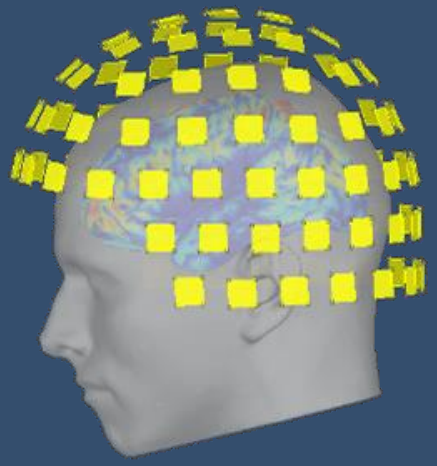
MEG and EEG analysis using

Brainstorm

http://neuroimage.usc.edu/brainstorm



Cutting Gardens

USC University of Southern California

USC Viterbi School of Engineering

Los Angeles Garden

USC University of Southern California

Cleveland Clinic

McGill

neuro

October 2023

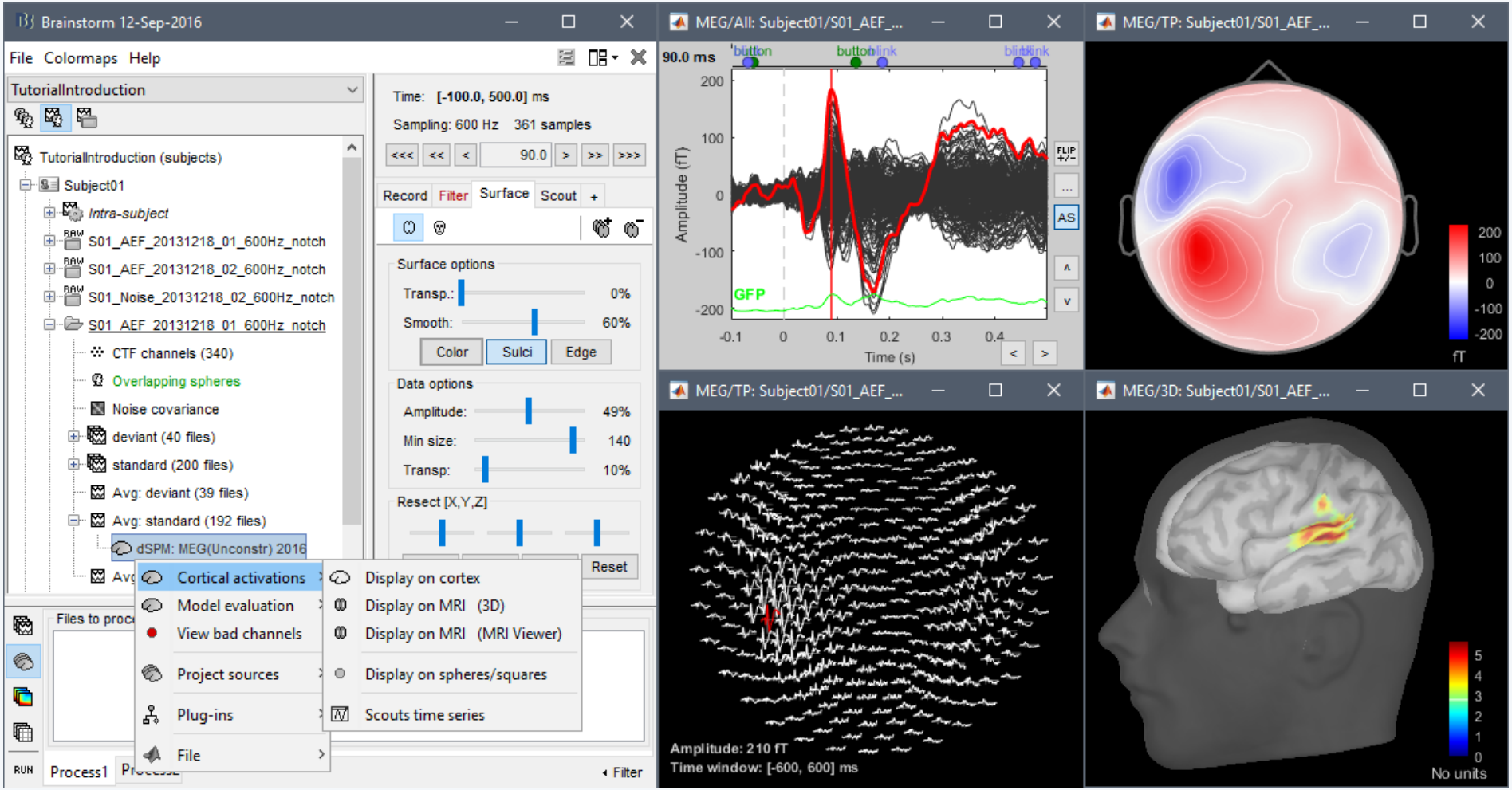
Brainstorm

- Free and open-source application
- Matlab & Java: Platform-independent
- Designed for Matlab
- Stand-alone version available
- Interface-based: click, drag, drop
- No programming experience required
- Daily updates of the software
- Supports most common file formats





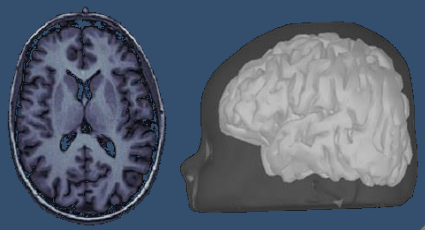
Graphic interface



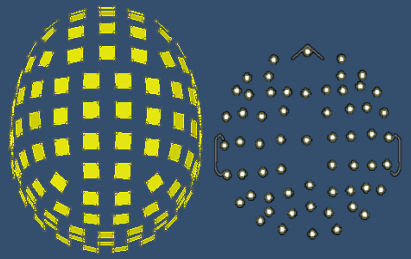
Brainstorm

Workflow

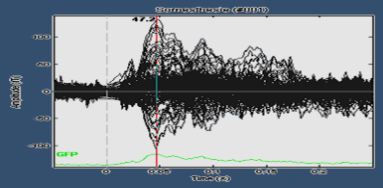
Anatomy



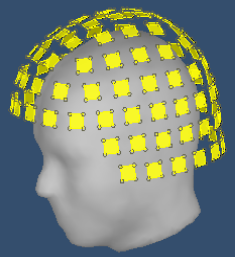
Sensors



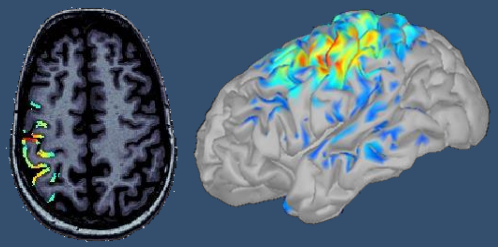
EEG/MEG



Co-registration



Source estimation



Analysis

Averages
Contrasts
Group analysis
Time-frequency
Connectivity

Single subject

Anatomy
Link recordings
MRI registration

Importing

PSD
Filters
Bad channels
Artifacts
Correction
Bad segments

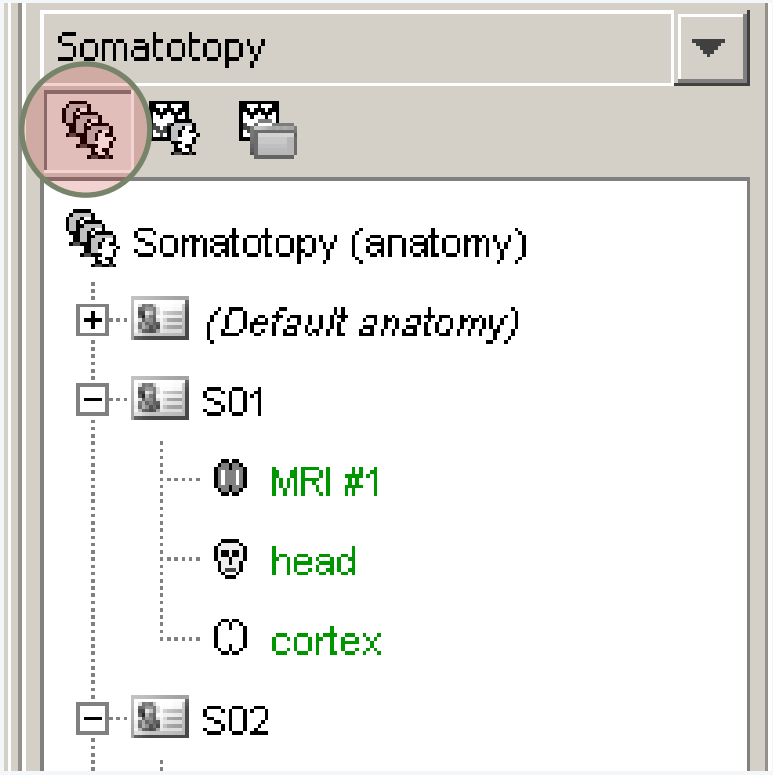
Pre-processing

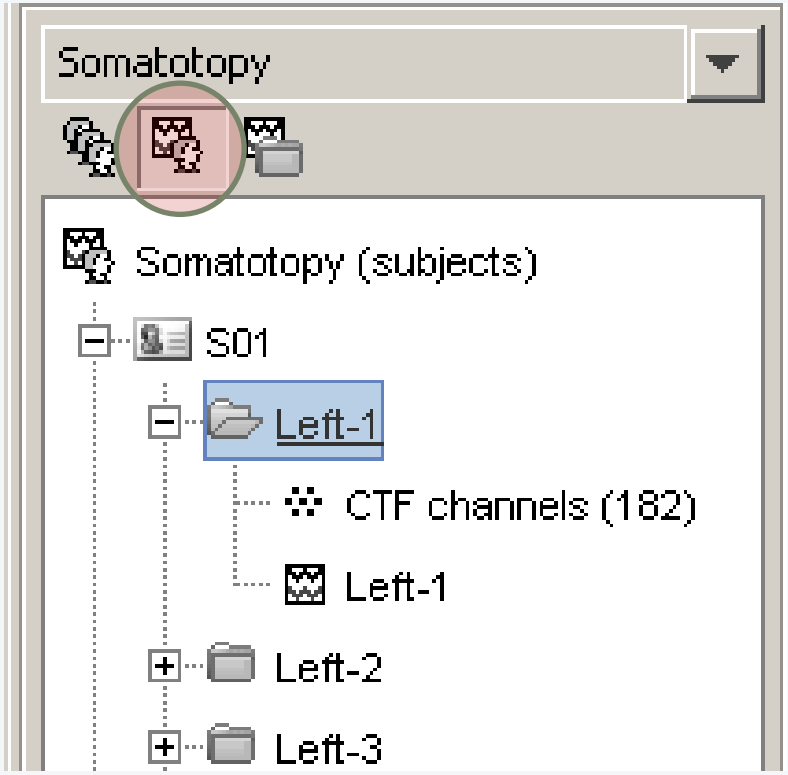
Events
Epoching
Averaging
Sources
Time-frequency

Analysis of the experimental data

Loop:
all acquisition runs
all subjects

Database





- Three levels:
  - Protocol
  - Subject
  - Condition

- Popup menus
- All files saved in Matlab .mat
- Same architecture on the disk

Brainstorm

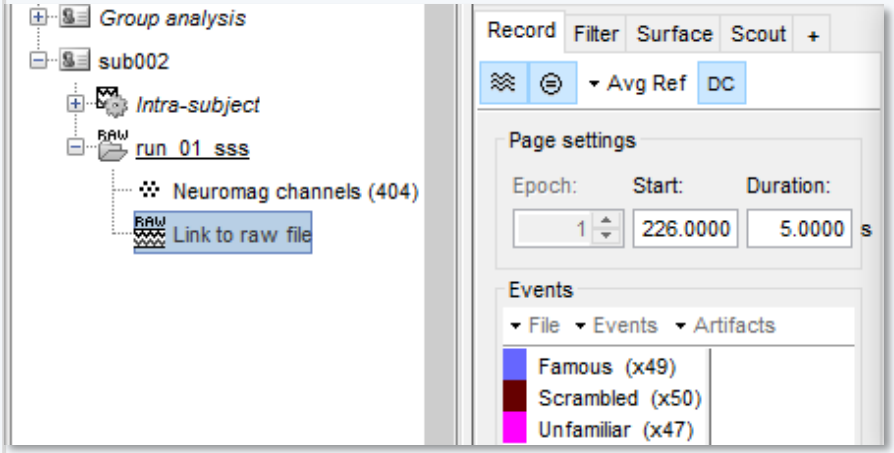
Import

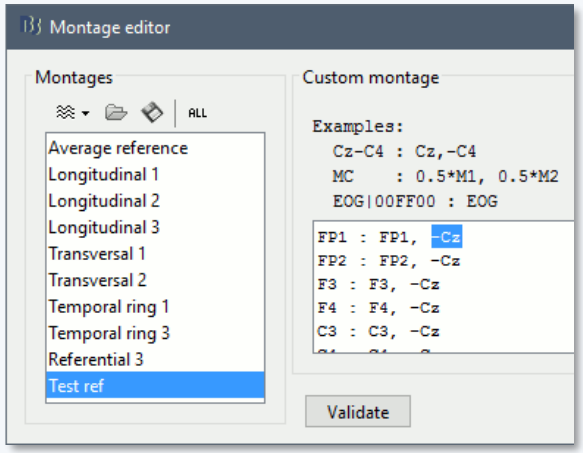
Anatomy
Link recordings
MRI registration

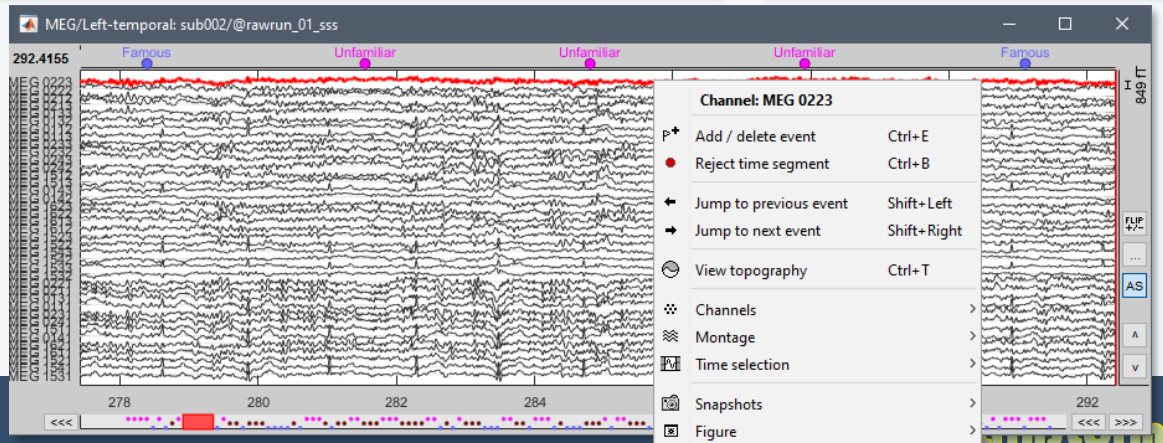
PSD
Filters
Bad channels
Artifacts
Correction
Bad segments

Markers
Epoching
Averaging
Sources
Time-frequency

- Original files linked to the database (no copy)
- Rich data viewer with flexible montage editor
- Optimized reading functions

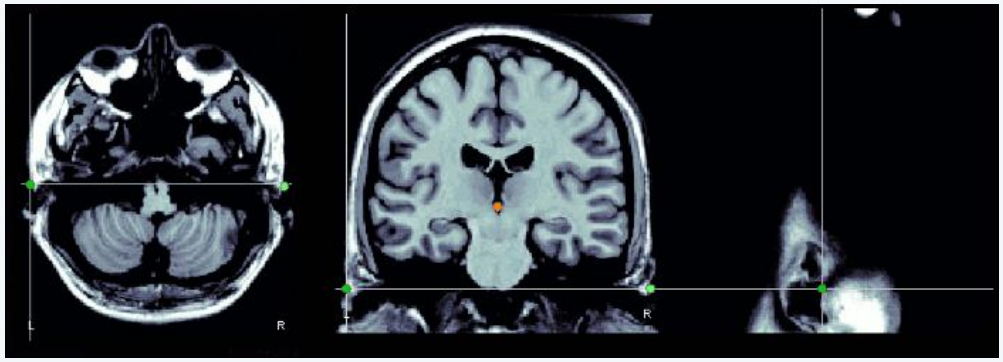






Co-registration MEEG / MRI (1)

- Basic estimation based on three points:
  Nasion (NAS), Left ear (LPA), Right ear (RPA)
- MRI: Marked in the volume with the MRI Viewer
- MEEG: Obtained with a tracking system (Polhemus)



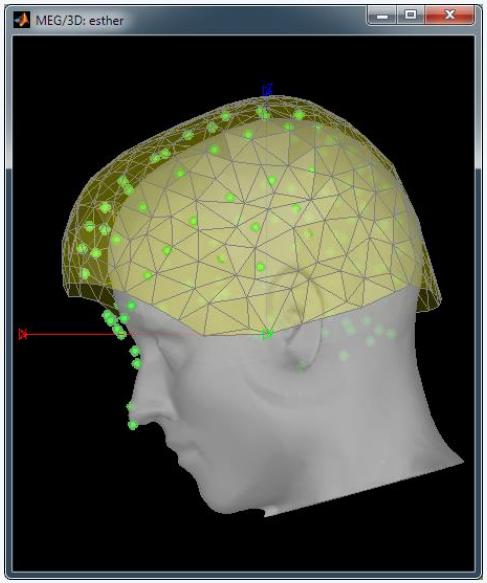
Co-registration MEEG / MRI (2)

