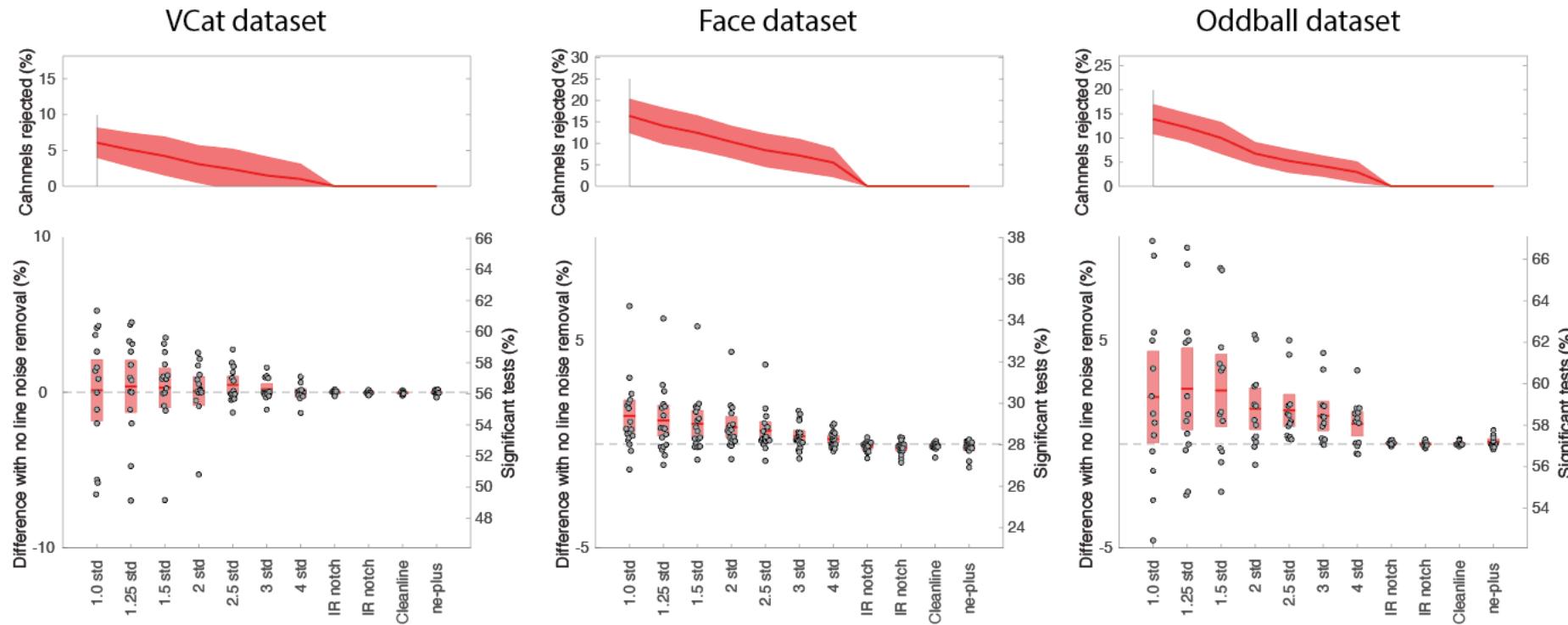


Tim R. Mullen, Christian Kothe, et al.(2015) Real-time neuroimaging and cognitive monitoring using wearable dry EEG. IEEE Transactions on Biomedical Engineering. DOI:10.1109/TBME.2015.2481482

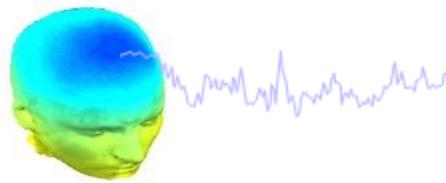
- ▶ Interpolating bad channels does not increase significance for reasonably clean data



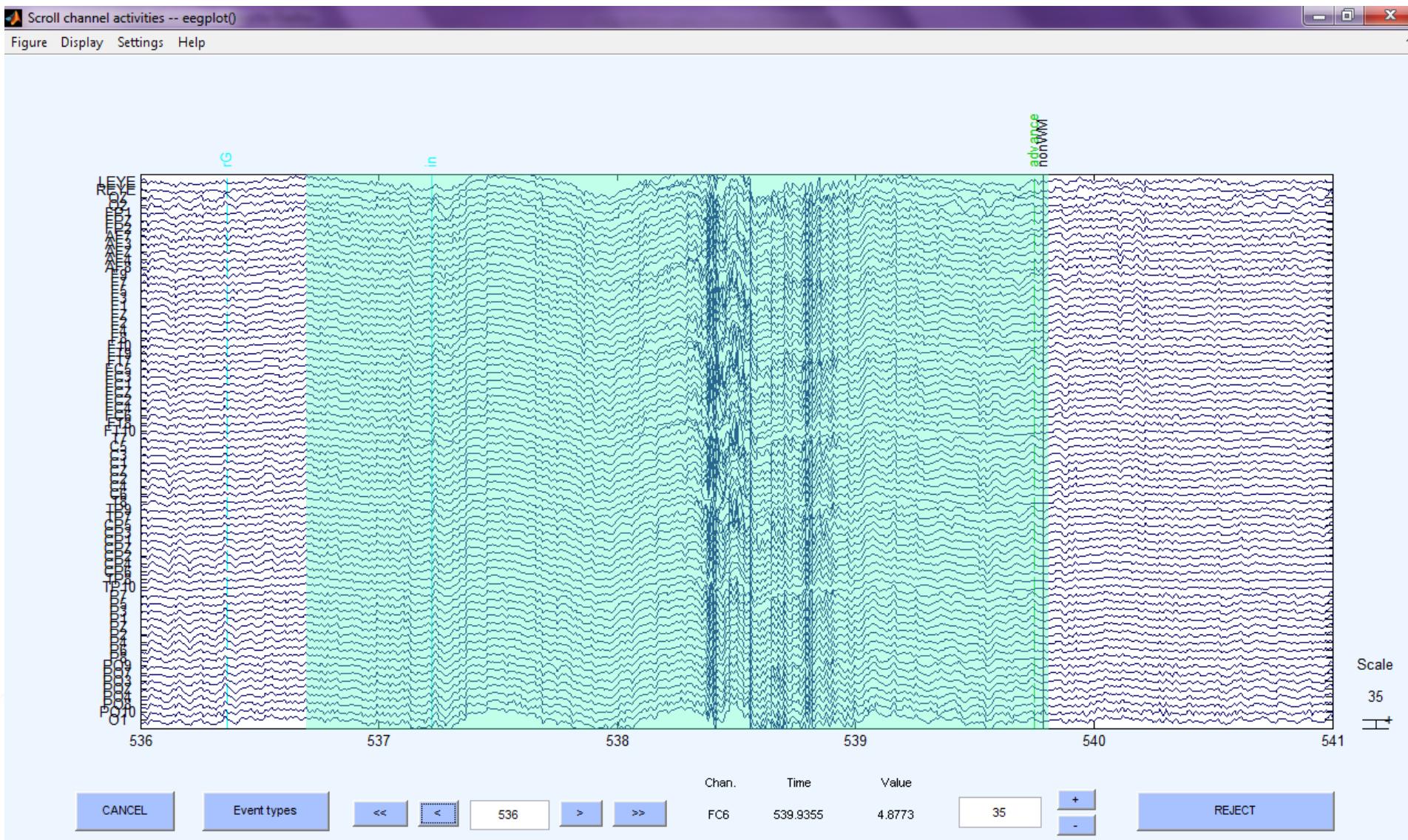
What about line noise?



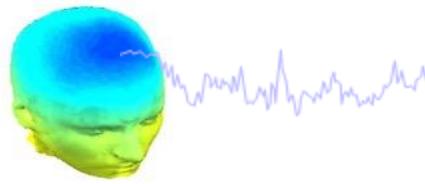
- ▶ Removing and interpolating noisy channel helps
- ▶ Notch filtering or using line-noise removal methods does not (for these datasets)



Rejecting continuous data



The powerful ASR method



NIH National Library of Medicine
National Center for Biotechnology Information

PubMed.gov

"artifact subspace reconstruction"

Advanced Create alert Create RSS

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Sorted by: Best match Display options

19 results

RESULTS BY YEAR

2014 2022

ARTICLE ATTRIBUTE

Associated data

ARTICLE TYPE

Evaluation of Artifact Subspace Reconstruction for Automatic Artifact Components Removal in Multi-Channel EEG Recordings.

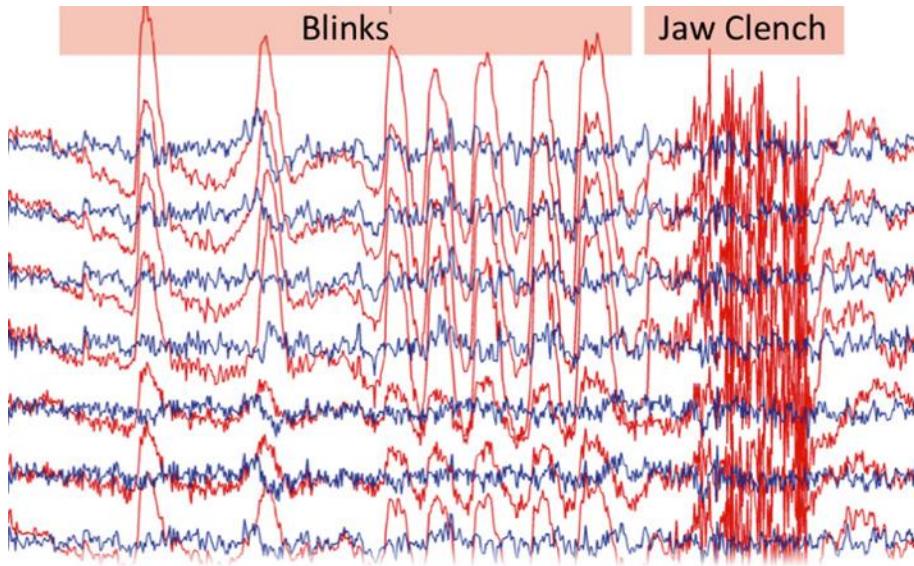
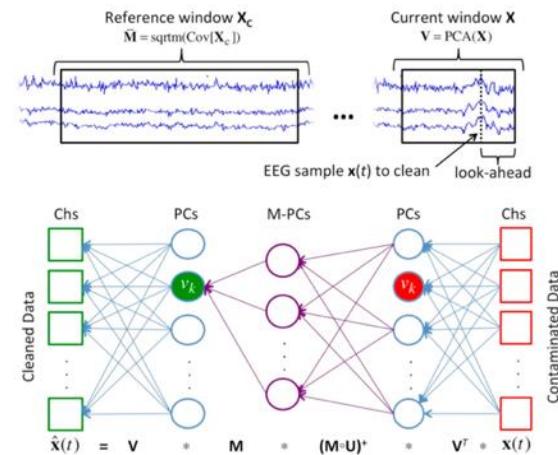
Cite Chang CY, Hsu SH, Pion-Tonachini L, Jung TP.
IEEE Trans Biomed Eng. 2020 Apr;67(4):1114-1121. doi: 10.1109/TBME.2019.2930186. Epub 2019 Jul 22.
PMID: 31329105

OBJECTIVE: **Artifact subspace reconstruction (ASR)** is an automatic, online-capable, component-based method that can effectively remove transient or large-amplitude artifacts contaminating electroencephalographic (EEG) data. ...SIGNIFICANCE: With an appropriate ...

Evaluation of Artifact Subspace Reconstruction for Automatic EEG Artifact Removal.