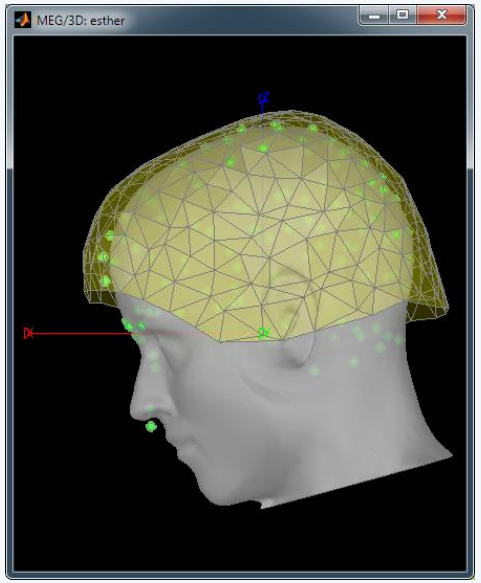
Anatomy
Link recordings
MRI registration

PSD
Filters
Bad channels
Artifacts
Correction
Bad segments

Markers
Epoching
Averaging
Sources
Time-frequency

- Automatic adjustment based on head shape: Fitting Polhemus points on the MRI head surface
- Final registration must be checked manually
- Polhemus driver included in Brainstorm





Quality control

Anatomy
Link recordings
MRI registration

PSD
Filters
Bad channels
Artifacts
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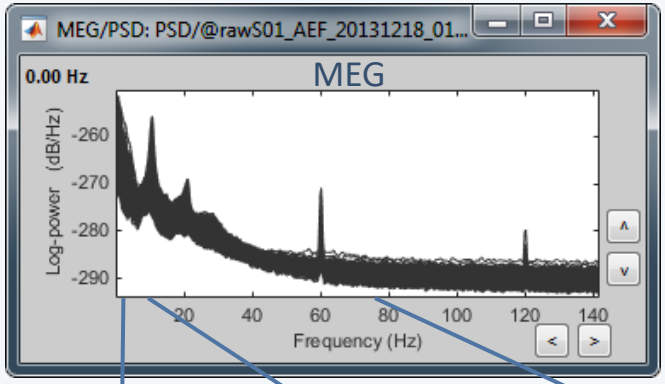
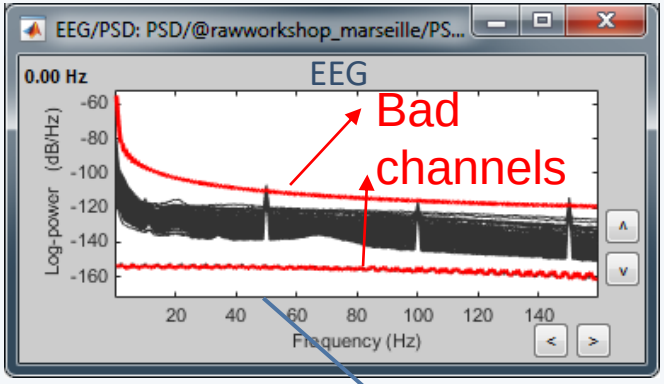
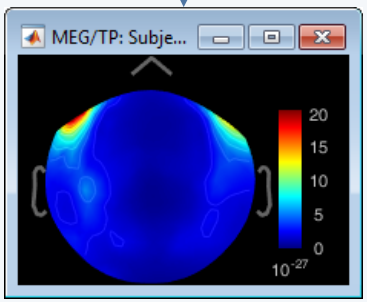
Bad segments

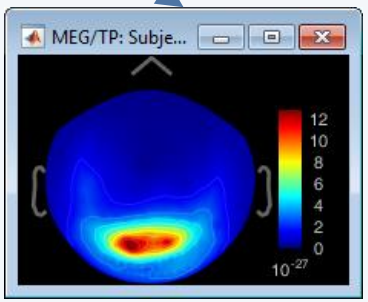
Markers
Epoching
Averaging
Sources
Time-frequency

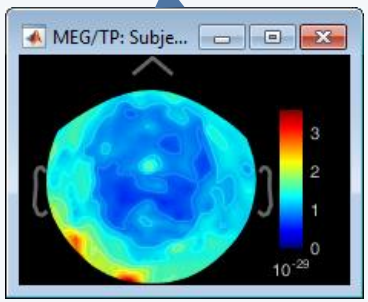
- Power spectrum density for quality control

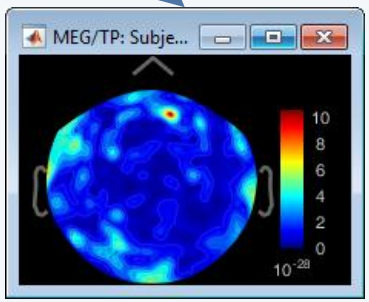












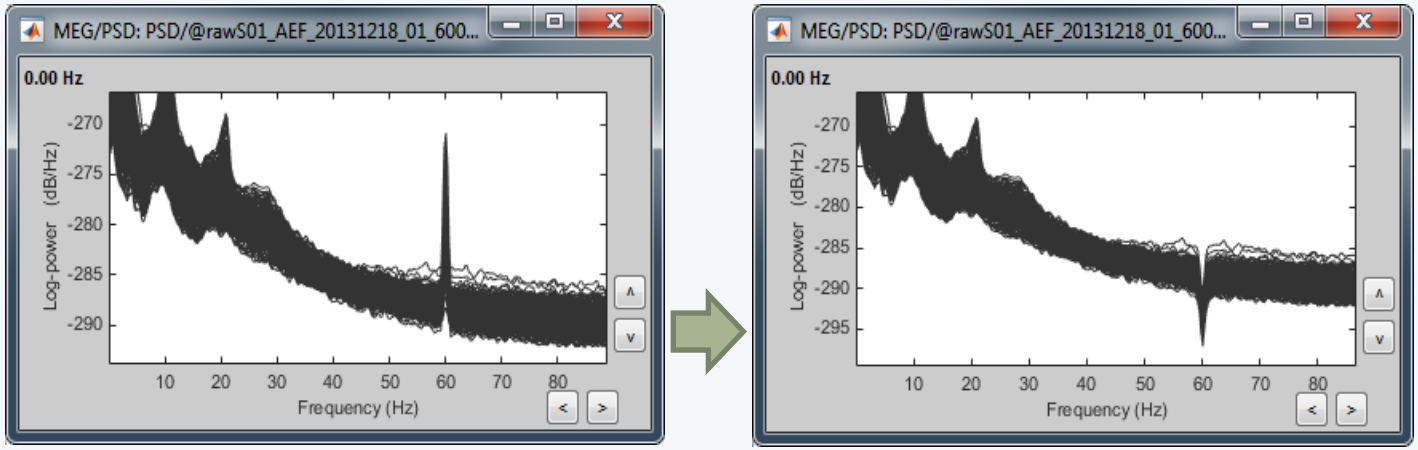
< 3Hz: Eyes | 10Hz: Alpha | > 40Hz: Muscle | 50/60Hz

Brainstorm

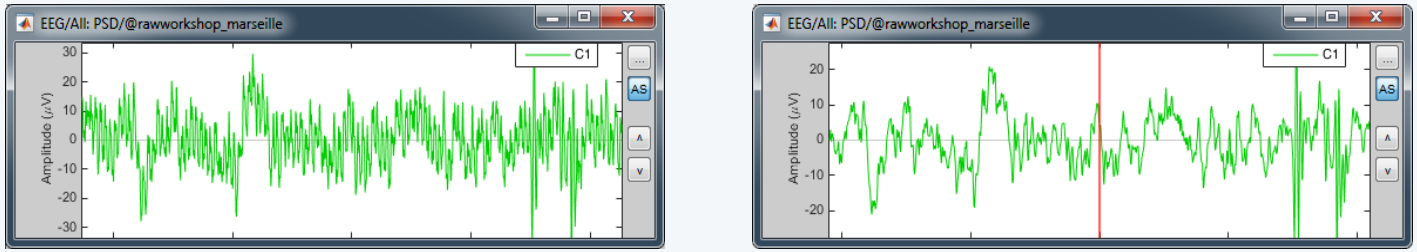
Pre-processing

- Notch filter: Removes 50Hz/60Hz power line noise (and harmonics)

PSD

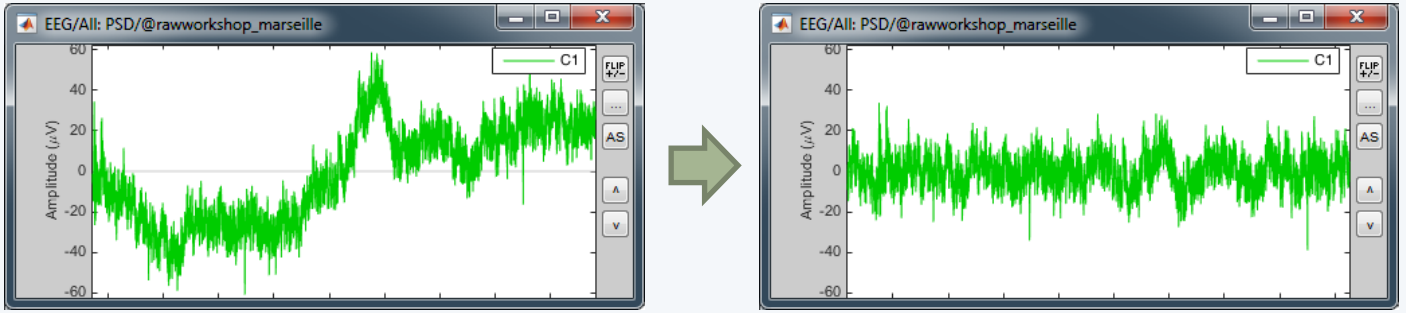


Signal

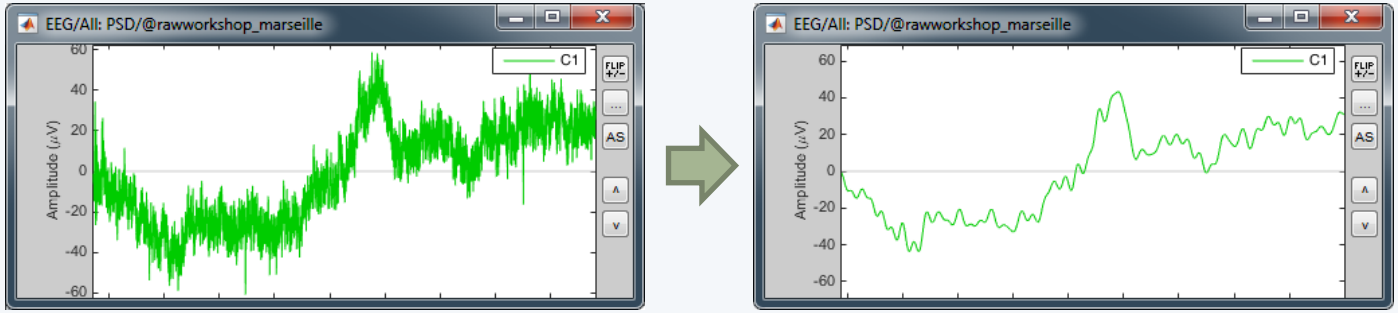


Pre-processing

- High-pass filter: Removes slow components (eye movements, breathing, sensor drifts…)



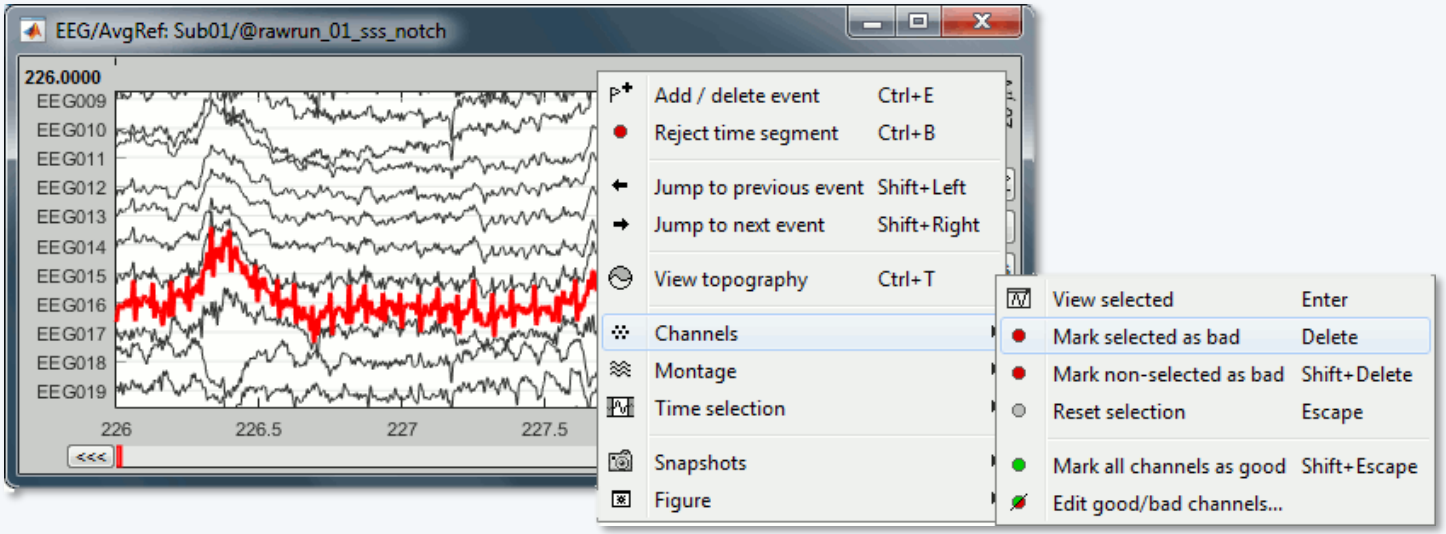
- Low-pass filter: Remove high-frequencies



Brainstorm

Pre-processing

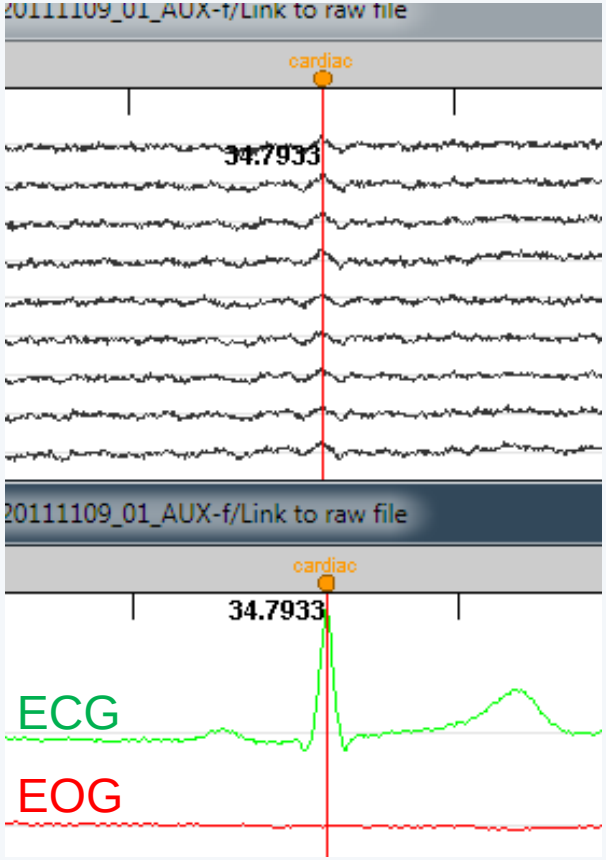
- Manual inspection of the recordings
- Interactive selection of bad channels
- Re-reference the EEG if necessary (Average ref)

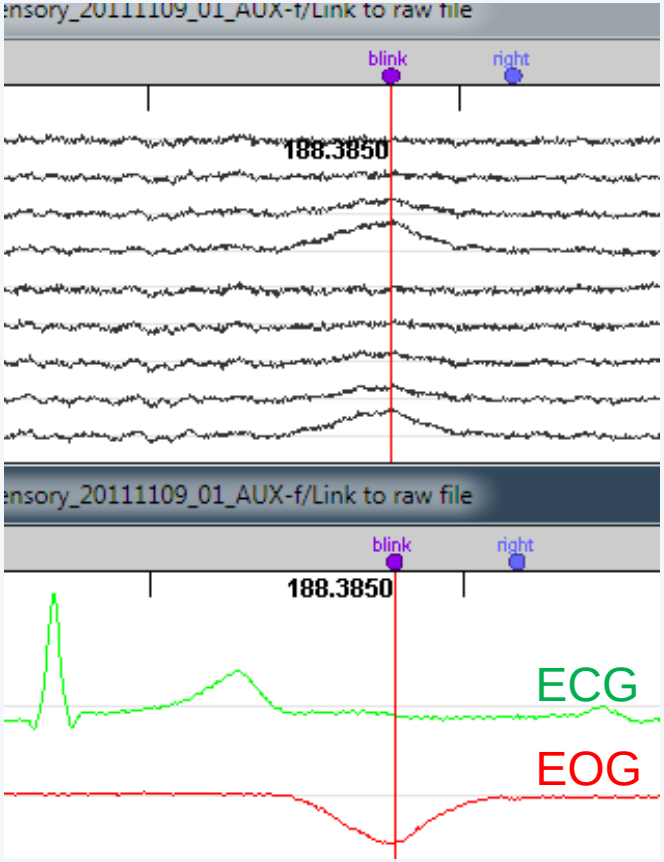


Brainstorm

Pre-processing

- Automatic detection of blinks and heartbeats (peak detection, or explicit amplitude threshold)





Brainstorm

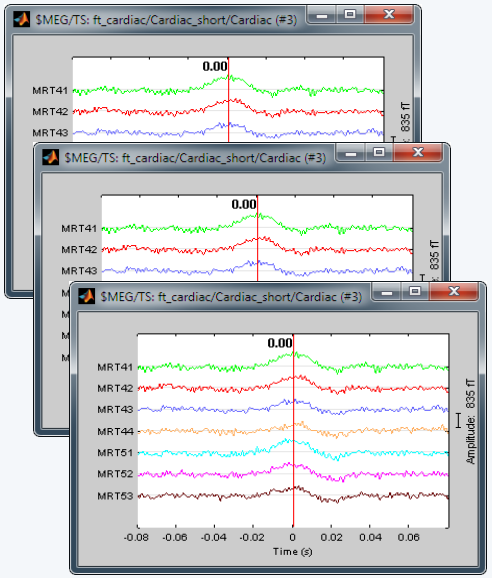
Artifact correction

- Two categories of artifacts:
  - Well defined, reproducible, short, frequent:
    - Heartbeats, eye blinks, eye movements, some stimulators
    - Unavoidable and frequent: we cannot just ignore them
    - Can be modeled and removed from the signal efficiently
  - All the other events that can alter the recordings:
    - Movements, building vibrations, metro nearby…
    - Too complex or not repeated enough to be modeled
    - Safer to mark them as bad segments, and ignore them

Pre-processing

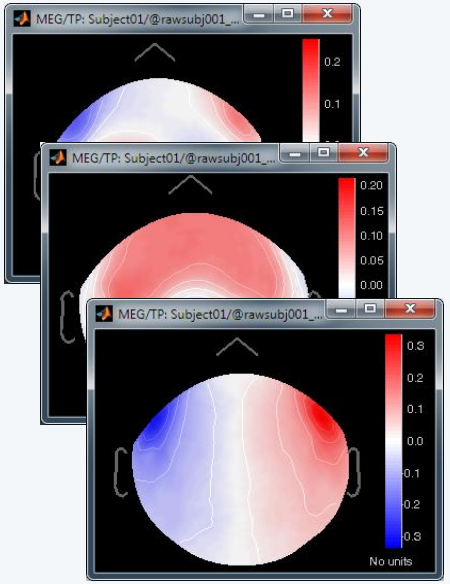
- Correction with Signal Space Projections (SSP)

Detect artifacts



PCA

Spatial components



Select components and compute a linear projector to remove their contribution from the recordings

Brainstorm

Pre-processing

Anatomy
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Markers
Epoching
Averaging
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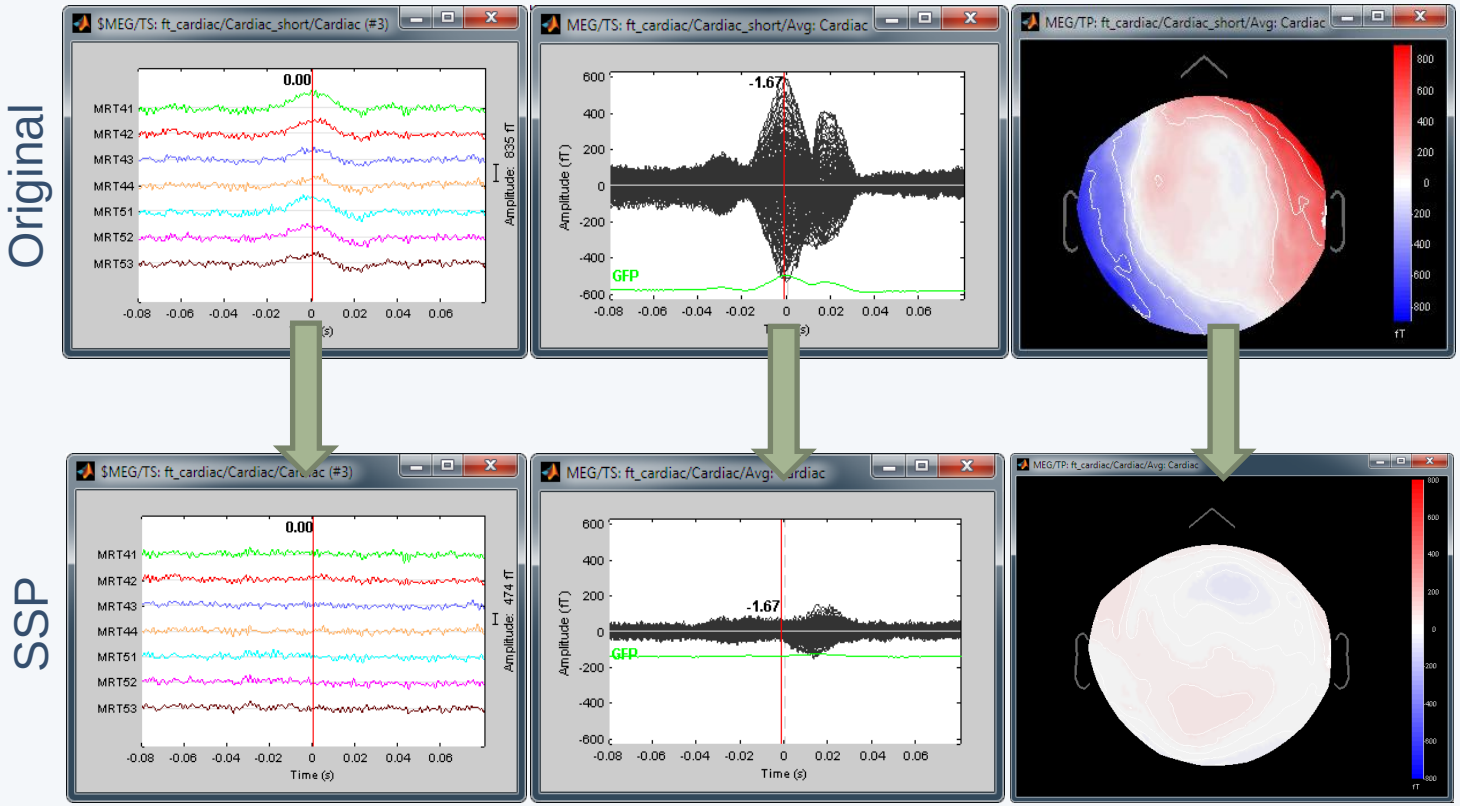
Time-frequency

- Example: Cardiac artifact



Brainstorm

Pre-processing

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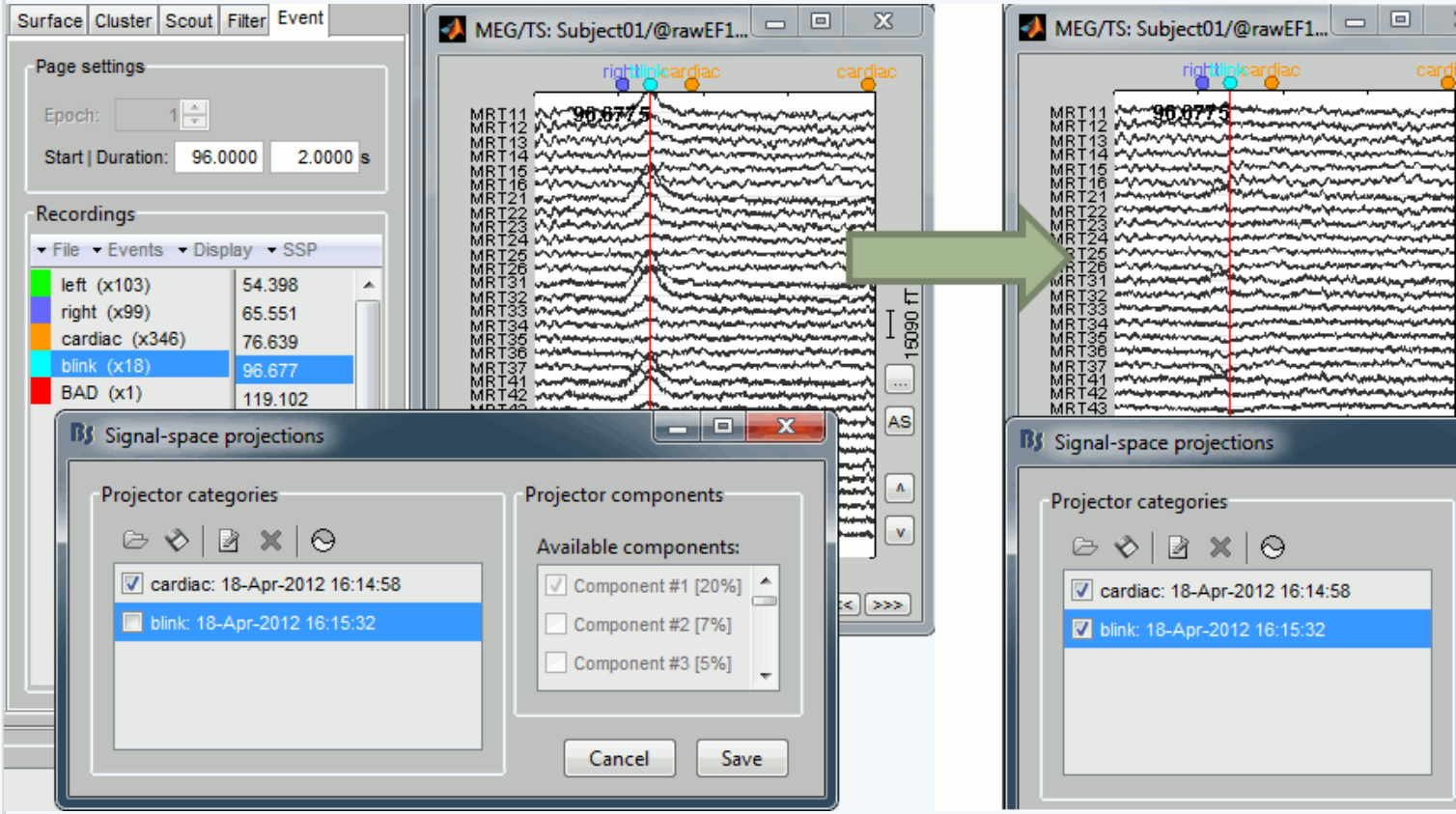
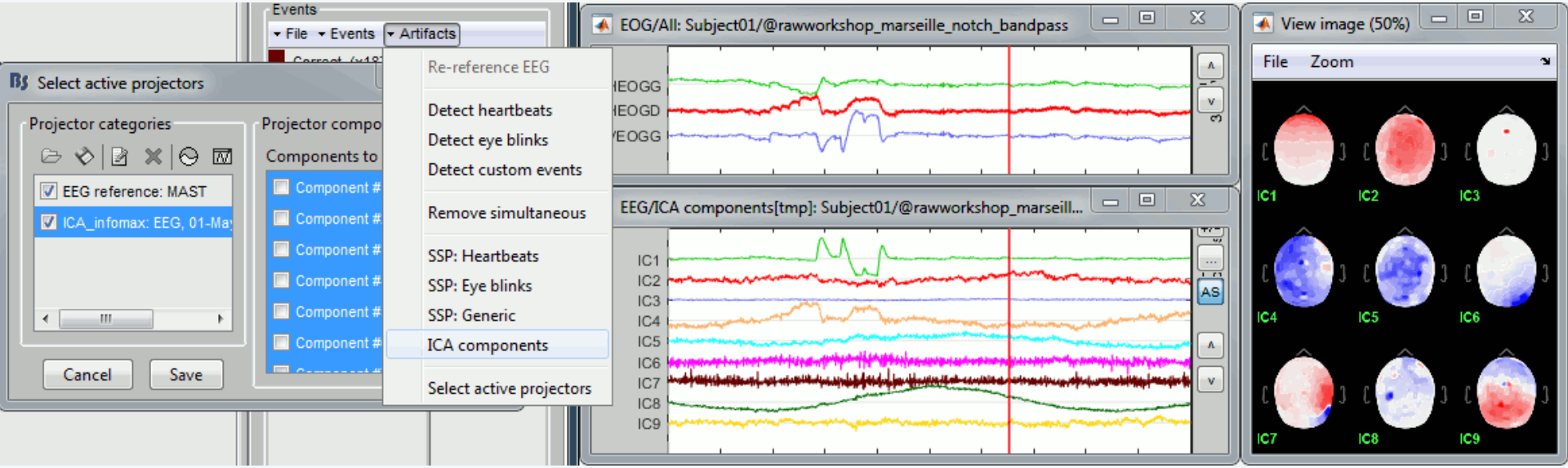
- Example: Blink



Pre-processing

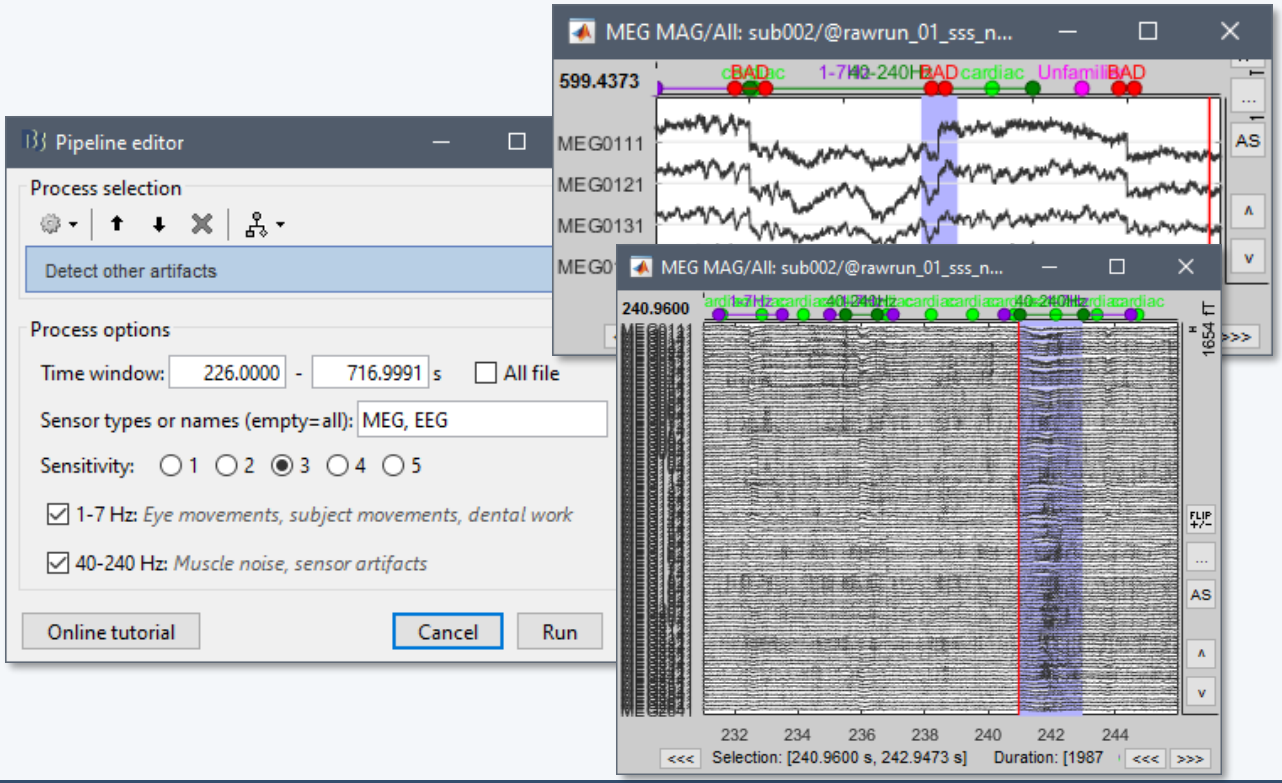
- Independent component analysis (ICA):
  - Popular in the EEG literature
  - Alternative to SSP for low number of sensors
  - Already implemented: Infomax and JADE (EEGLAB)