Cite Chang CY, Hsu SH, Pion-Tonachini L, Jung TP.
Annu Int Conf IEEE Eng Med Biol Soc. 2018 Jul;2018:1242-1245. doi: 10.1109/EMBC.2018.8512547.
PMID: 30440615

One of the greatest challenges that hinder the decoding and application of electroencephalography (EEG) is that EEG recordings almost always contain artifacts - non-brain signals. Among existing automatic artifact-removal methods, **artifact subspace reconstr ...**



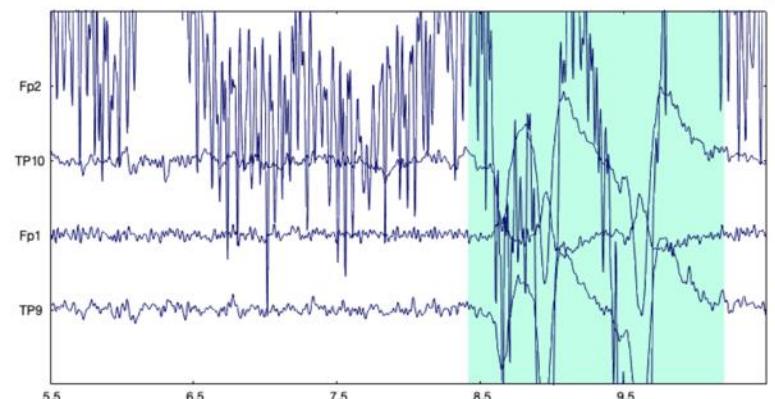
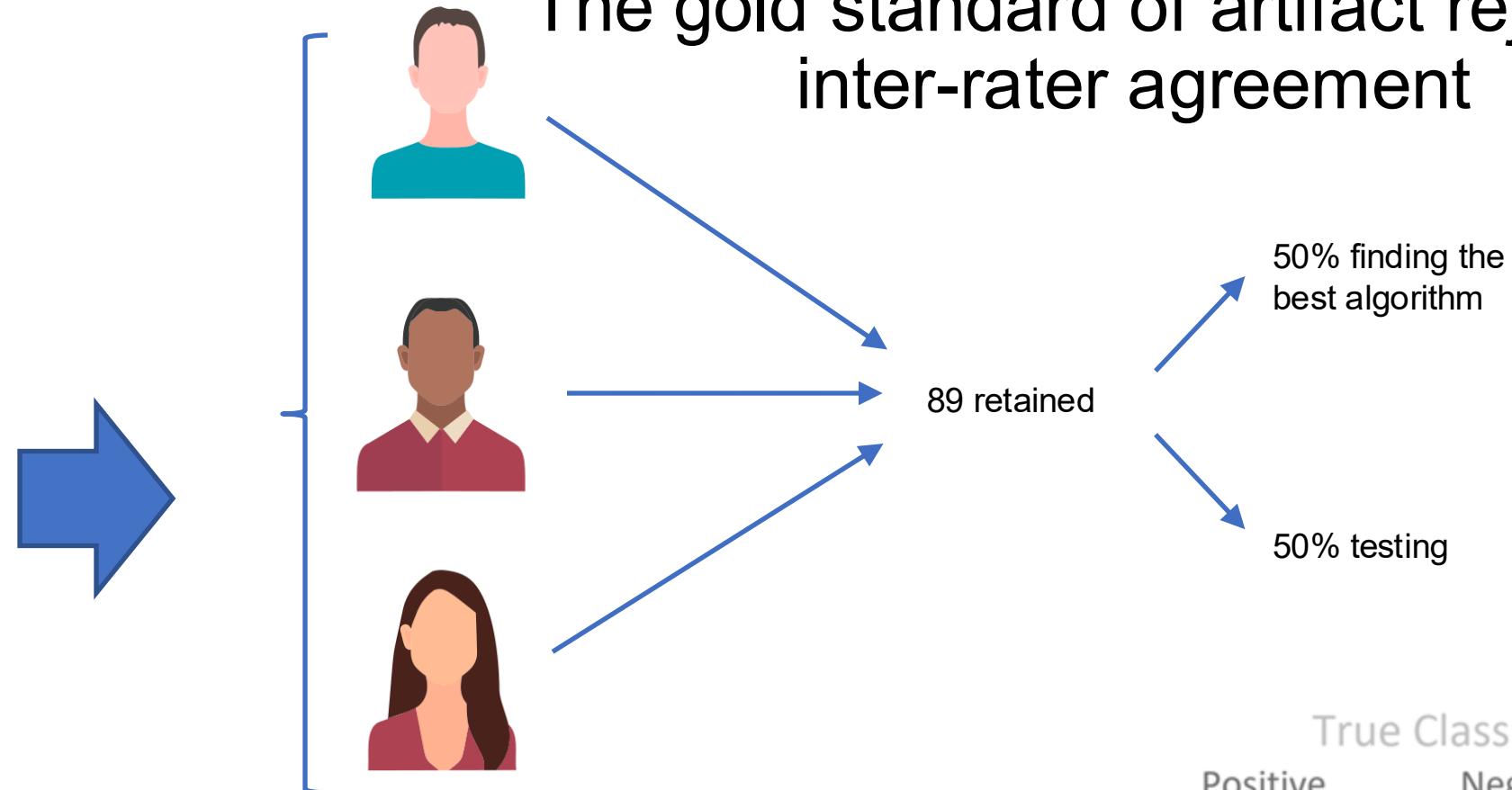
► For offline analysis, ASR is usually used to **detect and remove** but not correct data

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

100 files of 12 min

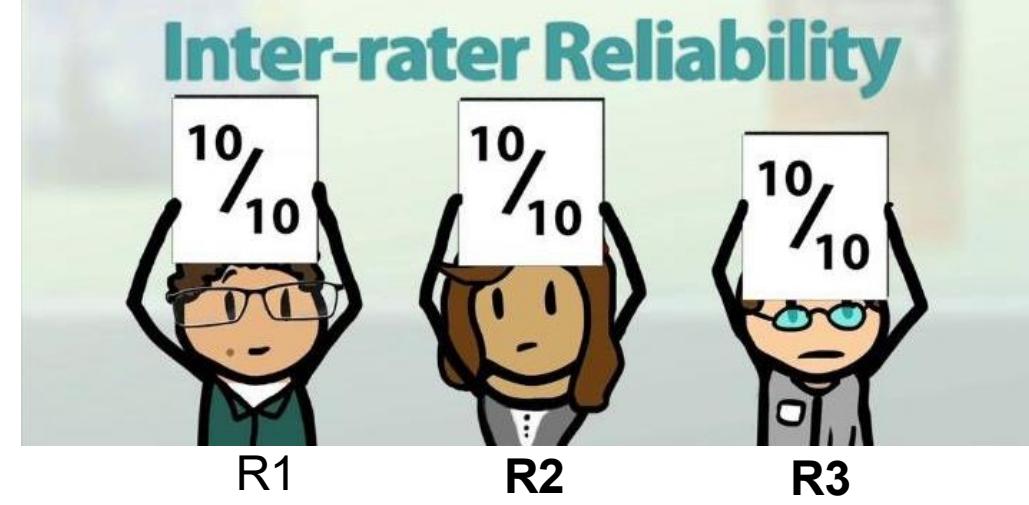
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96c5274f-38ef-4be9-b39f-7c5fc567ae87.set

The gold standard of artifact rejection: inter-rater agreement



Predicted Class	True Class
Negative	Positive
TP	FP
FN	TN

BAD portion of data

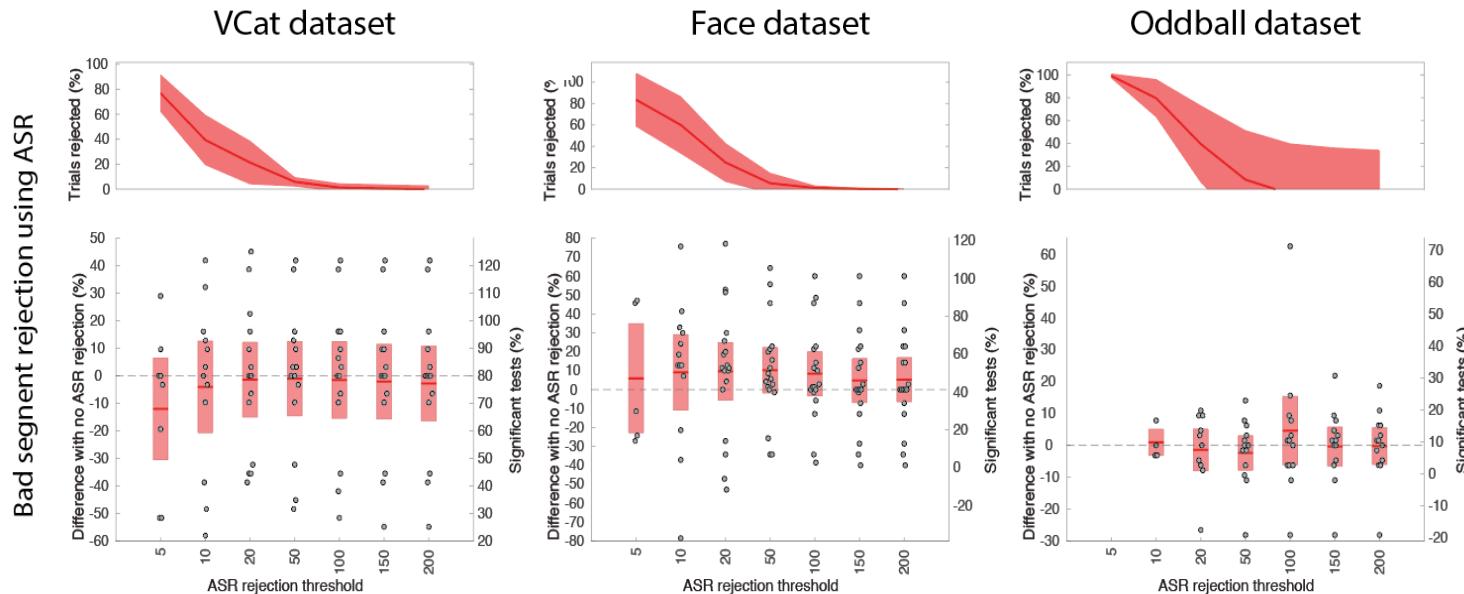
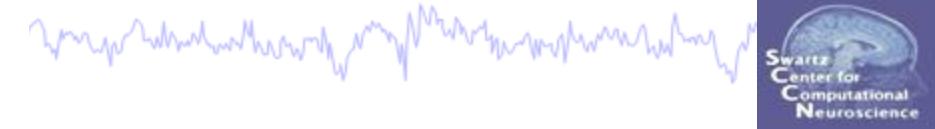


	% rejection	vs R1	vs R2	vs R3	Accuracy
R1	37	n/a	80.7	79.7	80.2
R2	37	80.7	n/a	78	79.4
R3	30	79.7	78	n/a	78.8
ASR (11)	31	81.9	82.4	80.6	81.6 (79.5 83.6)

- ▶ ASR with threshold 11 is closer to each human rater than raters are with each other on the test data