Brainstorm

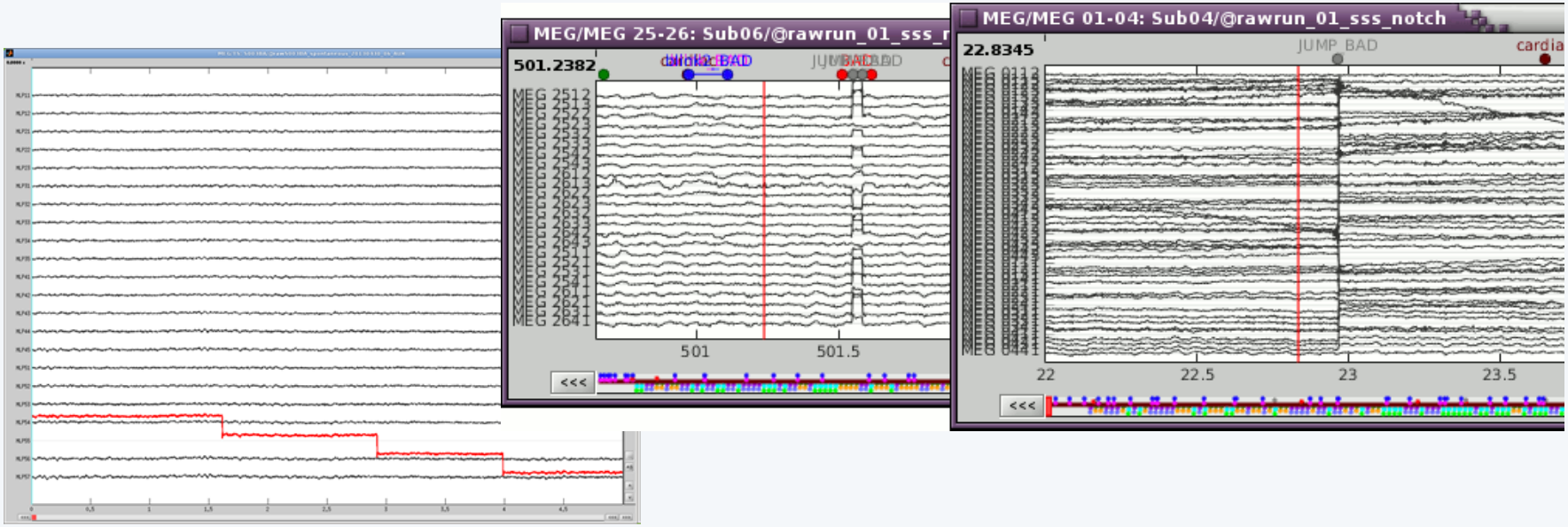
Pre-processing

- Automatic detection of artifacts (RMS-based)
- Manual screening of all the recordings is advised (scroll all the sensors by pages of 10-20s)
- Exclude: Blinks, movements, SQUID jumps



Brainstorm

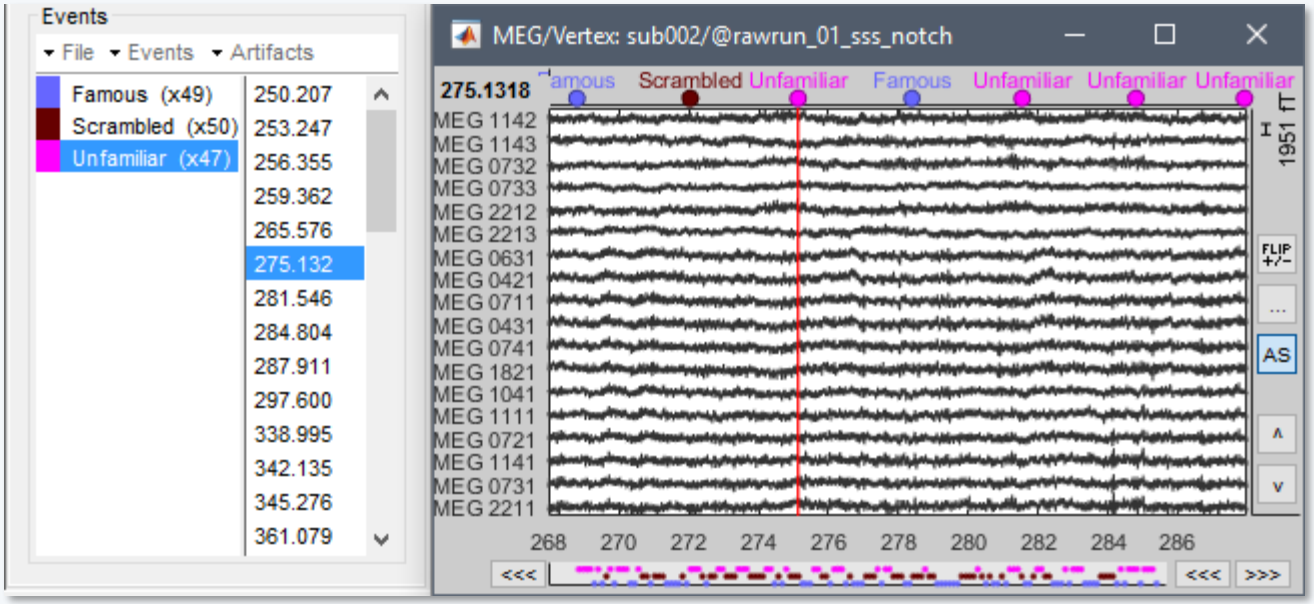
- Sharps steps followed by a change of baseline value
- Mark the channels as bad before running MaxFilter
- Or mark the segments as bad in Brainstorm



Epoching

- Two types of experiments:
  - Steady-state or resting-state (ongoing activity)
  - Event-based (stimulus, response, spike…)

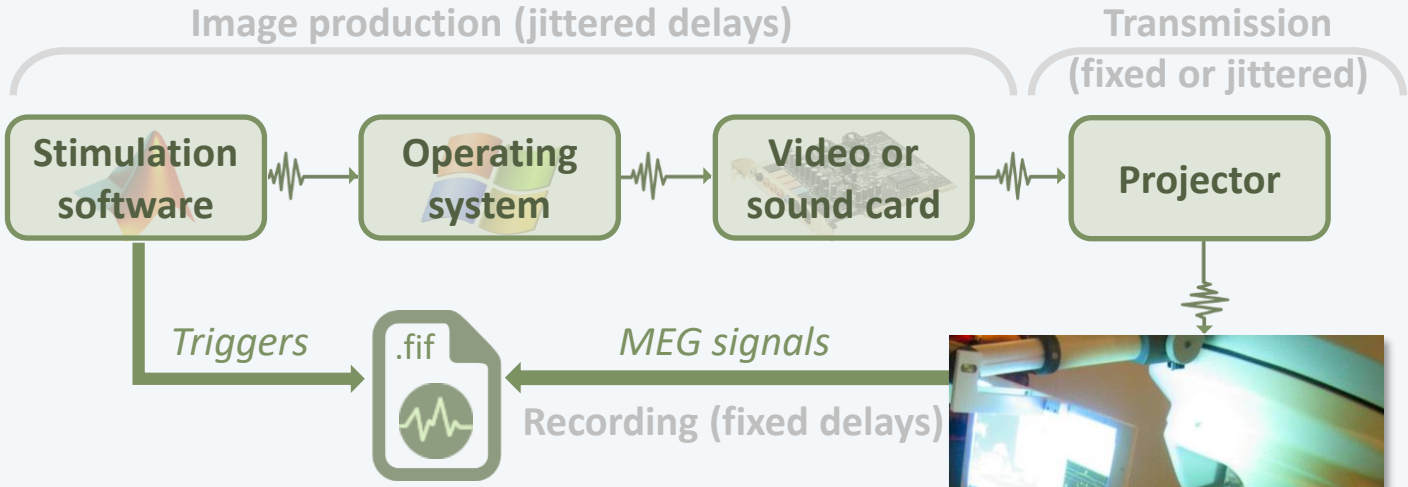
- How to get event markers in the recordings?

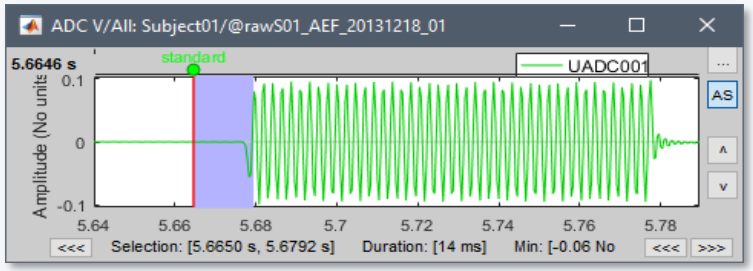


Brainstorm

Epoching

- Reading the triggers saved by the presentation software (includes jittered OS delays)

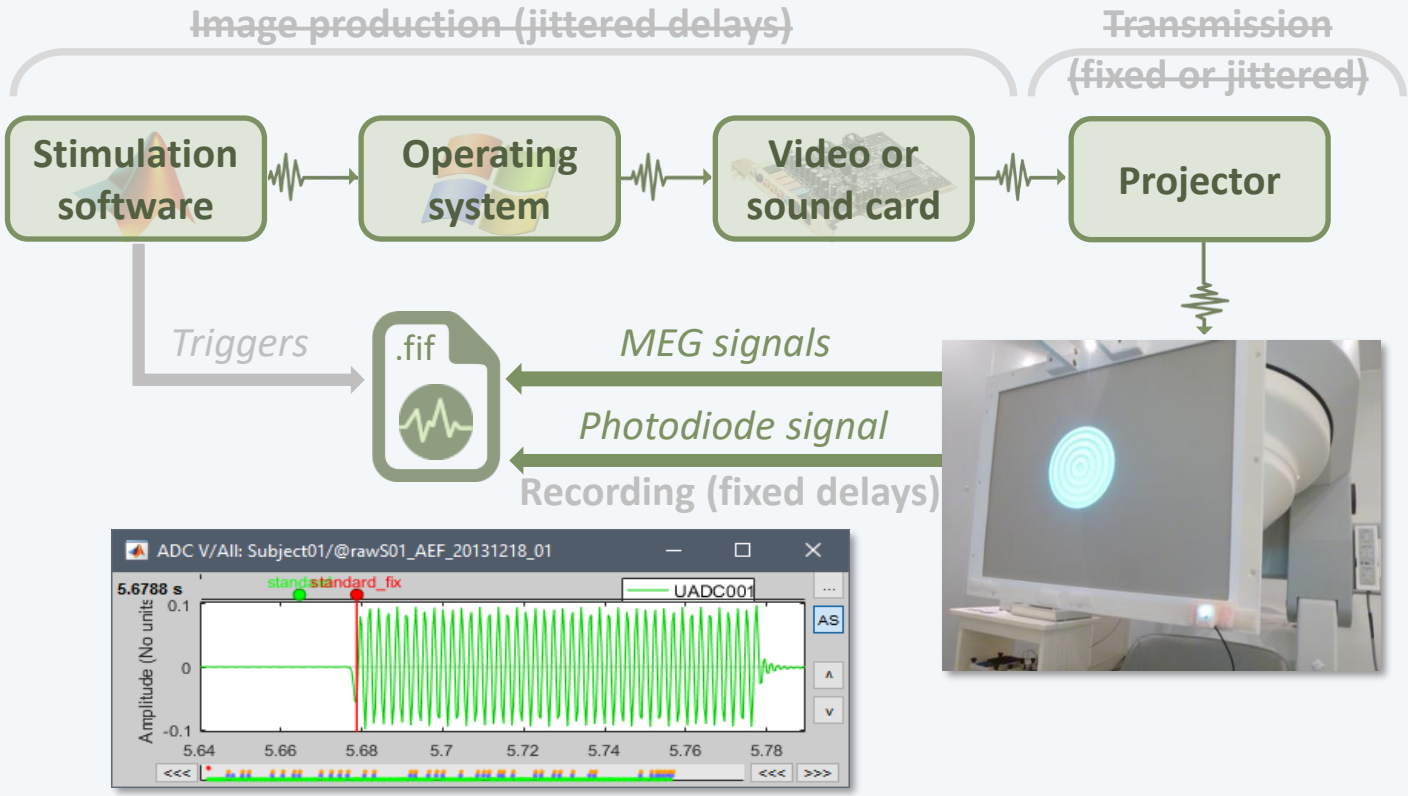




- File triggers are never aligned with the real stim

Epoching

- Reading information recorded on the subject side (photodiode, microphone, response box…)

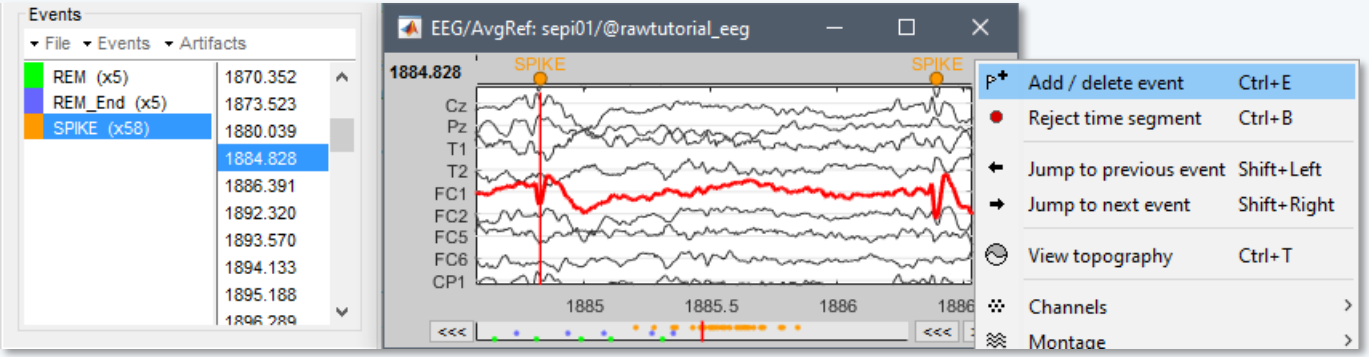


- Avoids most uncontrollable jittered delays

Brainstorm

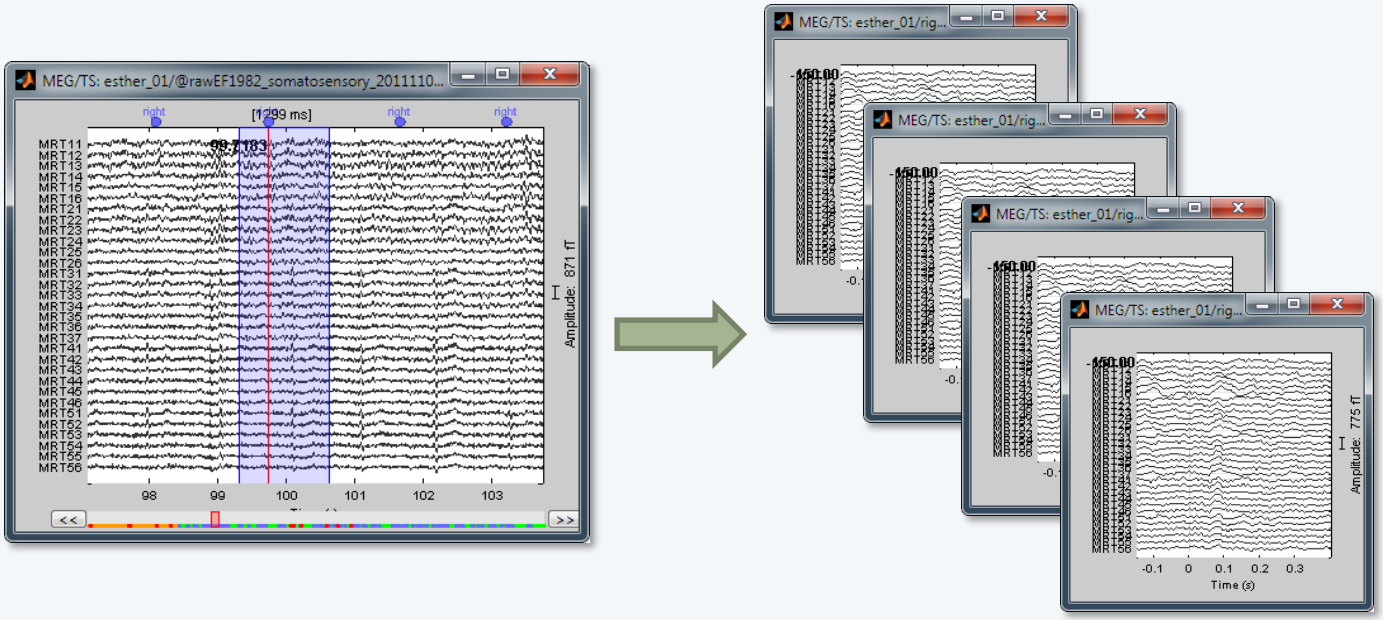
Epoching

- Reading the triggers save by the presentation software (includes jittered OS delays)
- Reading information recorded on the subject side (photodiode, microphone, response box)
- Manual or automatic marking of biological or behavioral events, post-acquisition (epileptic spikes, sleep spindles, rat position in a box…)
- Optimized workflow for clinicians (keyboard and mouse shortcuts, workspace…)



Epoching

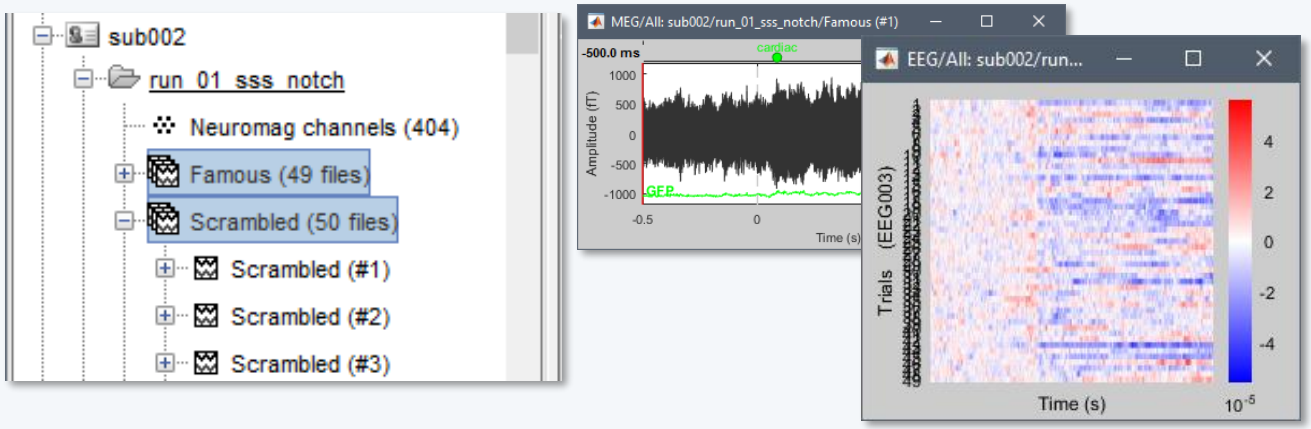
- Epochs = Trials = Short blocks of recordings around an event of interest.
- Epoching = Extracting epochs from the continuous recordings and saving them.



Brainstorm

Epoching

- In Brainstorm, each imported epoch is an independent file in the database.
- Accessible by event type or individually.

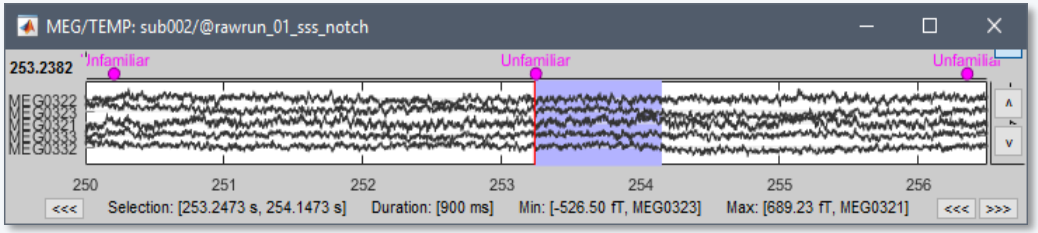


- In other programs, all the epochs from one run are saved in one single file (one file per event type, or one file with all the events).

Brainstorm

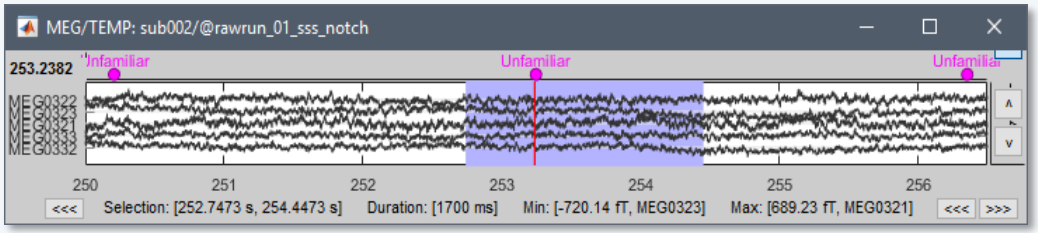
Epoching

- How to define the optimal epoch length ?
- Experimental design:
  Expected effect duration, inter-stimulus interval



[0,900] ms

- Analysis: Frequency filters and amplitude normalizations may require longer epochs



+ 200ms baseline
+ 300ms filters

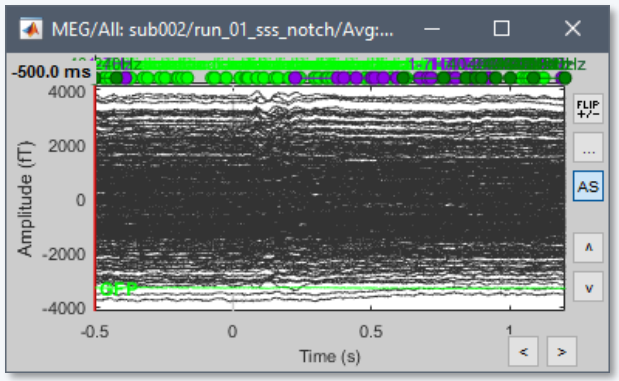
= [-500, 1200] ms

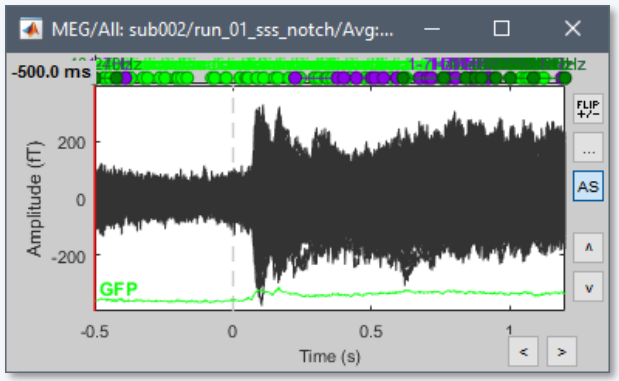
- Computational limitations: Size and time

Brainstorm

Epoching

- Processing steps that can be applied on epochs:
  - **DC offset correction**: Subtract the average estimated over a baseline period
  - **Detrending**: Subtract a linear trend estimated over a reference period
  - **Resampling**: Decrease the sampling rate
- This dataset: DC correction, baseline=[-500,0]ms



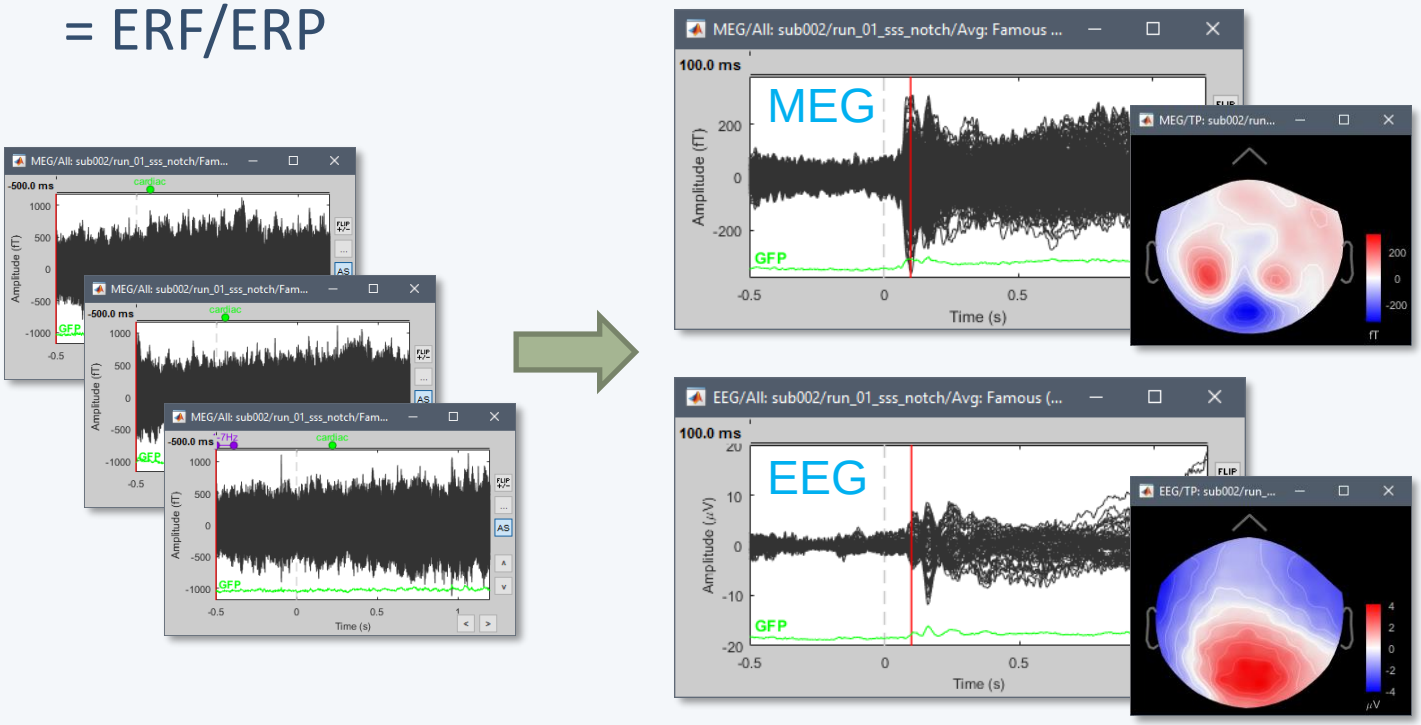


Brainstorm

Single subject

- Averaging the trials: Reveals the features of the signals that are locked in time to a given event

  = Event-related field / potential
  = Evoked response
  = ERF/ERP



Brainstorm

Single subject

- **EEG**: Averaging data across runs and subjects OK.
- **MEG**: Averaging across runs is not always accurate
  - Head shapes differ between subjects.
  - Head positions different between runs.
  - One sensor does not record the same thing in two different runs.
  - Coregistration of runs with Elekta MaxFilter helps but modifies a lot the recordings. Never use this to average across subjects.
  - Recommended: Estimate the sources for each run separately, then average in source space.

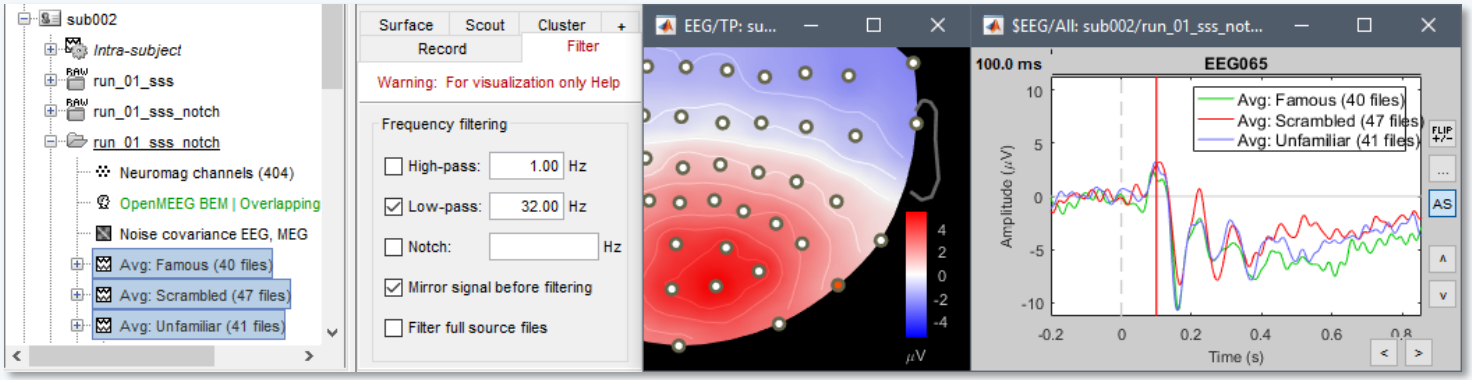
Single subject

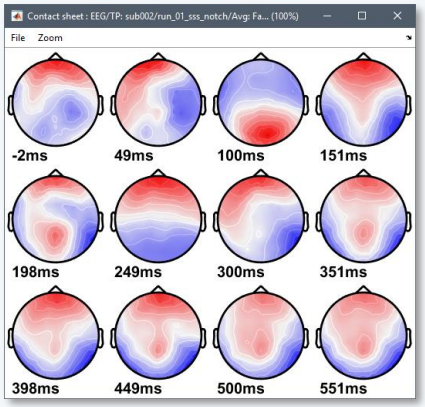
Anatomy
Link recordings
MRI registration

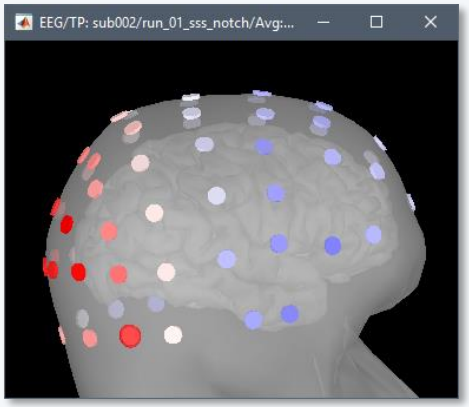
PSD
Filters
Bad channels
Artifacts
Correction
Bad segments

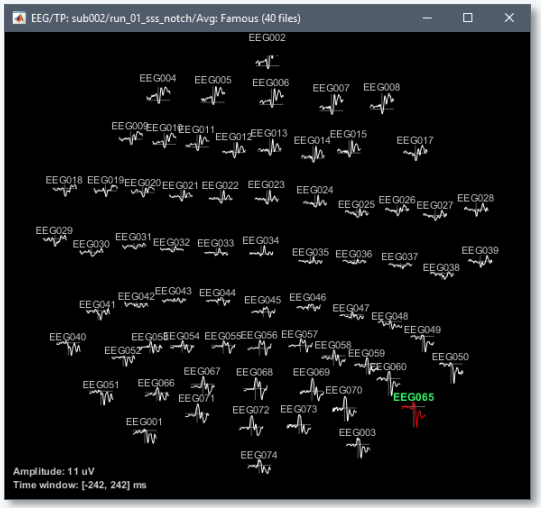
Markers
Epoching
Averaging
Sources
Time-frequency

- EEG ERP: Famous faces









Brainstorm

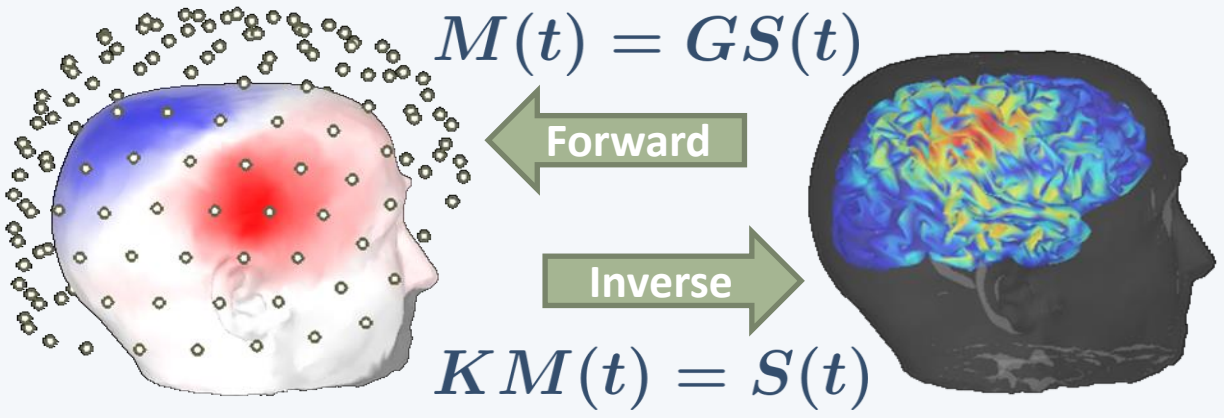
Single subject

$M(t)$ Sensor space: EEG or MEG sensors

$S(t)$ Source space: Cortex or full head volume

G Forward model: Overlapping spheres (MEG)
OpenMEEG BEM/DUNEuro FEM (EEG)

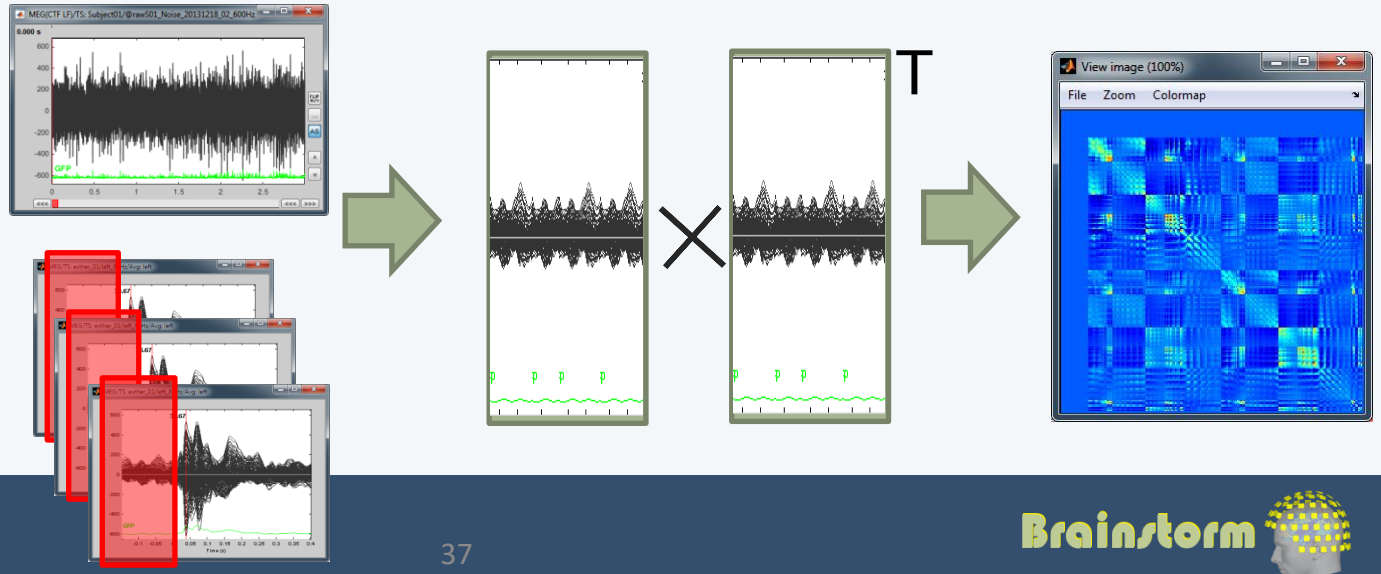
K Inverse model: **Minimum norm estimates**
Beamformers
Separately for MEG and EEG