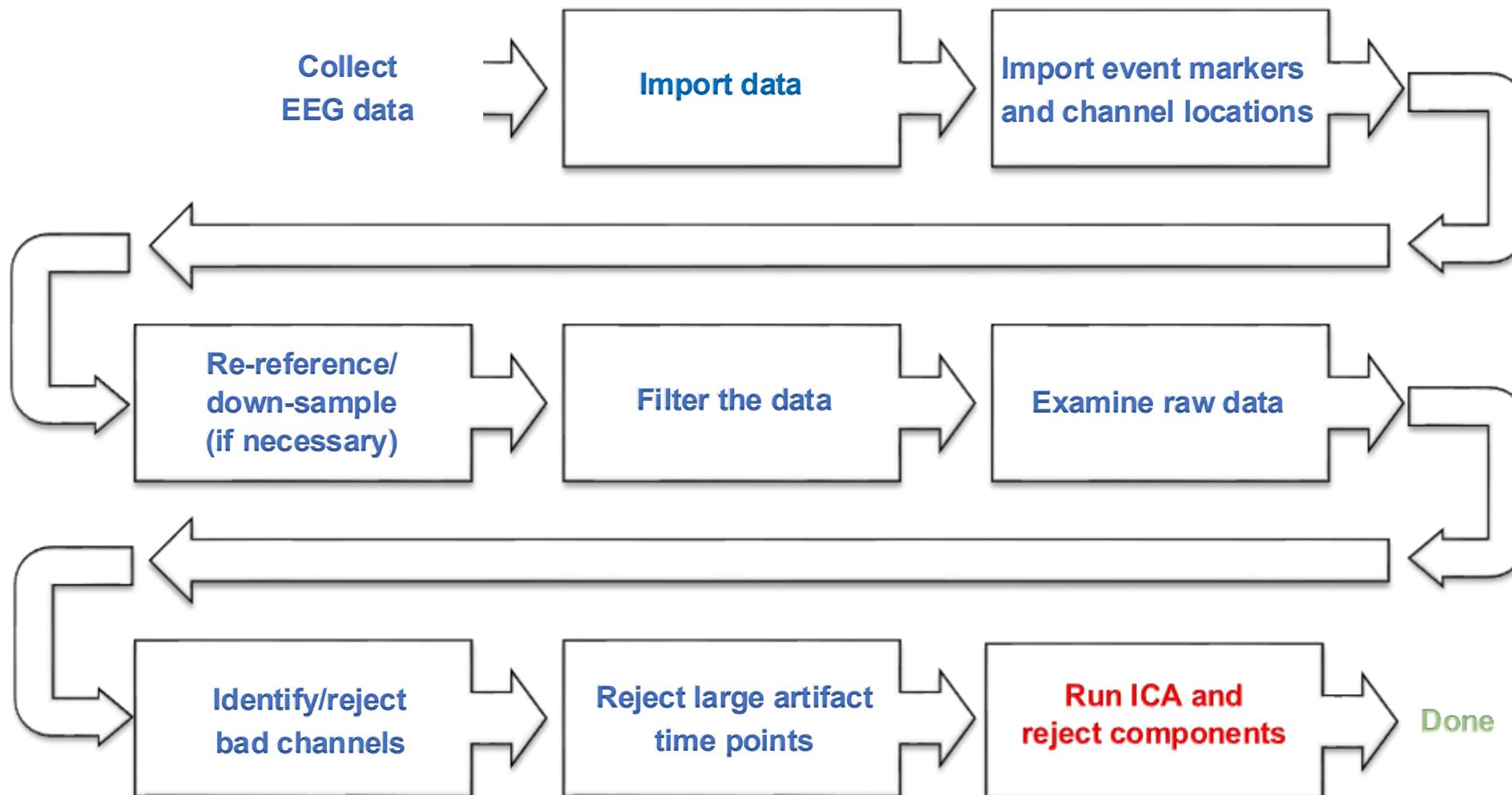


And yet...

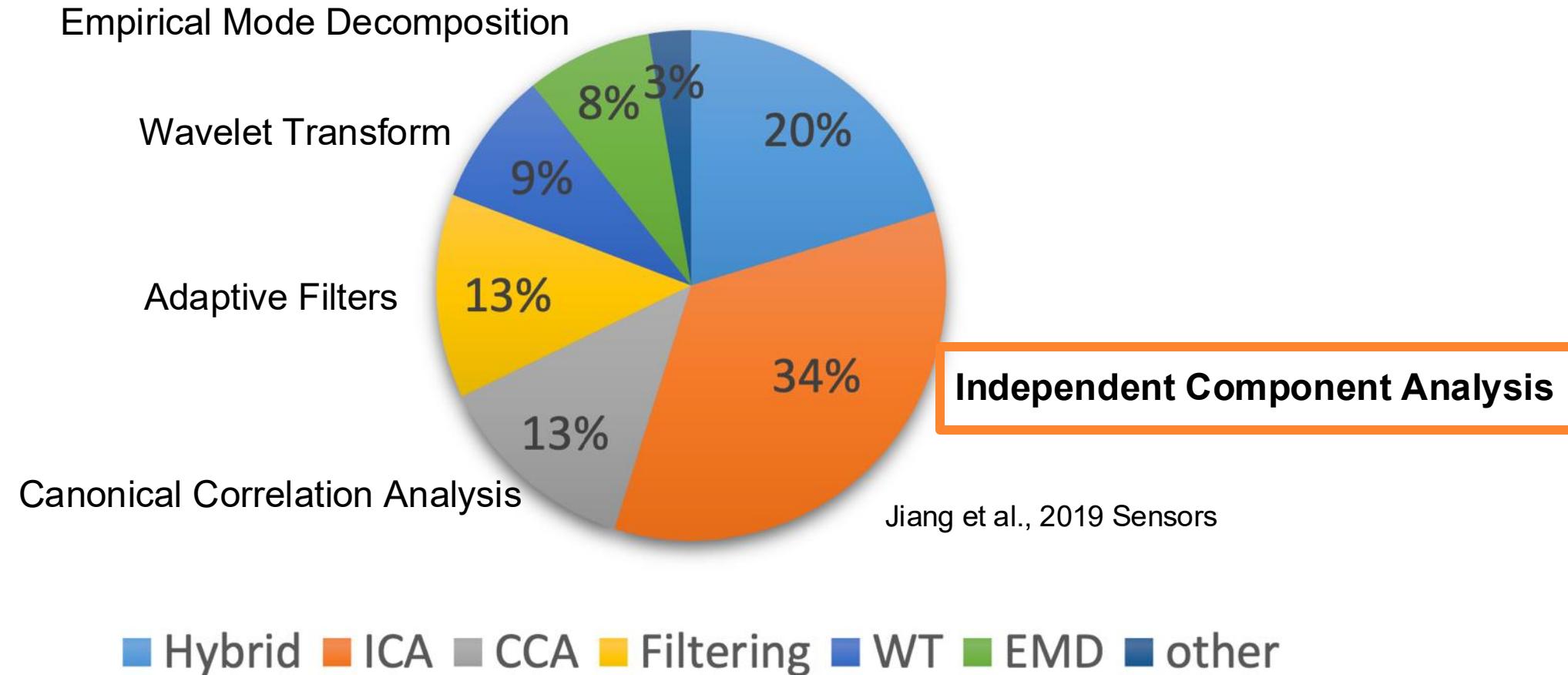
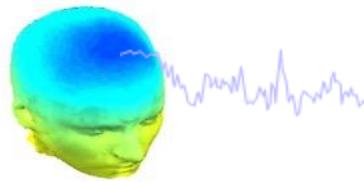


- ▶ For **reasonably clean data, ASR brings no gain**
- ▶ The removal of bad trials does not compensate for the loss of statistical power due to the lower trial count
- ▶ Brainstorm, MNE, Fieldtrip, and other EEGLAB other automated rejection methods show no gain either

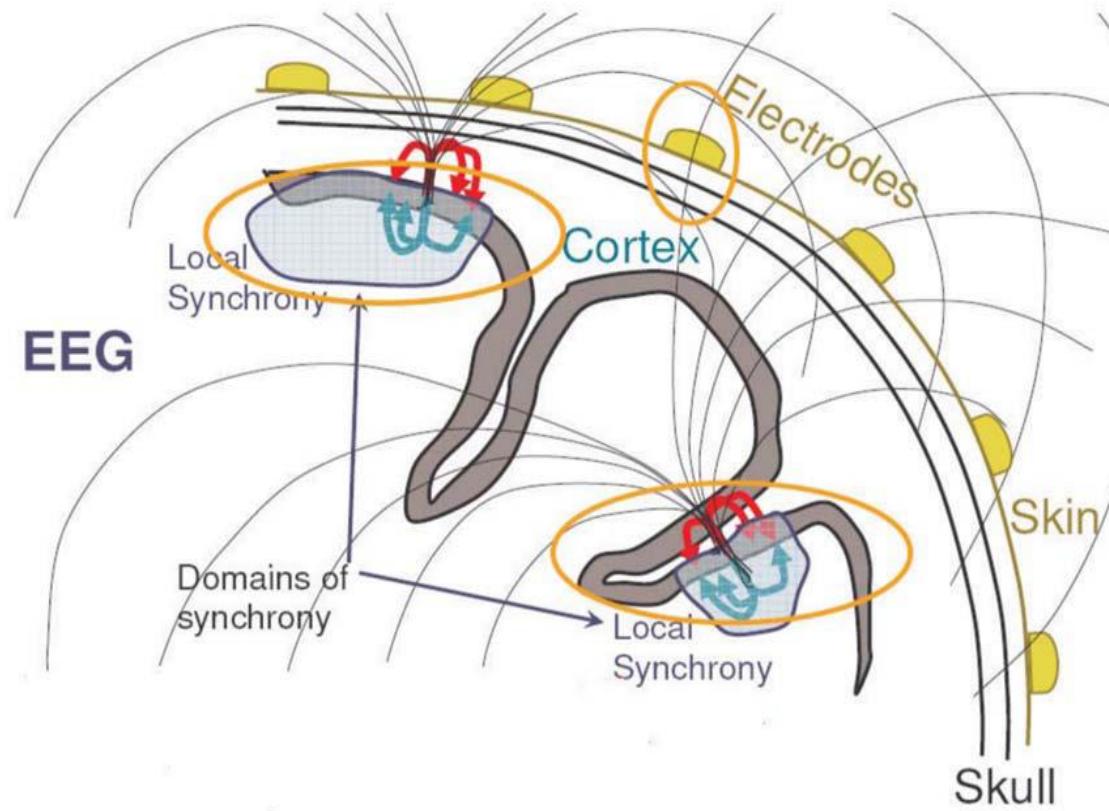
Pre-processing pipeline



Artefact correction methods

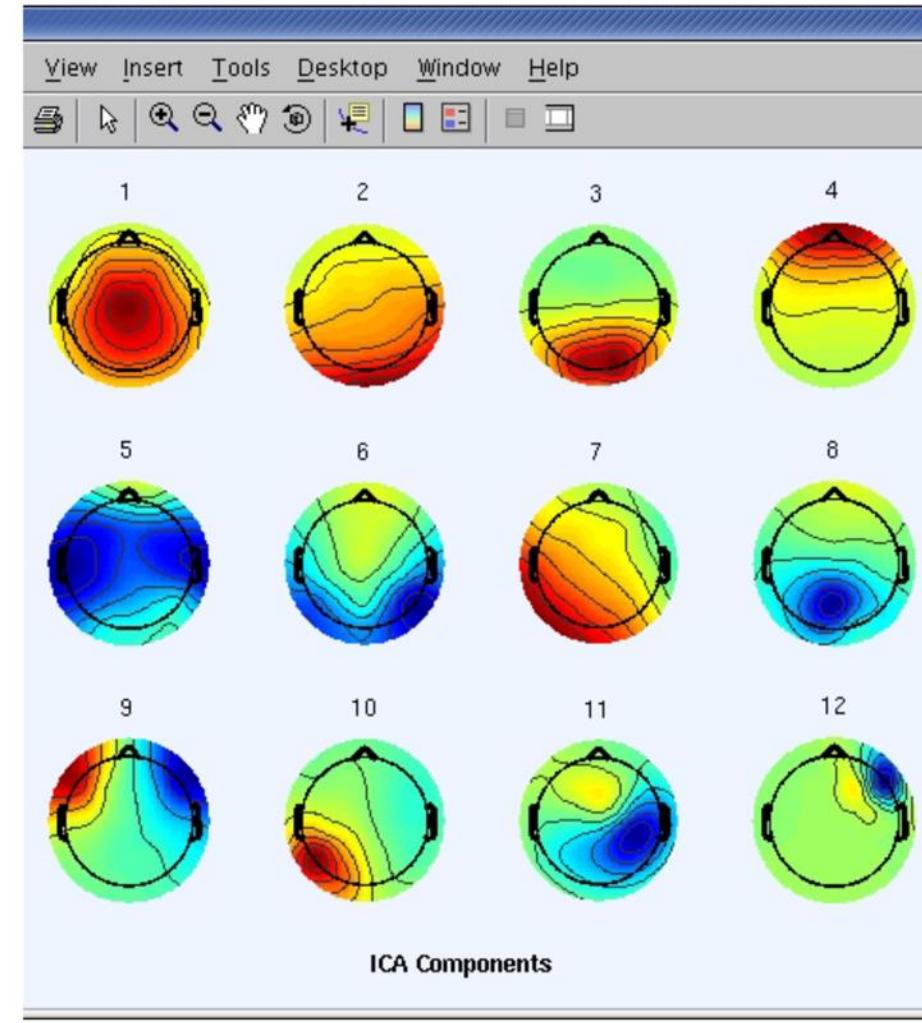
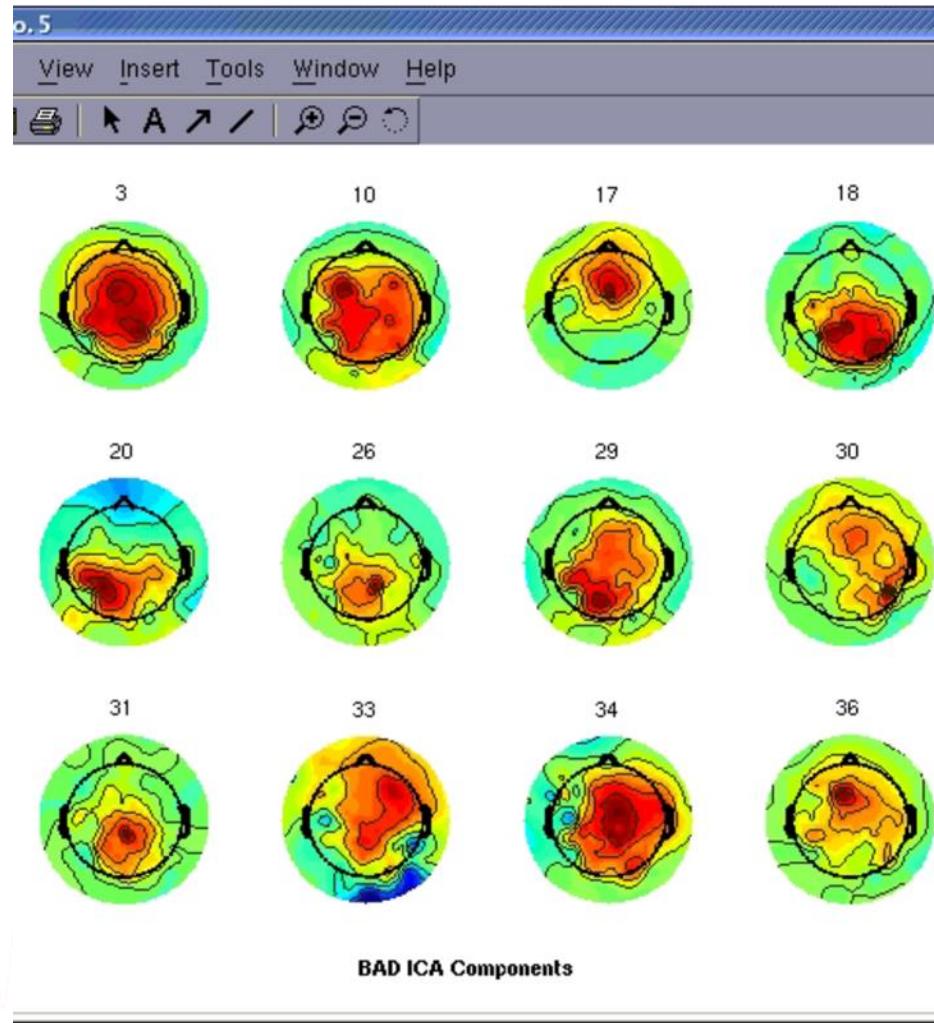
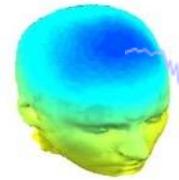