Brainstorm

Single subject

- The MNE model requires an estimation of the level of noise of the sensors
- Noise covariance matrix = covariance of segments that do not contain any “meaningful” data
- Empty room, pre-stim baseline, resting



Brainstorm

Single subject

Anatomy
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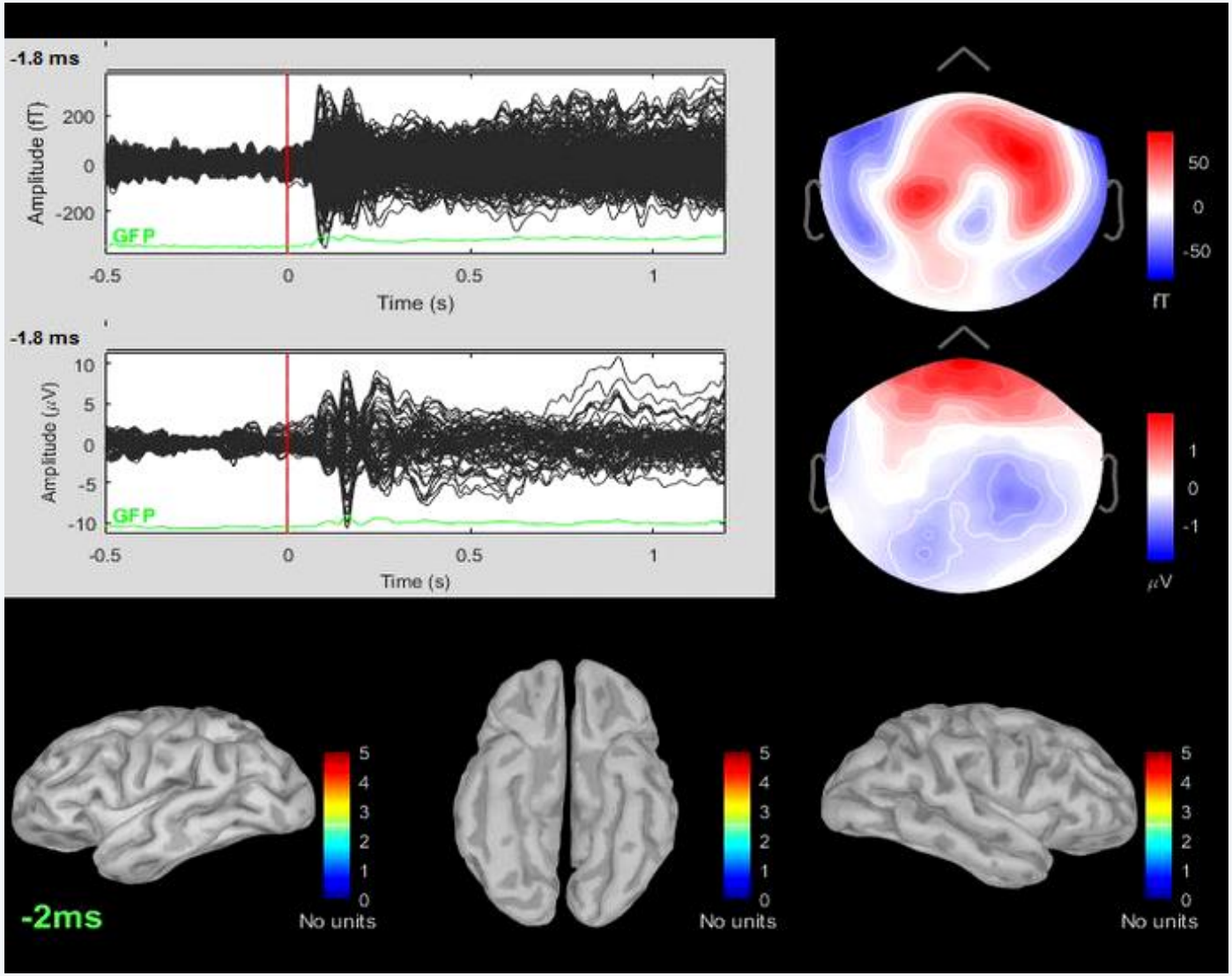
Averaging
Sources
Time-frequency

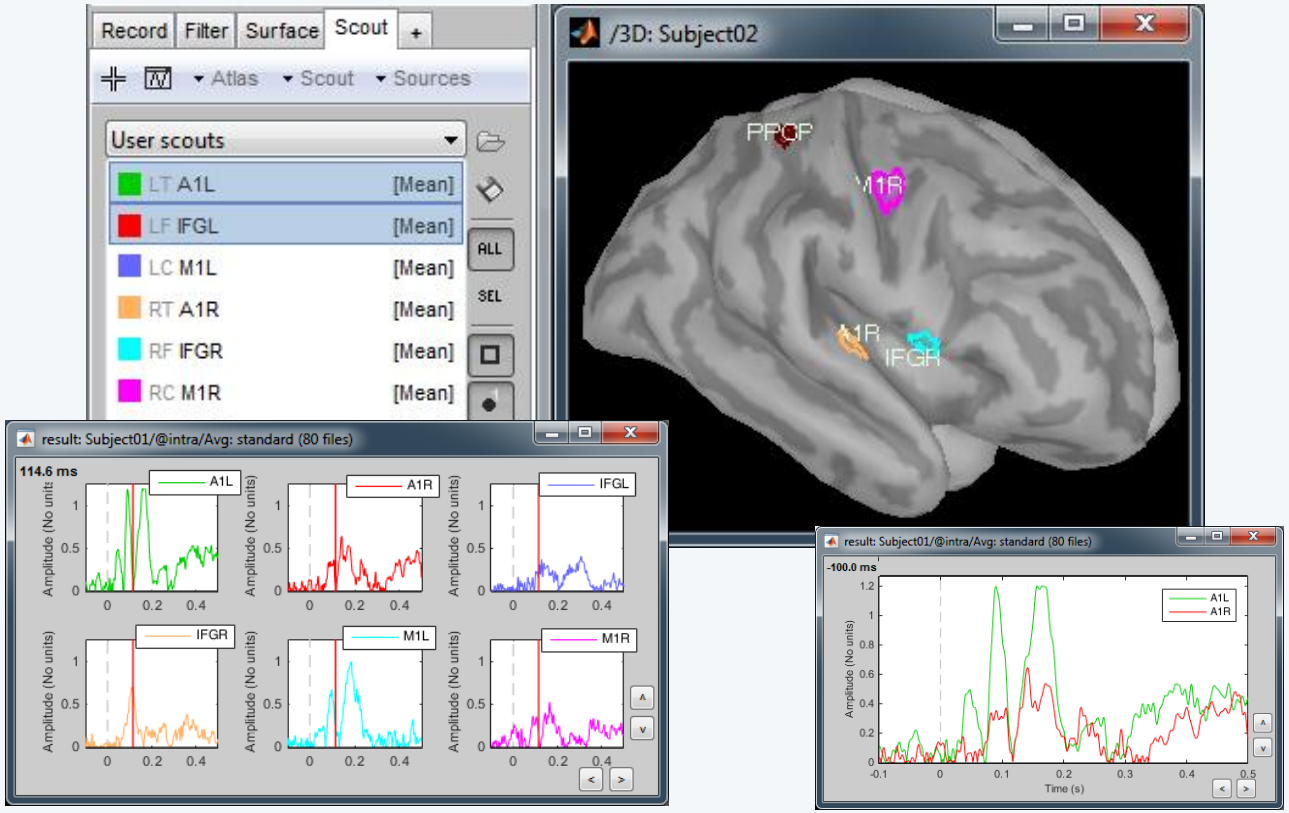
Famous faces



Brainstorm

Single subject

- Regions of interest at cortical level (scouts)
  = Subset of a few dipoles in the brain
  = Group of vertices of the cortex surface



Brainstorm

Single subject

Anatomy
Link recordings
MRI registration

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Bad segments

Markers
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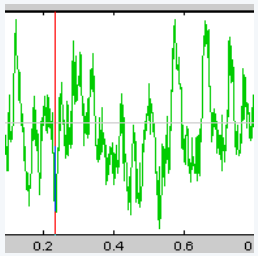
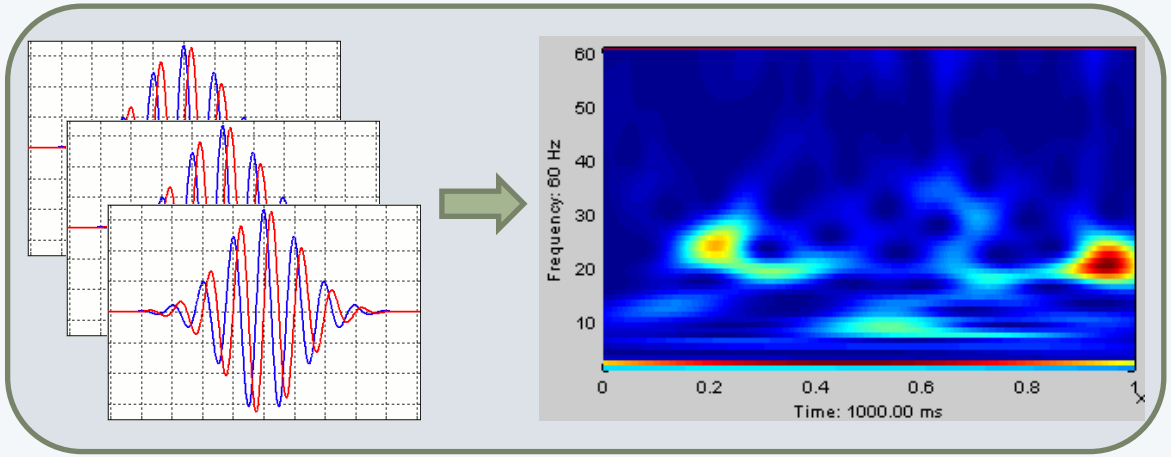
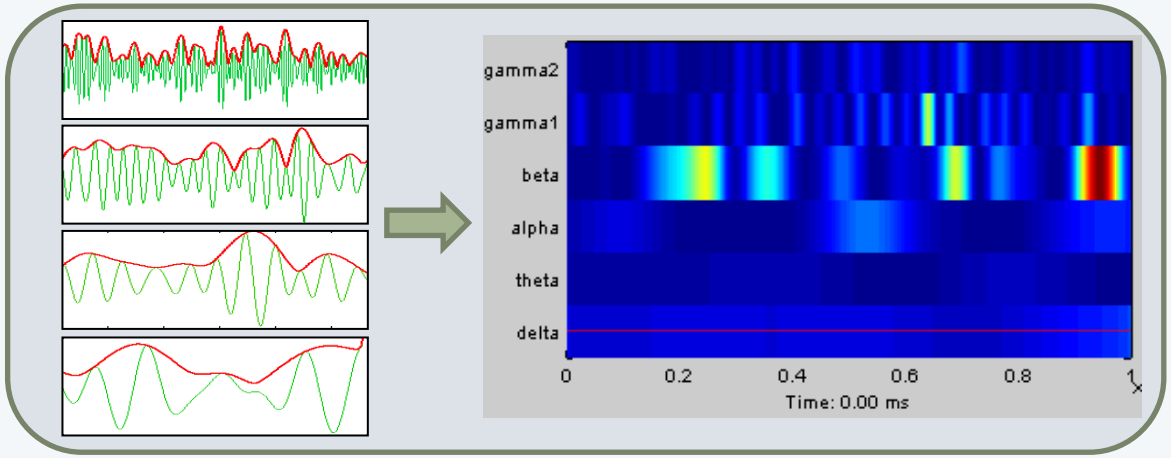
Sources
Time-frequency