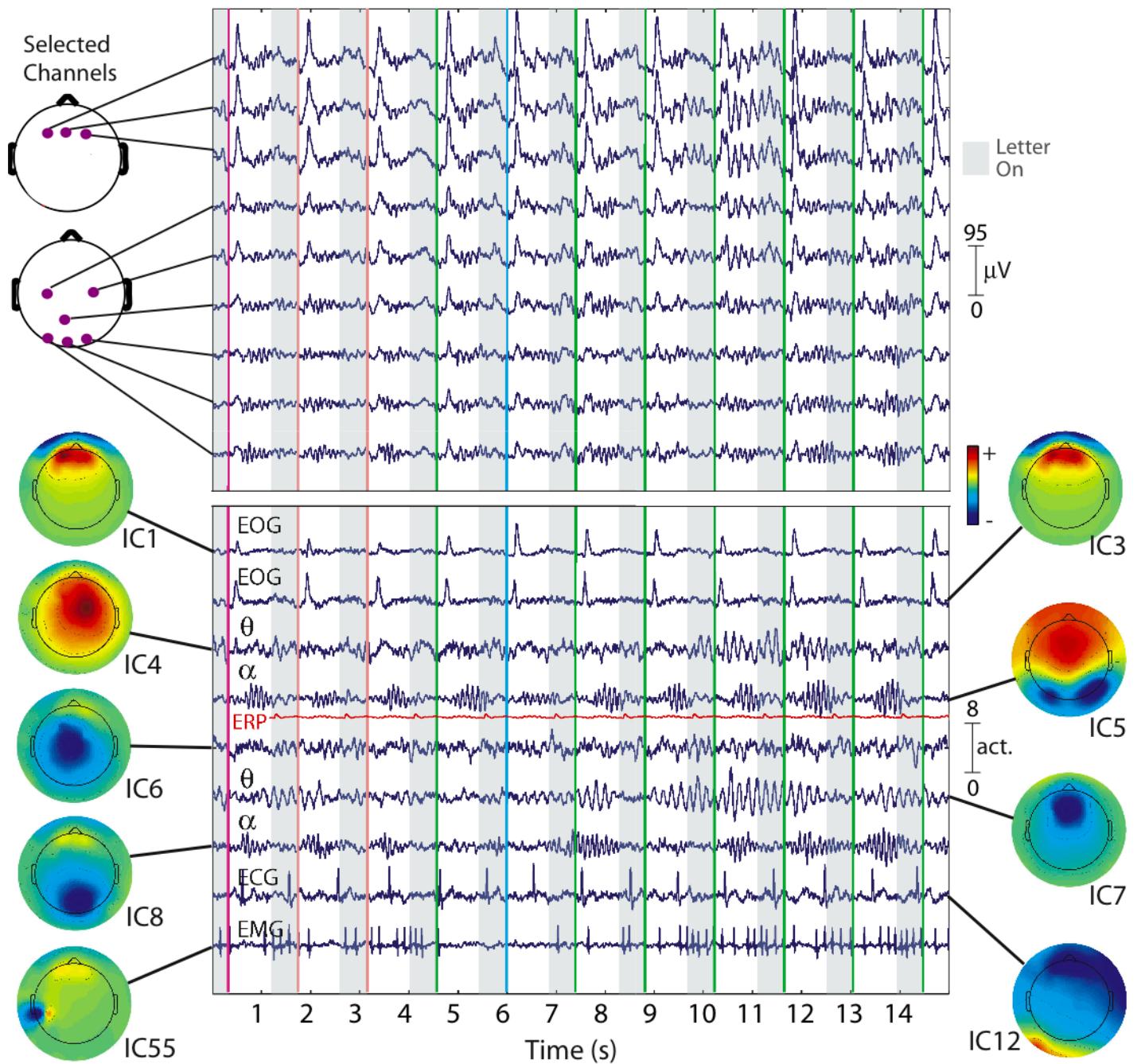
Independent Component Analysis



ICA – separates the EEG in temporally independent source signals (Makeig, 1996)

Quality of Decomposition





ICLabel Website and Label Collection

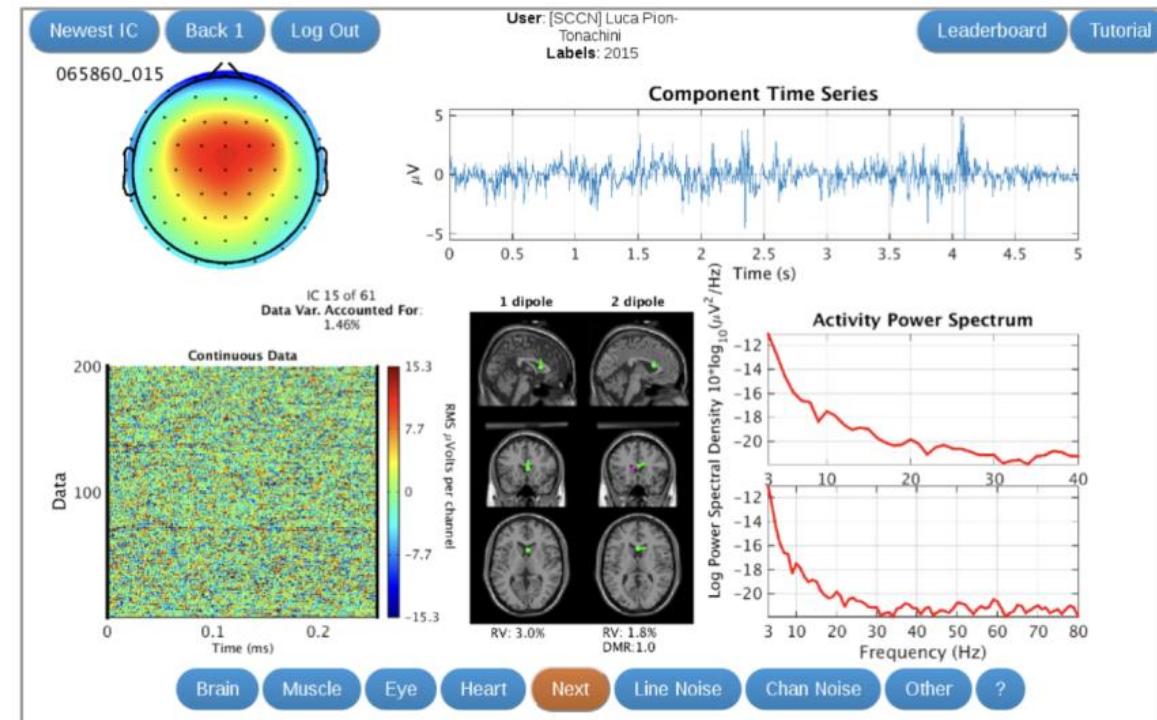
Summary: ask others to help out with labeling EEG components.

Website: labeling.ucsd.edu

Have experts from the SCCN and elsewhere label a subset.

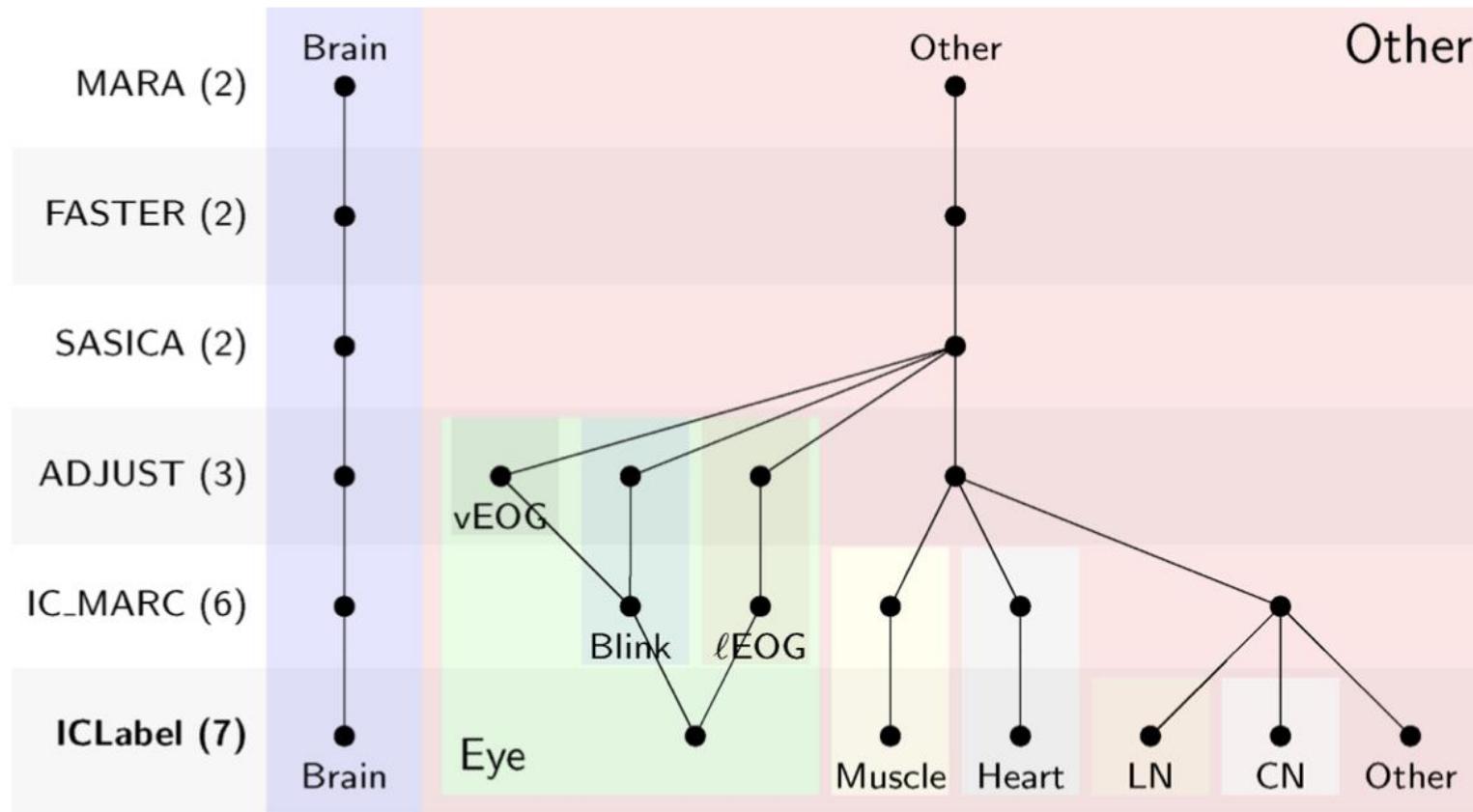
Ask the EEGLAB community to help label a larger subset.

Currently 328 contributing users and 34,000+ submitted labels.



Has been adapted for educational use as well.

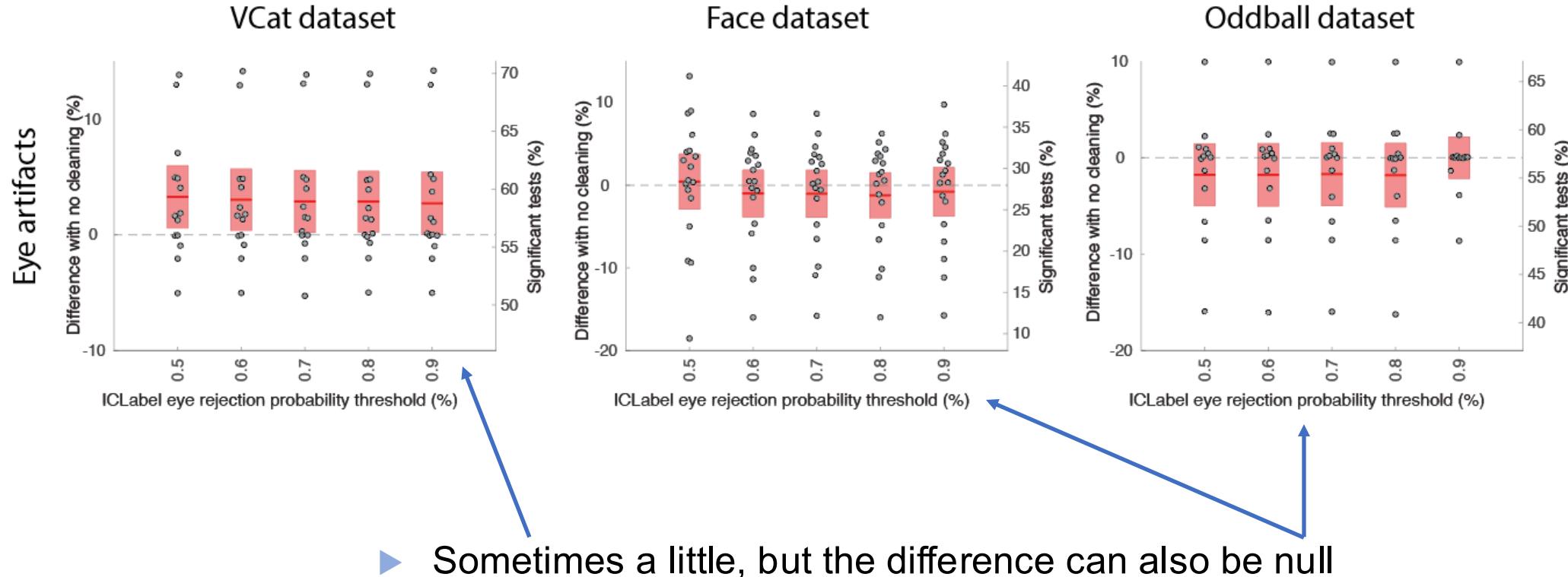
Automated ICA classification methods



Every method listed above is available as separate EEGLAB plugins

FieldTrip, MNE and Brainstorm can apply ICA (but automated classification are not available yet)

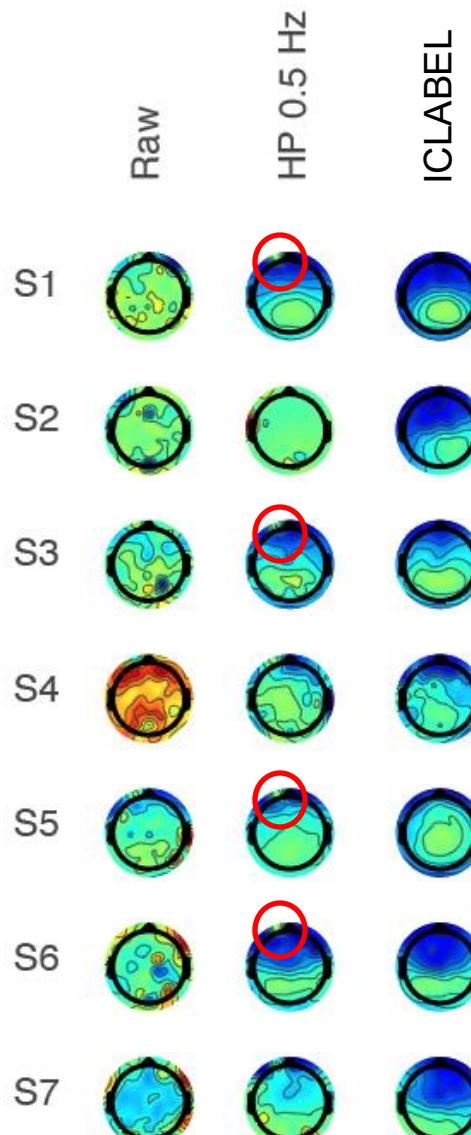
Does ICA help with ERP significance?



- ▶ Sometimes a little, but the difference can also be null
- ▶ Note that ICA may remove artifacts which contribute to differences between conditions (so this method of assessing performance is not ideal)

Should I even use ICA to remove artifacts, then?

- ▶ Yes, because it remove channel artifacts on scalp topographies (good for visualization)
- ▶ Yes, because it may improve subsequent source localization





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ICA's bug: How ghost ICs emerge from effective rank deficiency caused by EEG electrode interpolation and incorrect re-referencing

Hyeonseok Kim¹, Justin Luo², Shannon Chu¹, Cedric Cannard^{3,4},
Sven Hoffmann⁵ and Makoto Mivakoshi^{1,6,7*}

This is no ‘ICA bug’: Response to the article, “ICA’s bug: How ghost ICs emerge from effective rank deficiency caused by EEG electrode interpolation and incorrect re-referencing”

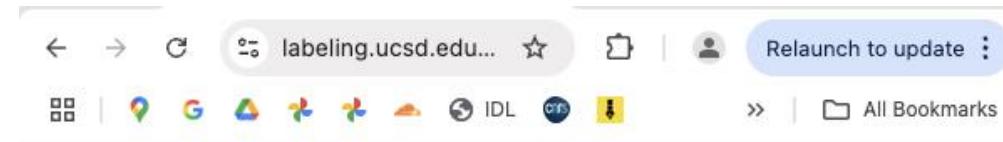
Arnaud Delorme*, Scott Makeig

(*corresponding author)

Swartz Center for Computational Neuroscience
Institute for Neural Computation
University of California San Diego 0559

Hands on !

Practicing ICLabel



ICLabel: Learning to Classify
Independent Components
of EEG Data

Email

Password

Login

[What Is This Site?](#)
[Need To Register?](#)
[Forgot Your Password?](#)
[Just want to practice?](#)
[Check Out The Leaderboard!](#)

Clean_rawdata in EEGLAB

The image shows the EEGLAB dev interface. On the left, the Tools menu is open, displaying various data cleaning and processing options. The option "Reject data using Clean Rawdata and ASR" is highlighted. On the right, the "pop_clean_rawdata()" dialog box is open, detailing the steps for data cleaning.

Tools Menu:

- Change sampling rate
- Filter the data
- Re-reference the data
- Interpolate electrodes
- Inspect/reject data by eye
- Automatic channel rejection
- Reject data using Clean Rawdata and ASR**
- Automatic continuous rejection
- Automatic epoch rejection
- Decompose data by ICA
- Reject data epochs
- Reject data using ICA
- Classify components using ICLabel

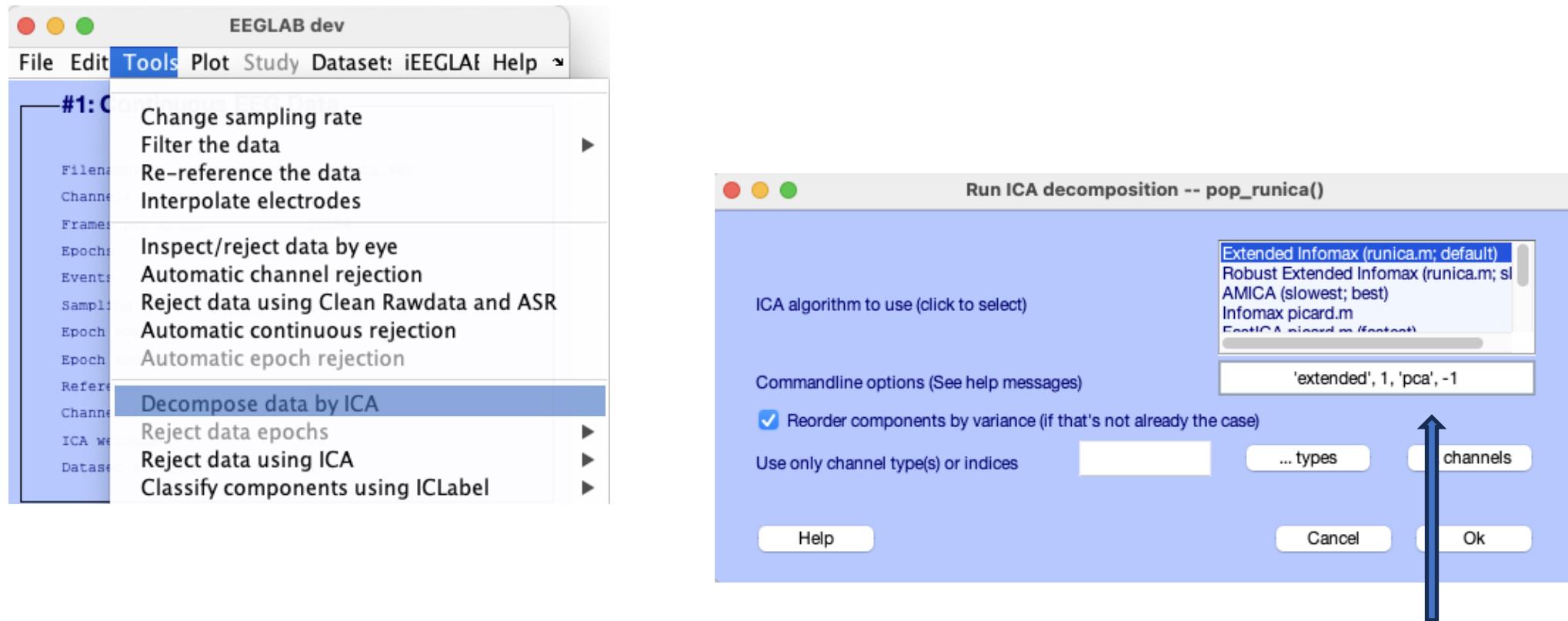
pop_clean_rawdata() Dialog Box:

- Remove channel drift (data not already high-pass filtered)
Linear filter (FIR) transition band [lo hi] in Hz
0.25 0.75
- Process/remove channels
 - Only consider these channels ...
 - Ignore these channels (ECG, EMG, ...)
 - Remove channel if it is flat for more than (seconds)
5
 - Max acceptable high-frequency noise std dev
4
 - Min acceptable correlation with nearby chans [0-1]
0.8
- Perform Artifact Subspace Reconstruction bad burst correction/rejection
 - Max acceptable 0.5 second window std dev
20
 - Use Riemannian distance metric (not Euclidean) - beta
 - Remove bad data periods (when uncheck, correct using ASR)
- Additional removal of bad data periods
 - Acceptable [min max] channel RMS range (+/- std dev)
-Inf 7
 - Maximum out-of-bound channels (%)
25
- Pop up scrolling data window with rejected data highlighted