Morlet wavelets





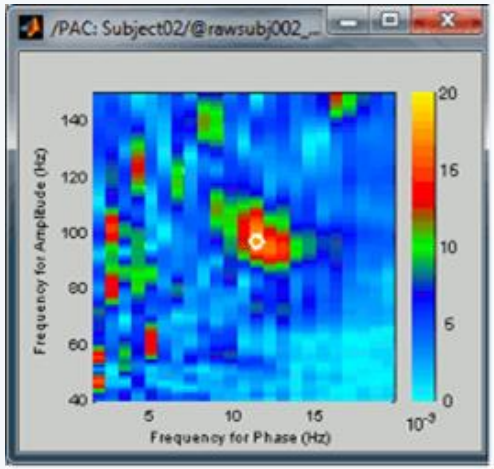
Hilbert transform + band-pass filter

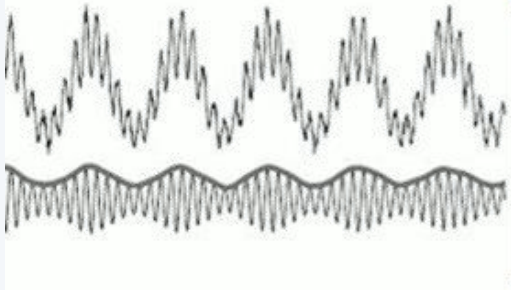


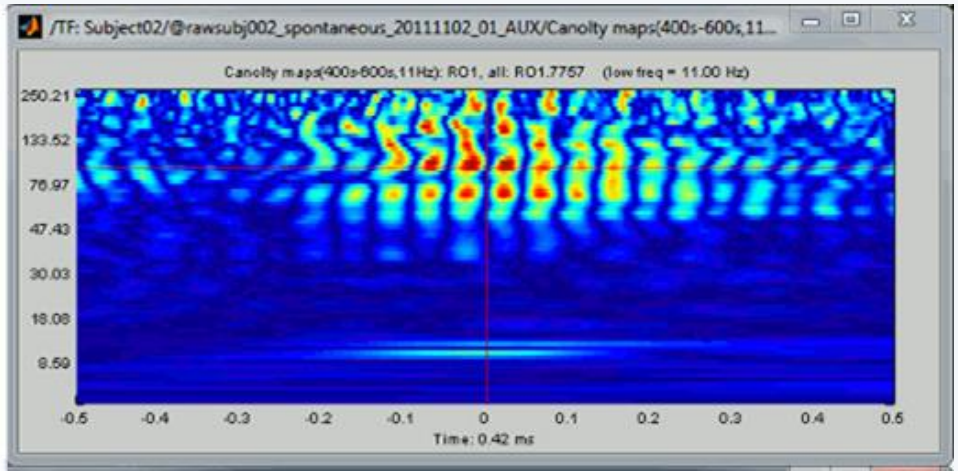
Brainstorm

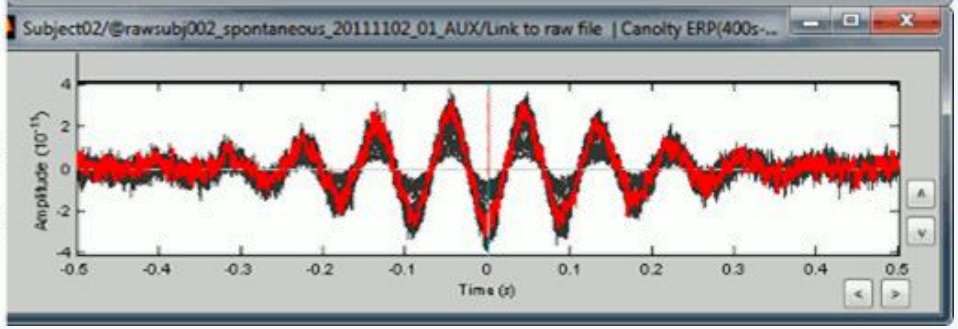
Single subject

- Phase-amplitude coupling





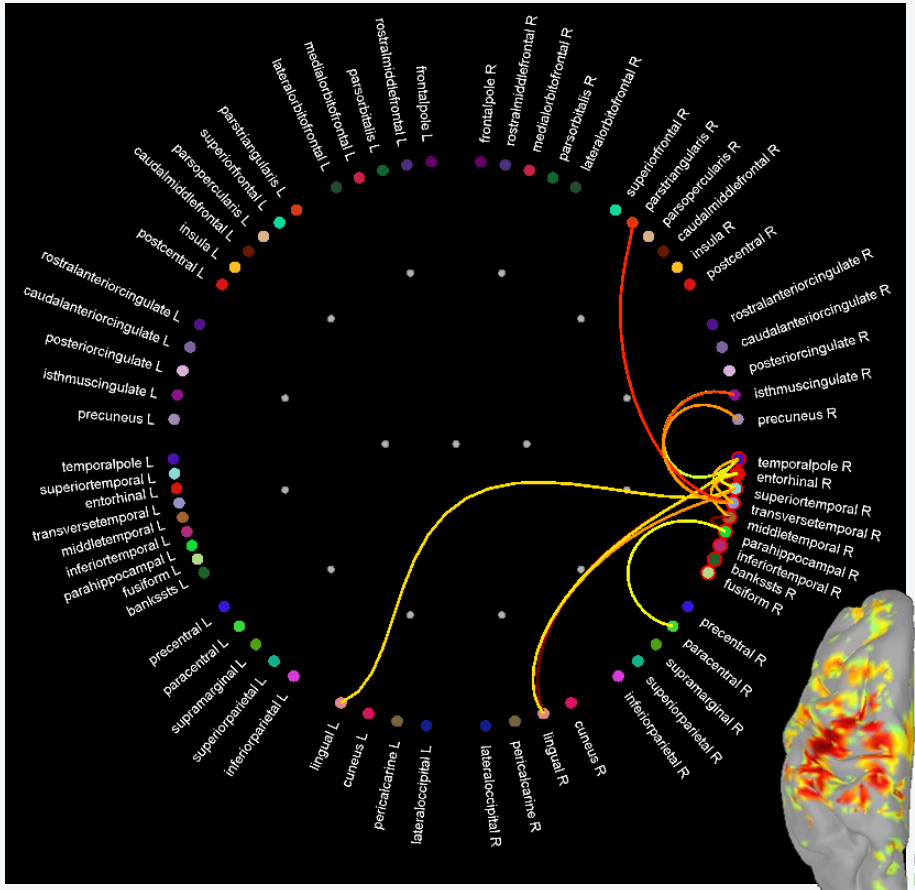




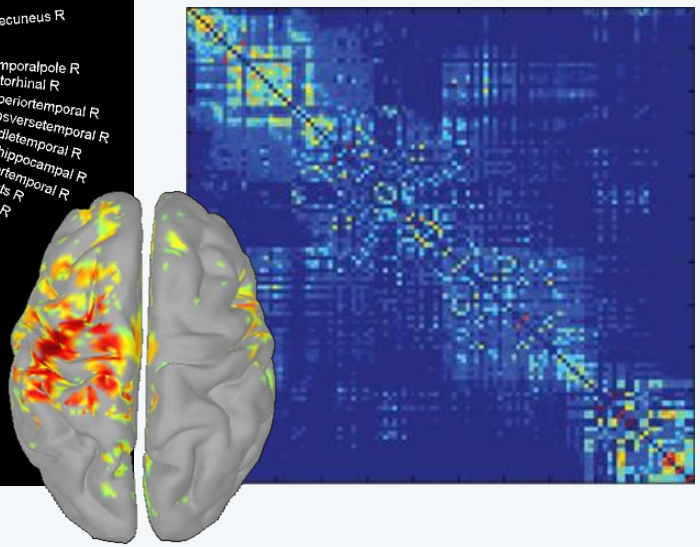
Brainstorm

Single subject

- Connectivity measures



- Correlation
- Coherence
- Phase locking value
- Granger causality



Brainstorm

Group analysis

Anatomy
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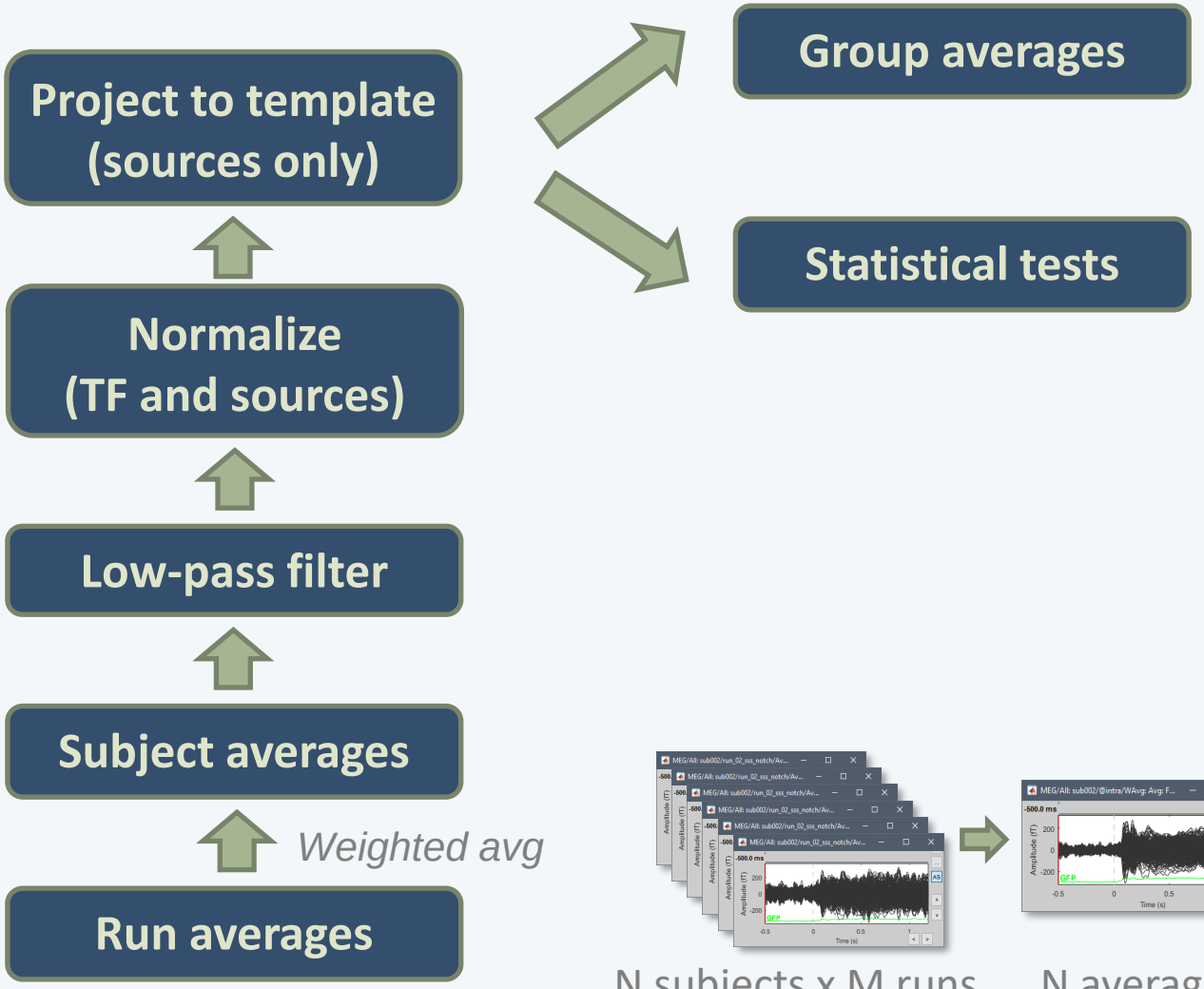
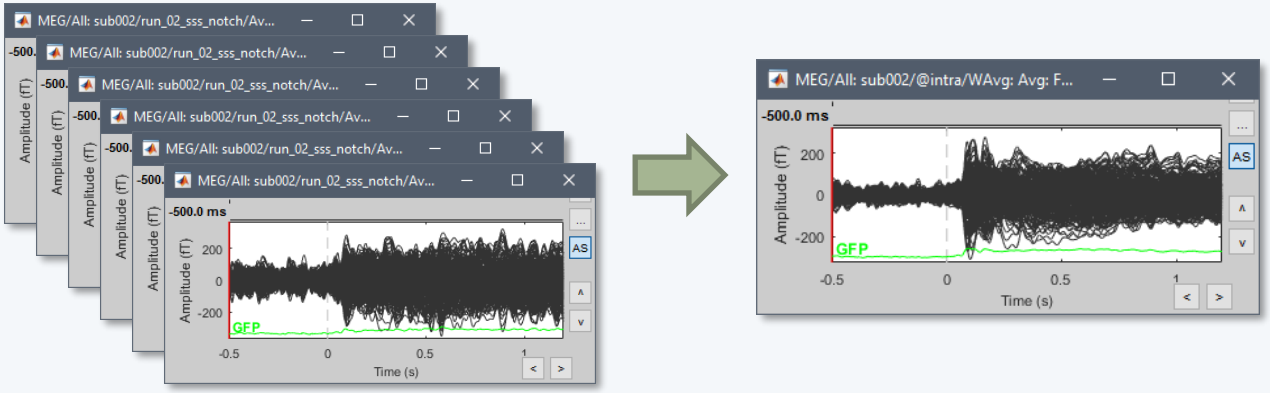
Time-frequency



Brainstorm

Group analysis

- Weighted average of 6 runs per subject (recordings, sources MEG/EEG, time-frequency)



- Sources: Compute within-subject differences
  - (Faces - Scrambled) and (Famous - Unfamiliar)
  - The sign of the MNE source amplitude is ambiguous, we will apply an absolute value before comparing between subjects

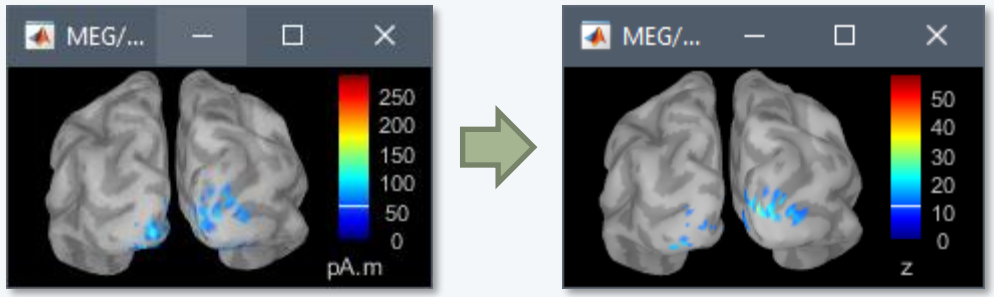
Group analysis

Subject averages
Low-pass
Normalize
Project

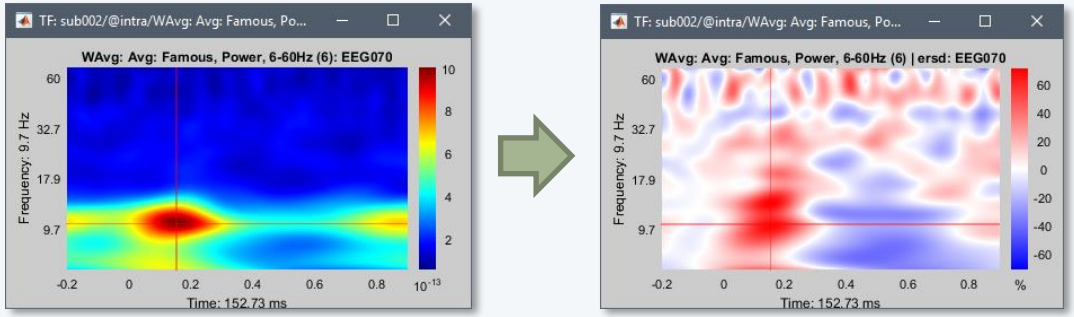
Group averages
Group statistics

Quality control
Workflow

- Amplitude normalization before group analysis
  Baseline = [-200,0]ms
- Sources: Z-score normalization wrt baseline
  S = (S – mean(baseline)) / std(baseline)



- Time-frequency: Event-related sync/desync
  TF = (TF – mean(baseline)) / mean(baseline) * 100



Brainstorm

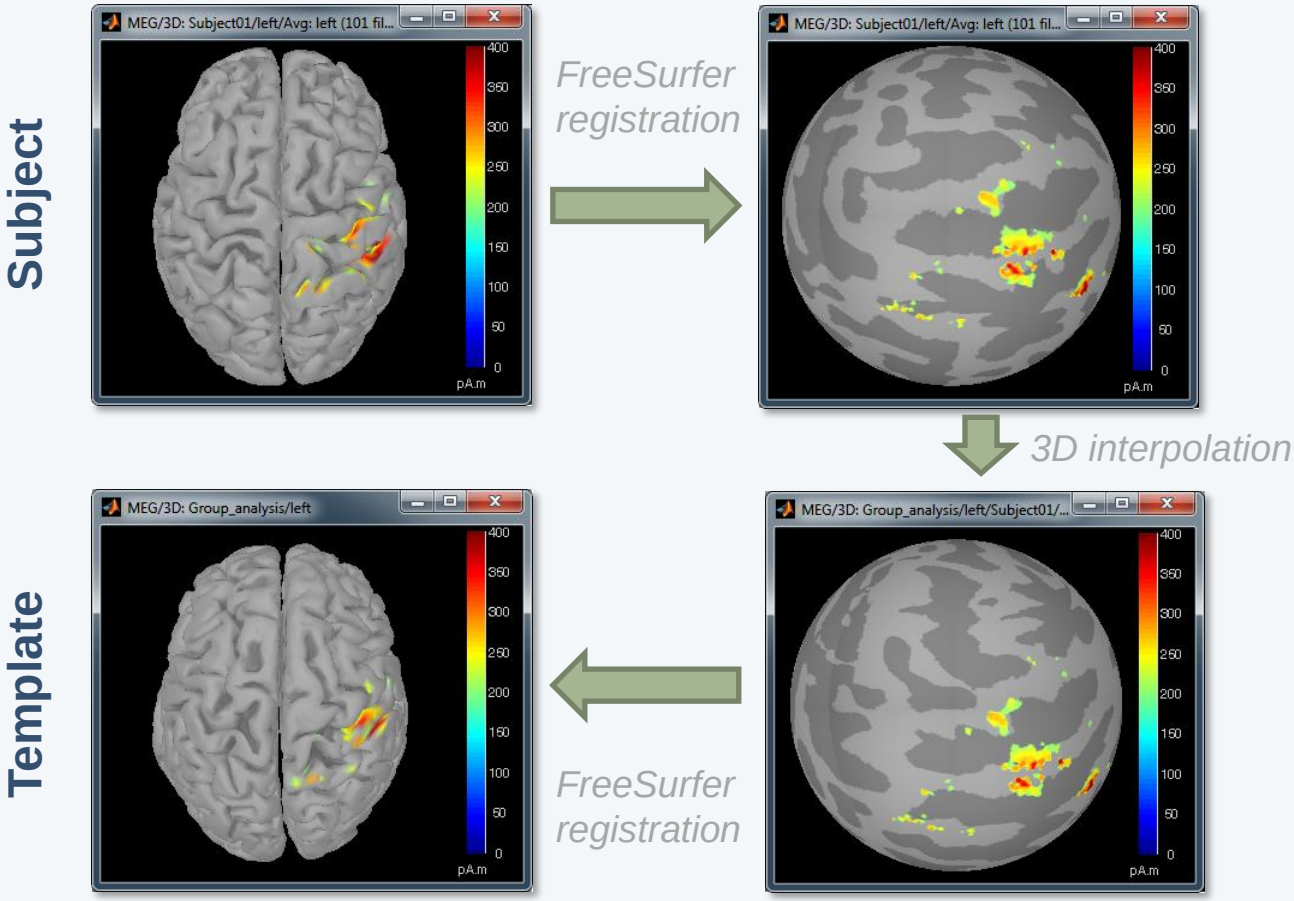
Group analysis

Subject averages
Low-pass
Normalize
Project

Group averages
Group statistics

Quality control
Workflow

- Using FreeSurfer registration



Brainstorm

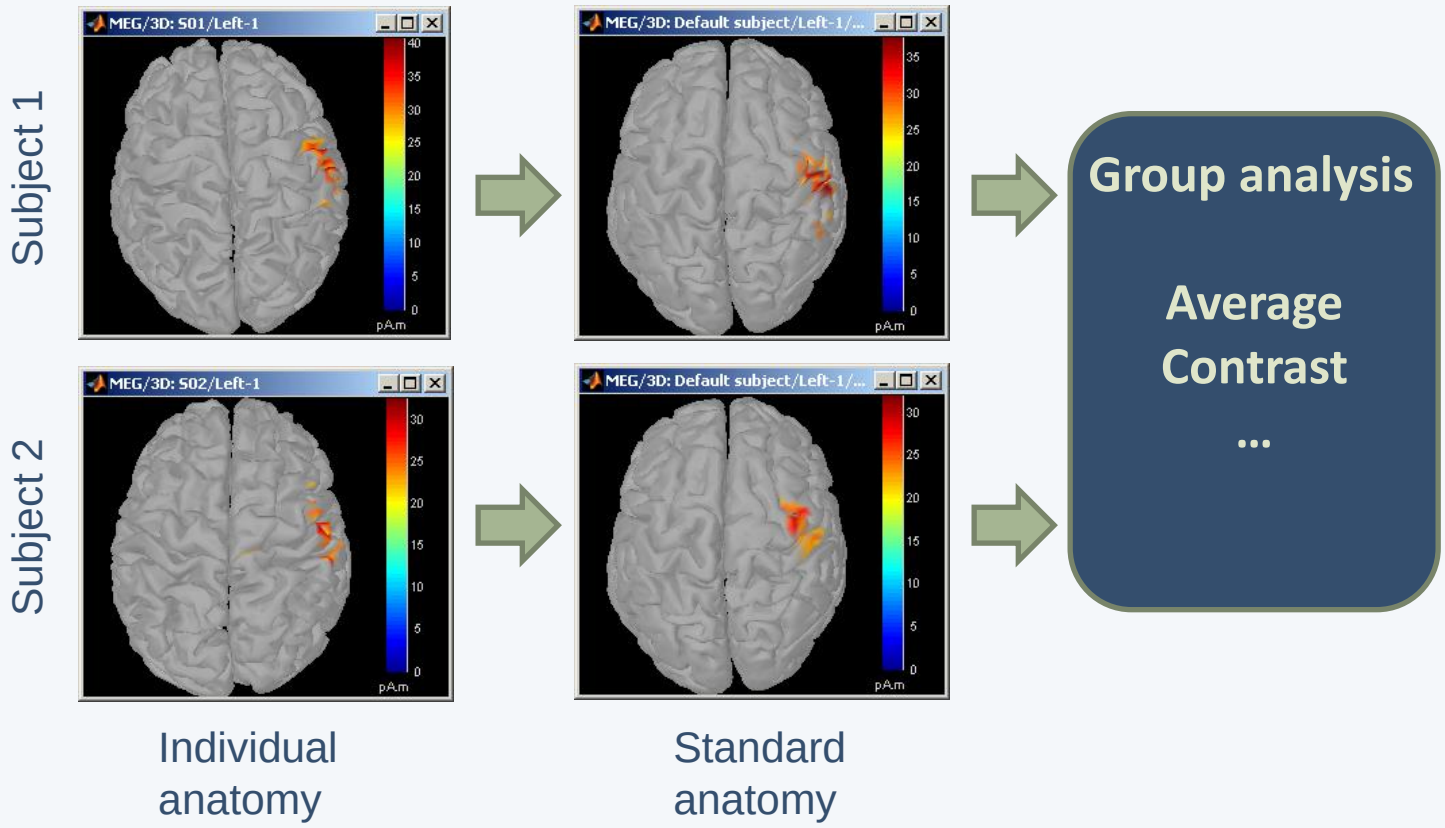
Group analysis

Subject averages
Low-pass
Normalize
Project

Group averages
Group statistics

Quality control
Workflow

- Registration of individual sources on a template
  (ICBM152, Colin27, DNI, infants…)