Legend:

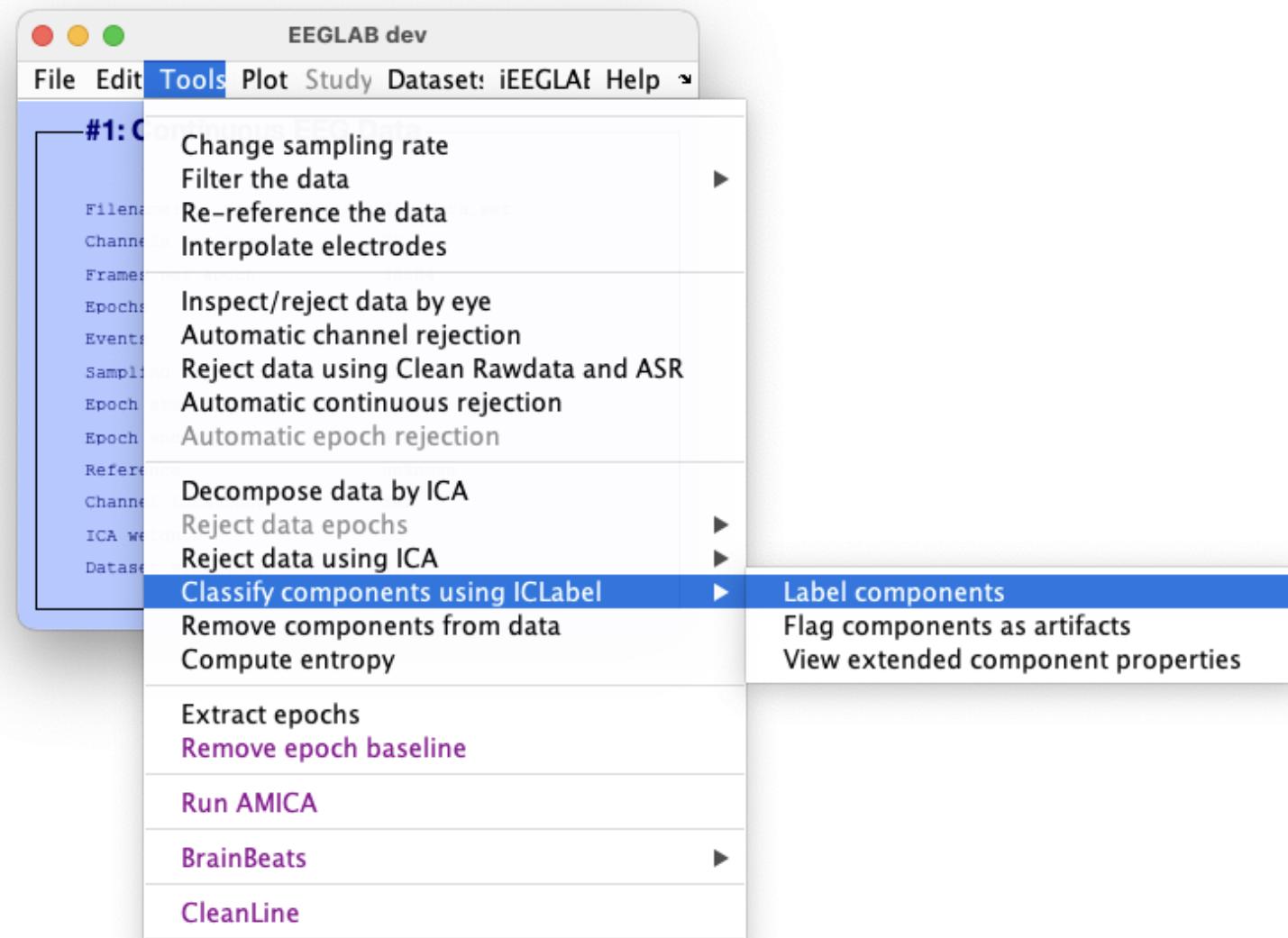
- { Filter the data
- { Channel rejection
- { ASR segment rejection
- { Final segment rejection based on simple thresholds on signal amplitude

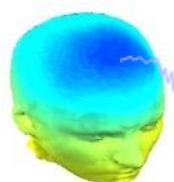
Clean_rawdata in EEGLAB



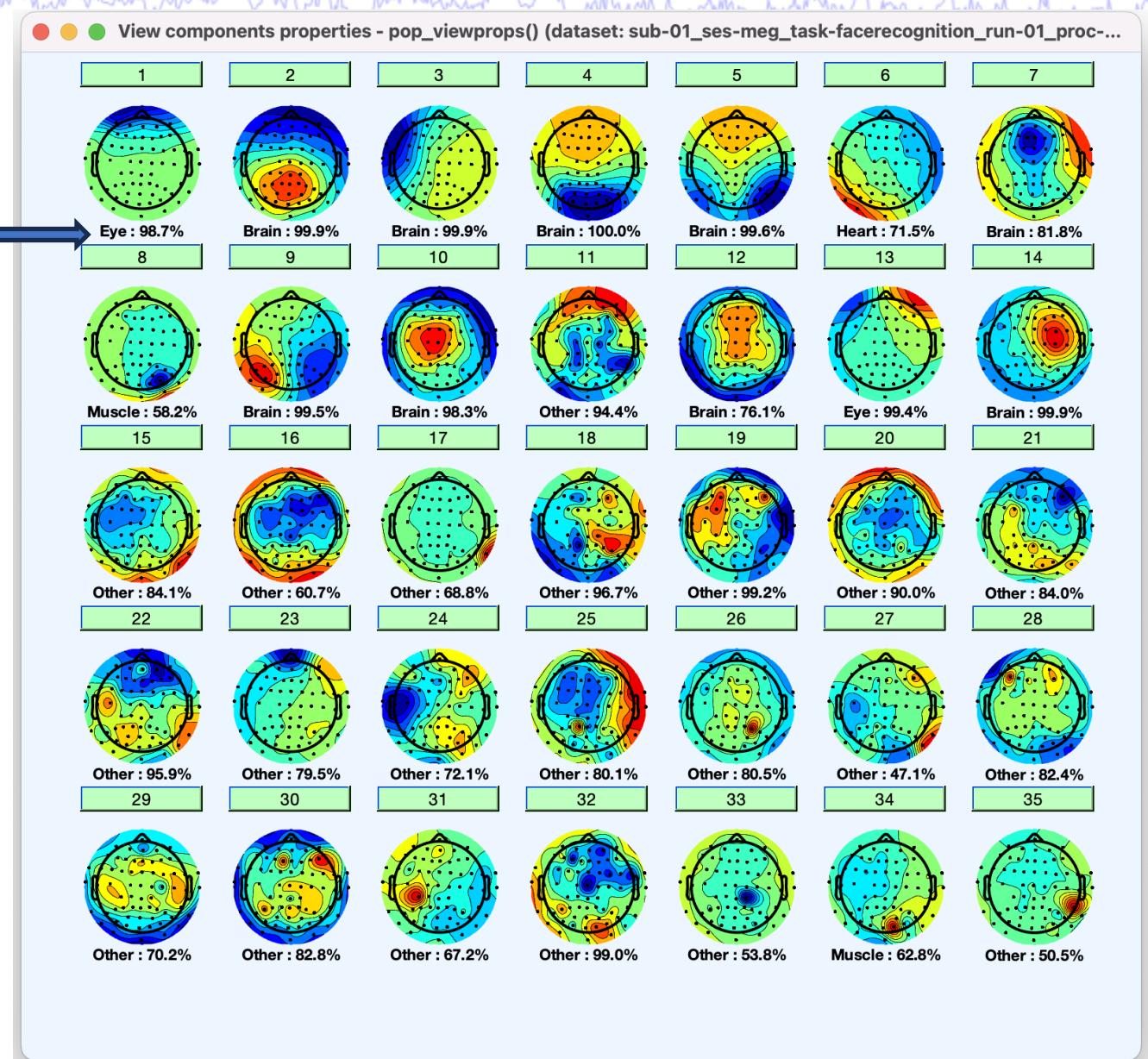
Use 'pca', -1 when average reference is calculated to decrease the dimension of the data by 1 before ICA (we will come back to that in the ICA lecture)

Run ICLabel

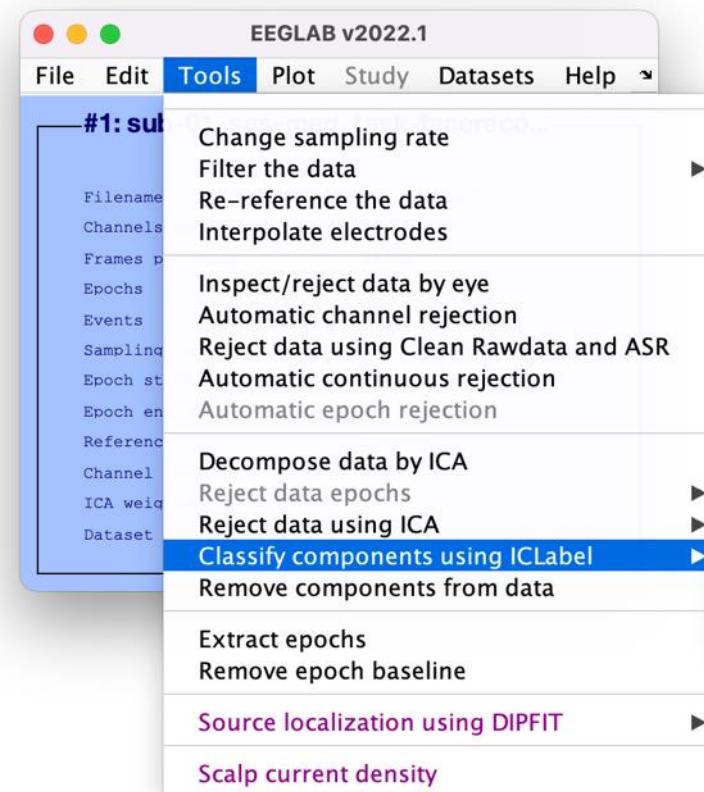




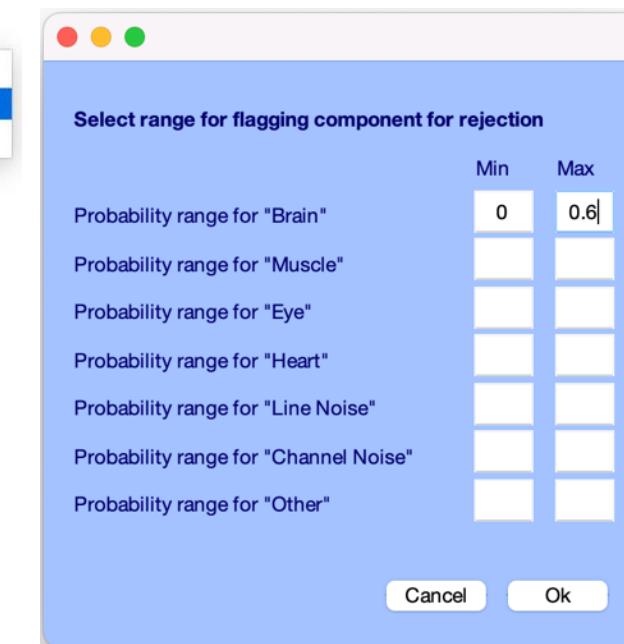
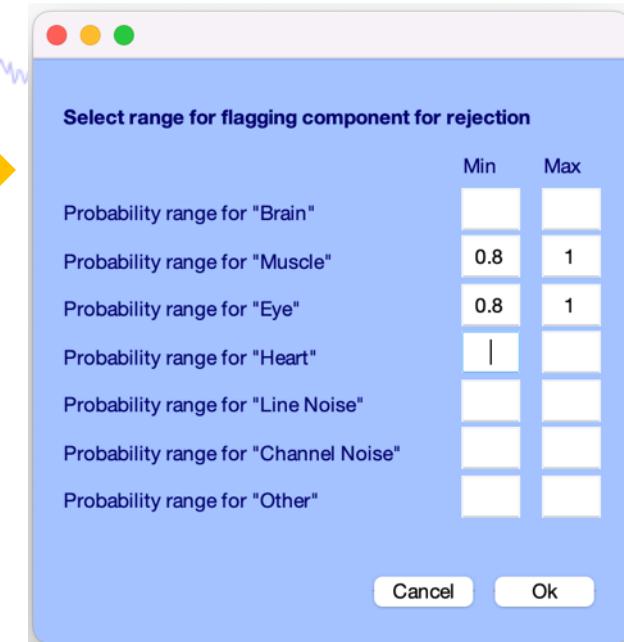
Look at component class
and probability of
belonging to that class.



Let's remove artefact ICs using IC Label classification probabilities



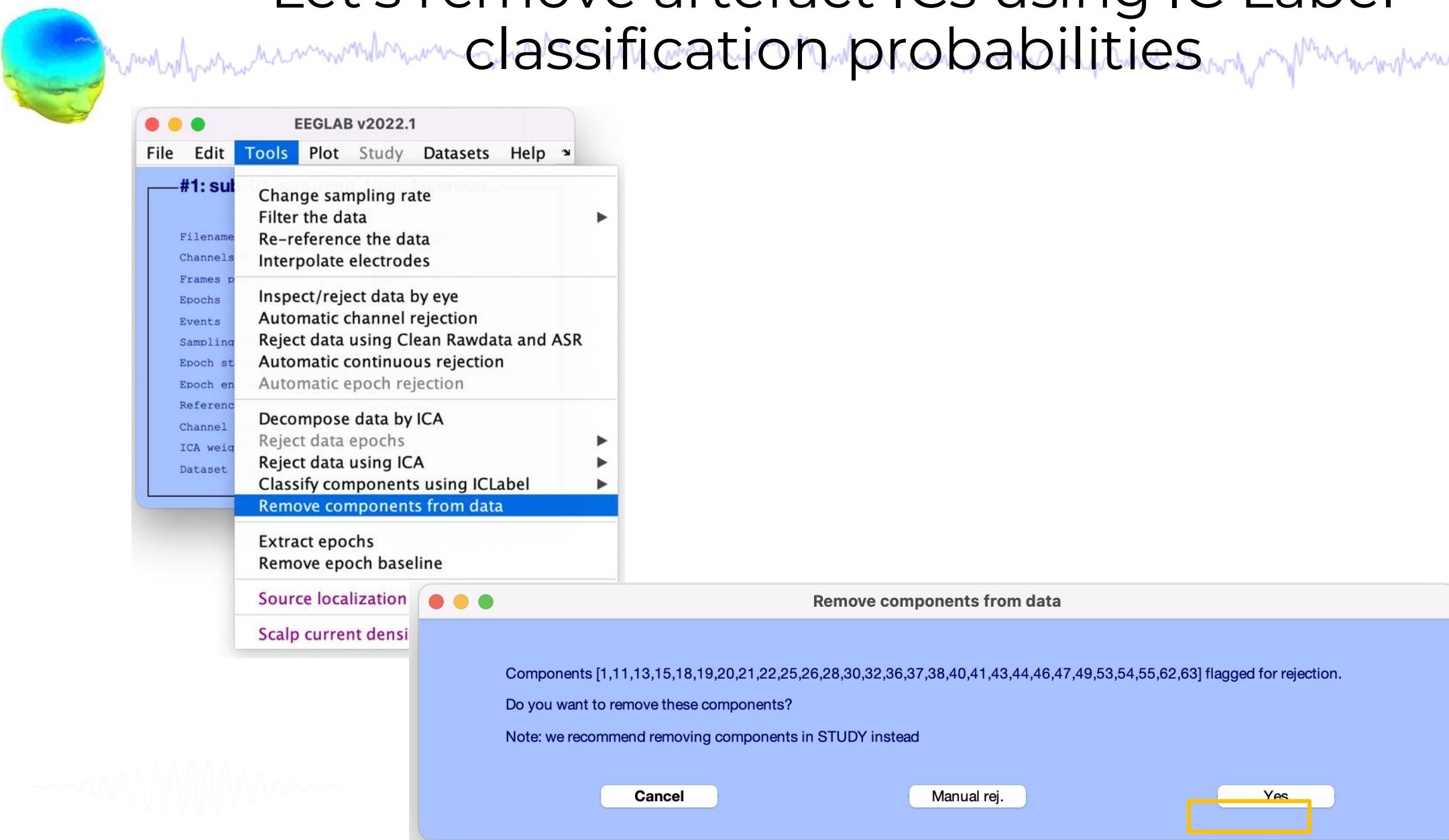
Either remove specific artefact ICs – here remove all ICs that have more than 80% probability to be muscle or eye components



Or remove all ICs that have less than 60% probability to be brain components (you can also choose a different probability – i.e. 70%)



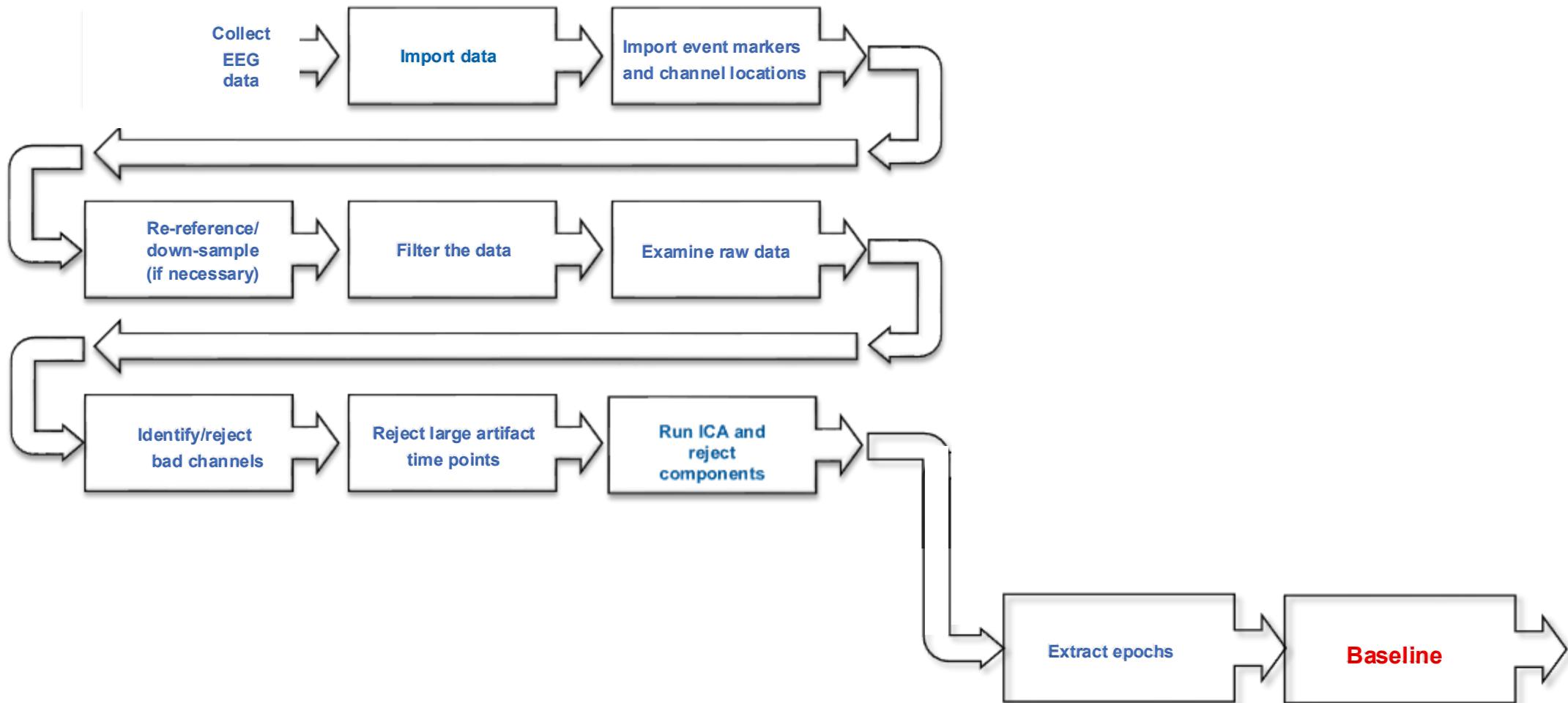
Let's remove artefact ICs using IC Label classification probabilities



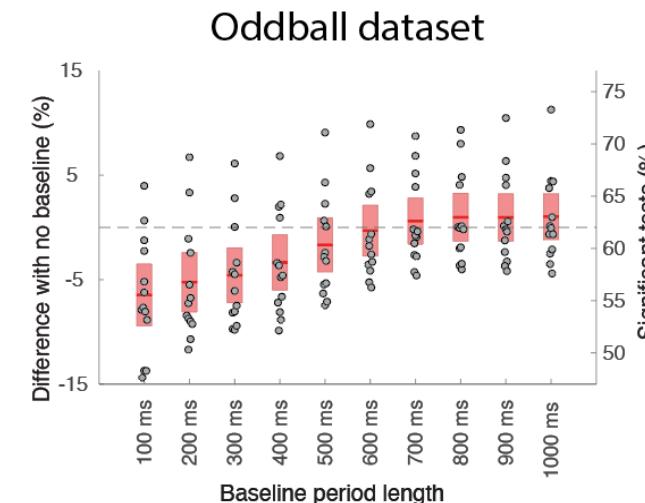
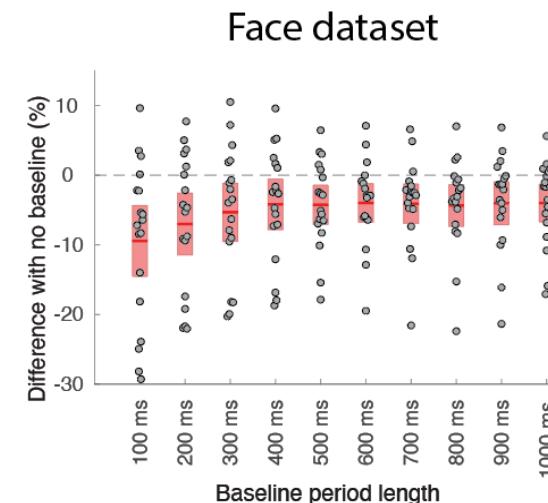
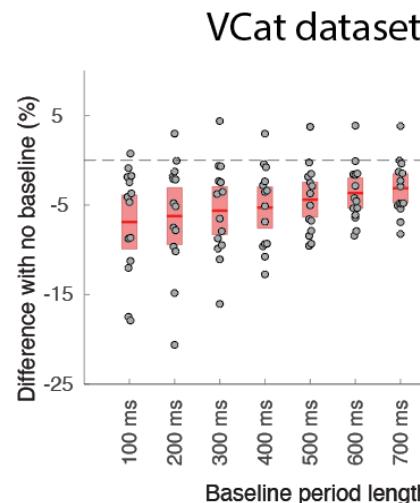
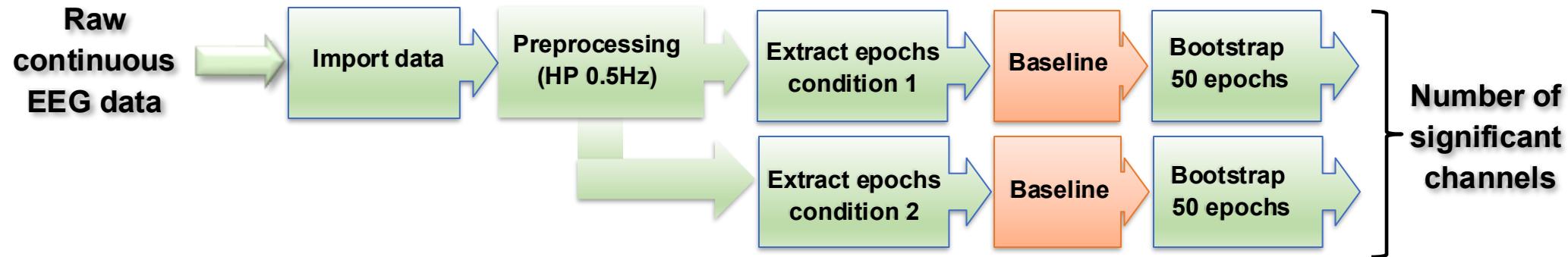
Hands on: Basic preprocessing

- Use menu item **Tools > Reject data using clean_rawdata and ASR**. Select filtering. Leave all defaults. Inspect the results (**Plot > Scroll data**)
- Use menu item **Tools > Run ICA data to run ICA**
- Use menu item **Tools > Classify components using ICLabel > Label components**, and inspect components
- **Note:** The preprocessing is more involved. It includes referencing, an initial call to **clean_rawdata** to remove bad channels, ICA, then a second call to **clean_rawdata** to remove corrupted portions of data. This order is specific to this dataset, which contains many blink artifacts that we do not want **clean_rawdata** to remove because ICA handles them. The procedure is described in *script_02_preprocess_data.m*. Later lectures will use the output of that script. If it has not already been run for you, you will need to run it.

What about removing the baseline?

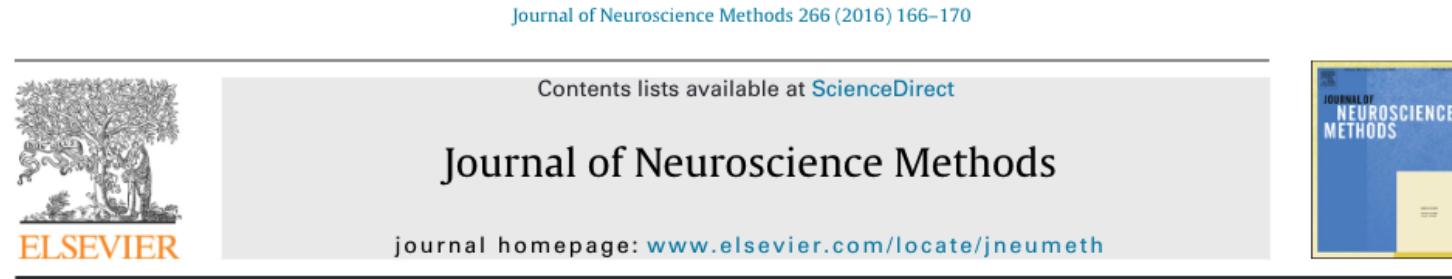


Influence of the baseline on ERPs



- ▶ Any baseline tend to decrease significance or has no effect (simply high-pass filter the data)
- ▶ Short baseline are worst

But wait... what about baseline with minimal High-Pass

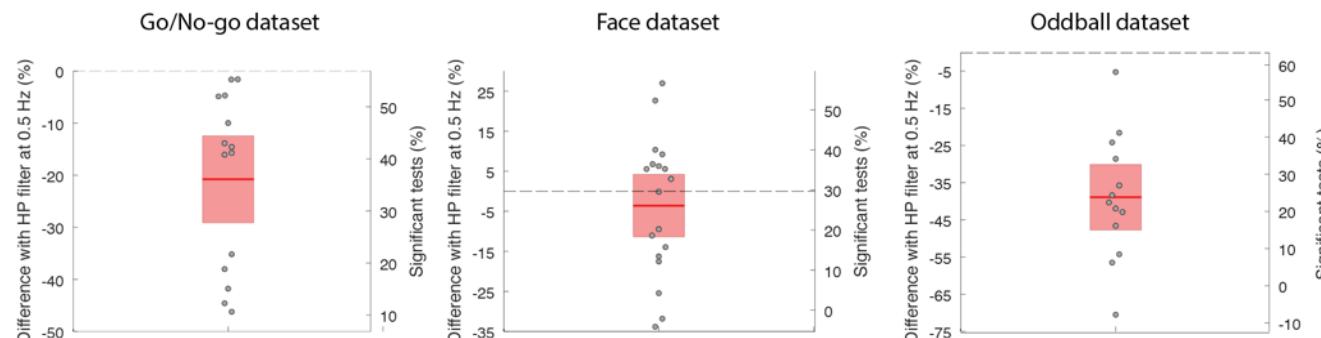


On high-pass filter artifacts (they're real) and baseline correction
(it's a good idea) in ERP/ERMF analysis



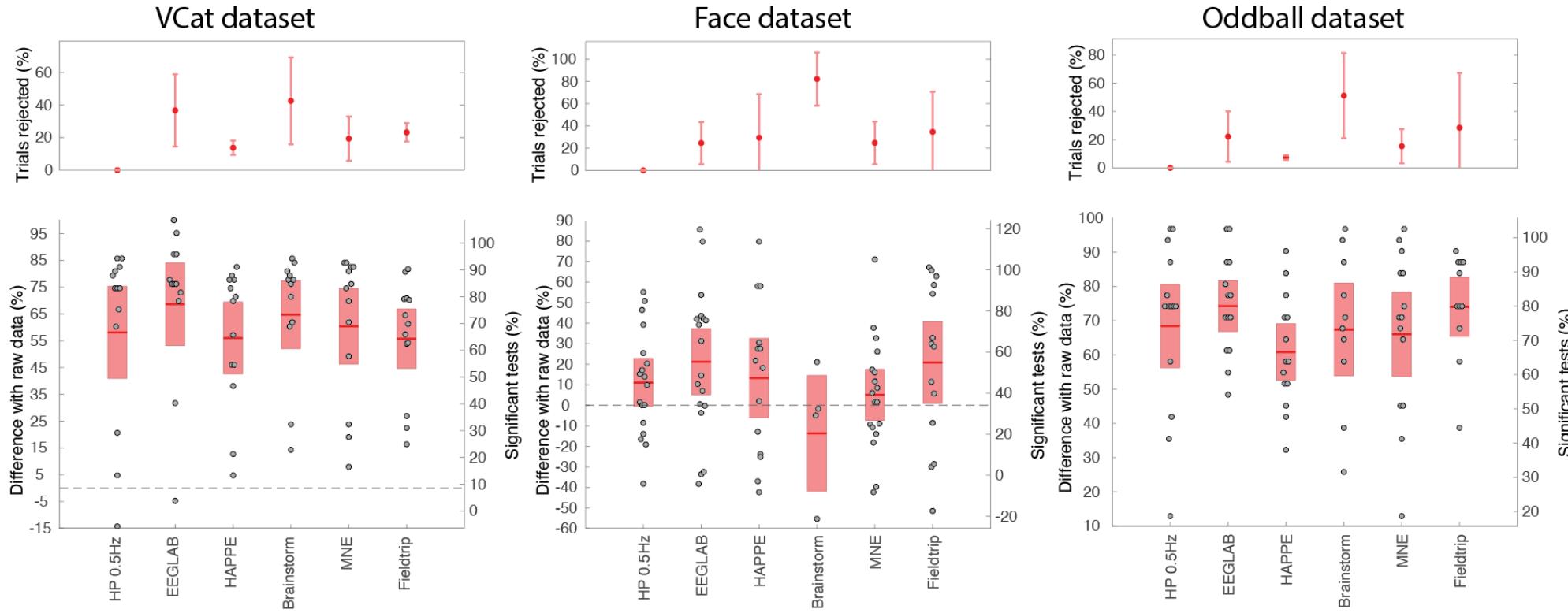
Darren Tanner ^{a,b,*}, James J.S. Norton ^b, Kara Morgan-Short ^c, Steven J. Luck ^d

- ▶ The article above advocate high-pass filter at 0.01Hz and a baseline of 100 ms
- ▶ Compared to high-pass at 0.5Hz and no baseline, the number of significant channels is often cut by half
- ▶ No baseline is preferable to maximize significance



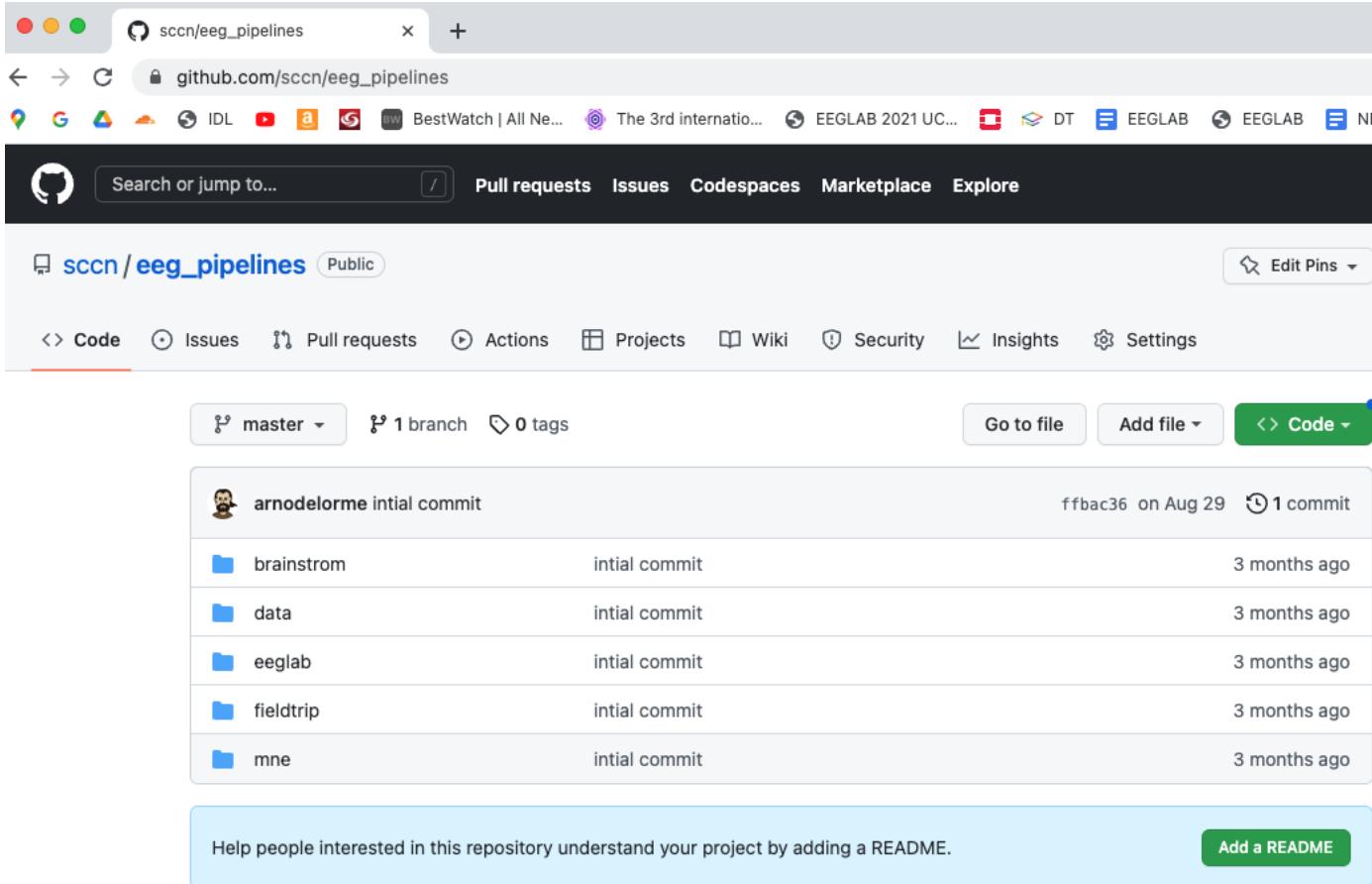
Is there an optimal preprocessing pipeline?

- ▶ Each automated artifact rejection optimized (EEGLAB, MNE, Brainstorm, Fieldtrip)



- ▶ Compared to high-pass at 0.5Hz, not much improvement of any pipeline (although EEGLAB pipeline the only one significantly superior to 0.5 Hz high pass for all 3 datasets – no other pipeline superior to 0.5 Hz high pass for any dataset)
- ▶ EEGLAB minor advantage due to line-noise contaminated channel interpolation and ICA automated rejection

Automated pre-processing pipelines available

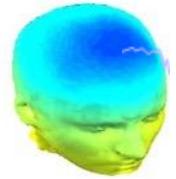


The screenshot shows the GitHub repository page for `sccn/eeg_pipelines`. The repository is public and contains one branch and no tags. The commit history shows five initial commits from `arnodelorme` for various software projects: brainstrom, data, eeglab, fieldtrip, and mne, all made on August 29, 2021. A message at the bottom encourages adding a README.

Commit	Author	Message	Date
ffbac36	arnodelorme	initial commit	on Aug 29
		brainstrom	3 months ago
		data	3 months ago
		eeglab	3 months ago
		fieldtrip	3 months ago
		mne	3 months ago

Help people interested in this repository understand your project by adding a README. [Add a README](#)

- ▶ Has test data
- ▶ Please comment and help improve the automated pipeline for each software



The EEGLAB Youtube Channel



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