Brainstorm

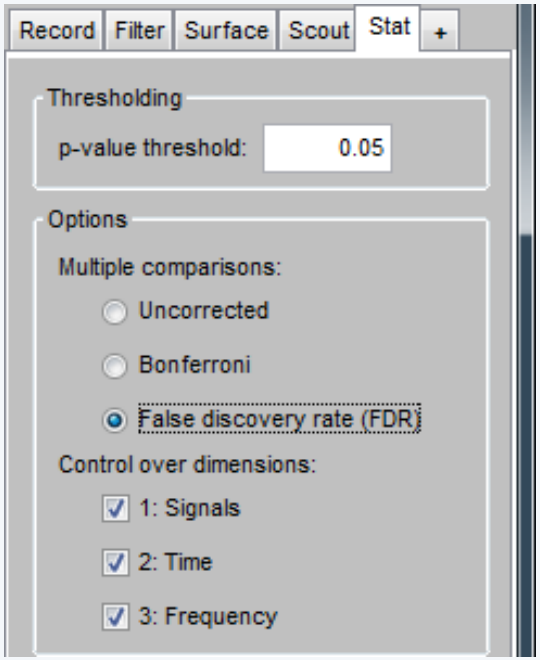
Group analysis

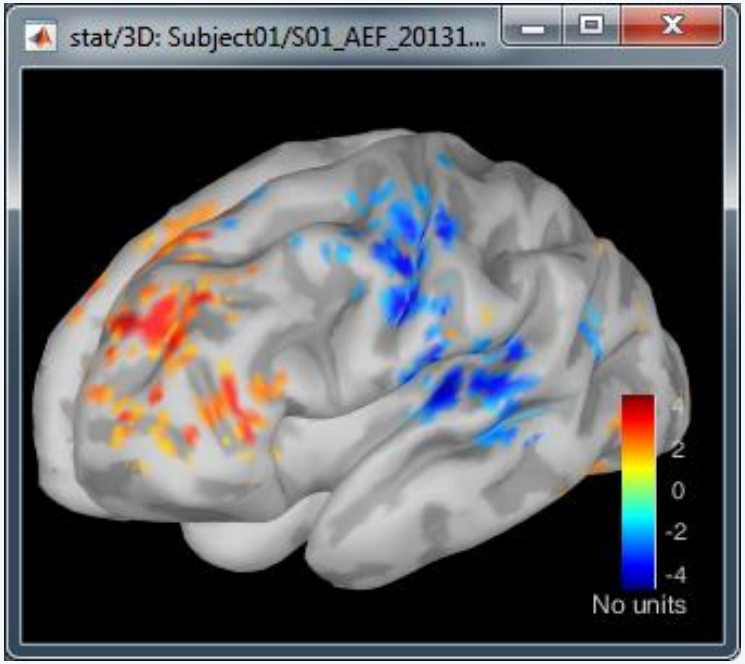
Subject averages
Low-pass
Normalize
Project

Group averages
Group statistics

Quality control
Workflow

- Contrasts between subjects or conditions
- Parametric t-test
- Cluster-based non-parametric tests
- Export to: **SPM**, R, Excel, SPSS, Matlab…





Brainstorm

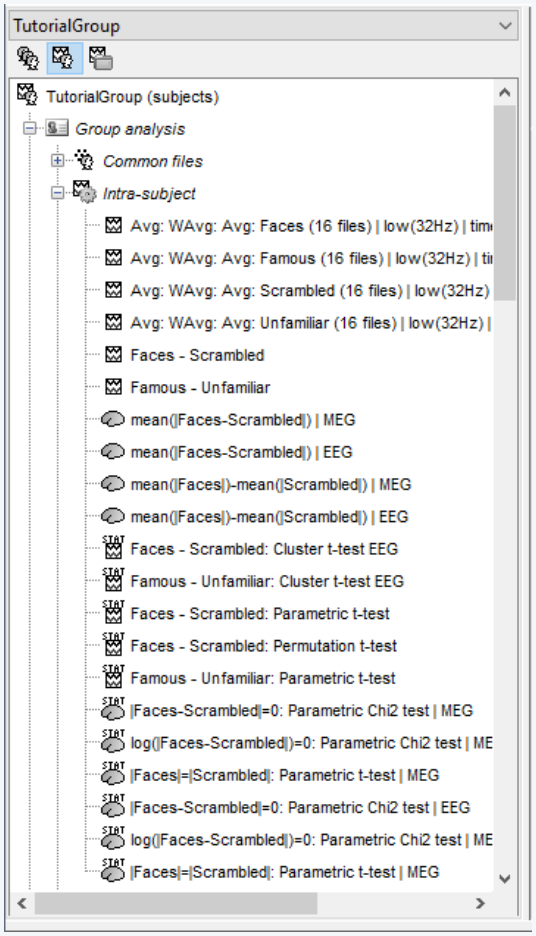
Group analysis

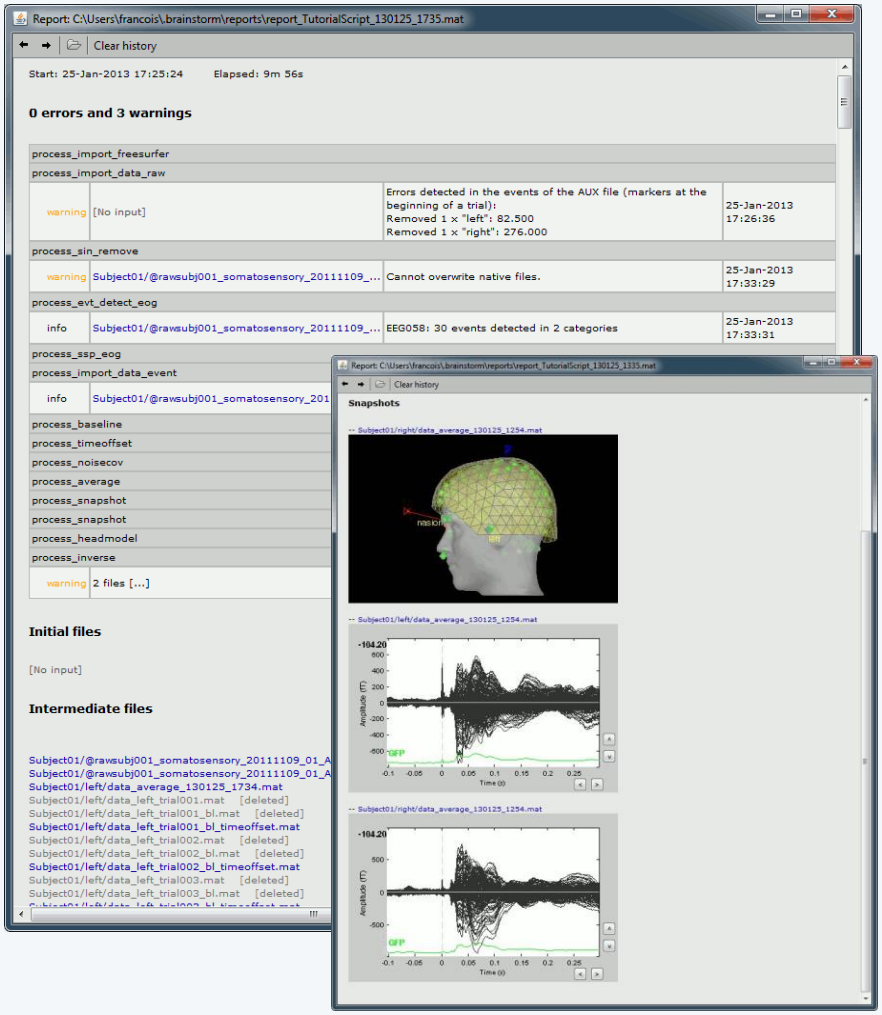
Subject averages
Low-pass
Normalize
Project

Group averages
Group statistics

Quality control
Workflow

- Execution reports with snapshots saved in HTML





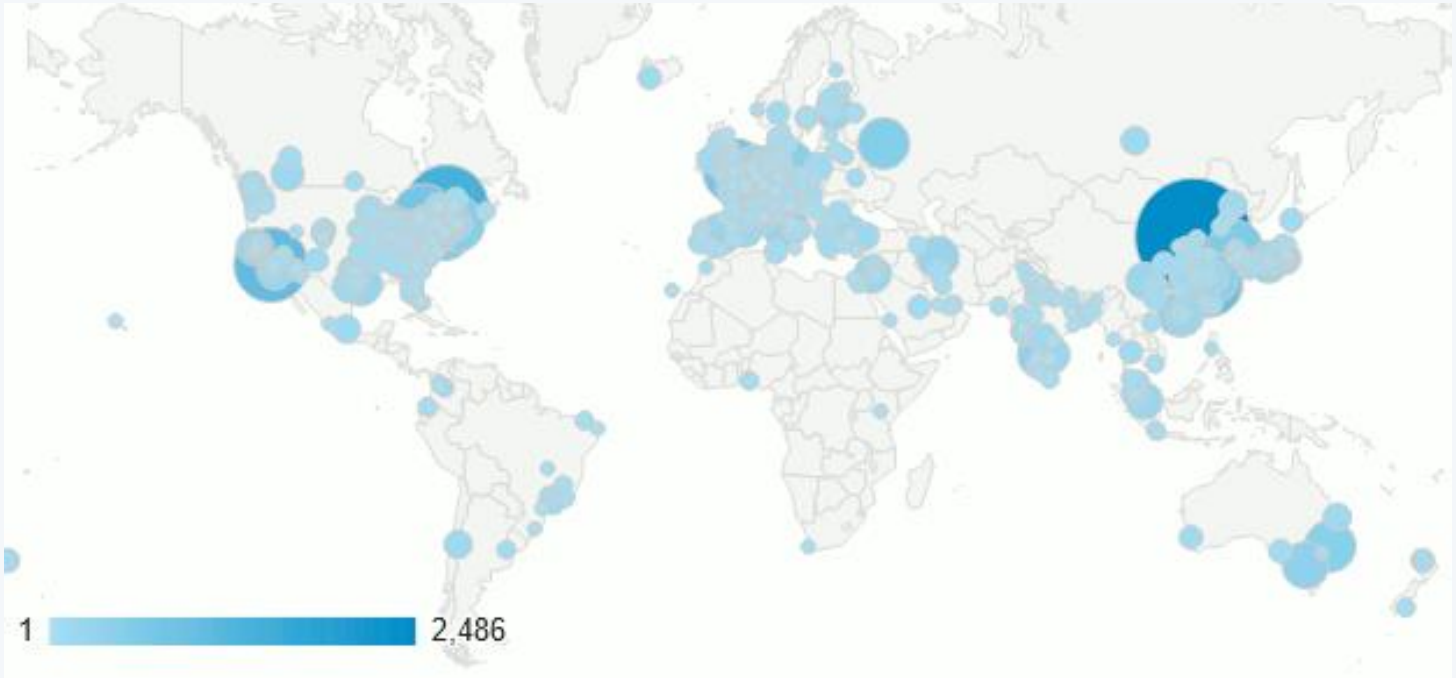
Brainstorm

Add your code to Brainstorm

- Direct manipulation of the files in Matlab
- Use the menu “Run Matlab command”
- Write a plugin:
  - Well documented API
  - Lots of example (170 functions written as plugins)
  - Open-source GitHub repository
- Examples of recent external contributions:
  - MVPA decoding (Oliva, MIT)
  - Microstate segmentation (Cacioppo, UChicago)
  - Eyetracker/EEG synchronization (Uni Freiburg)

User community (2023)

- 40,000+ users registered on the website



Find users next to you

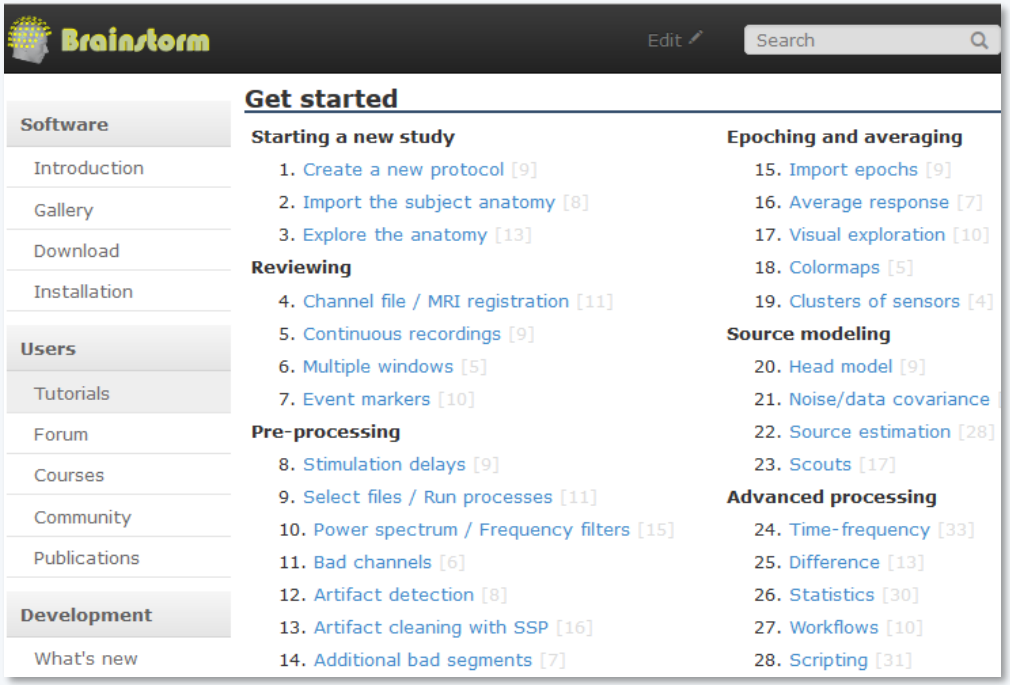
Location: montreal

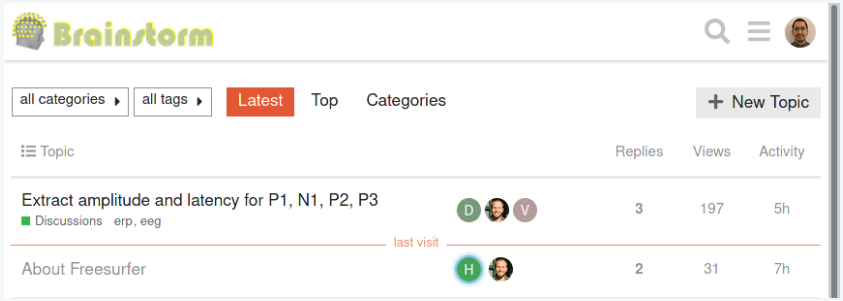
Users found: 847

Brainstorm

User support

- Online tutorials: 30-hour self-training program
- Active user forum: 150 posts/month
- Daily updates: 1500 downloads/month





@BrainstormSoftware

@brainstorm2day

@brainstorm-tools

Brainstorm

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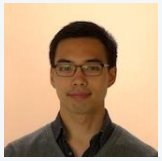
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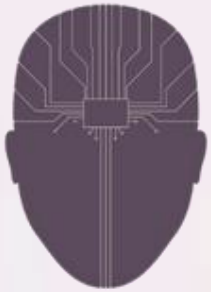
Edouard Delaire
Concordia

Next Brainstorm Workshop

2nd International Conference on

Artificial Intelligence in Epilepsy and Neurological Disorders



April 1st – 4th 2024

Park city, ut, usa

www.AIEPILEPSY-NEURO.com

Algorithms, machine learning, deep learning and artificial intelligence in epilepsy and neurological disorder clinical care, practice and research with special emphasis on devices, wearables, apps and platforms

This year on April 1st we will also hold a special Workshop on the Brainstorm Platform for Clinicians and Scientists and its use in Stereotactic EEG and Epilepsy Surgery

Organizing Committee:
Sam Lhatoo MD, Philippe Ryvlin, Michael Sperling, Sandor Beniczky

For any information: Aiepilepsy-neuro@ant-congres.com

Brainstorm

Team today

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Woojae Jeong

Chinmay Chinara

John Mosher

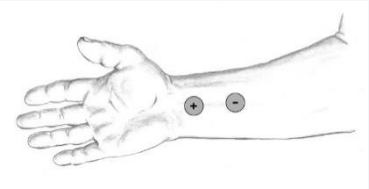
Richard Leahy

Workshop dataset

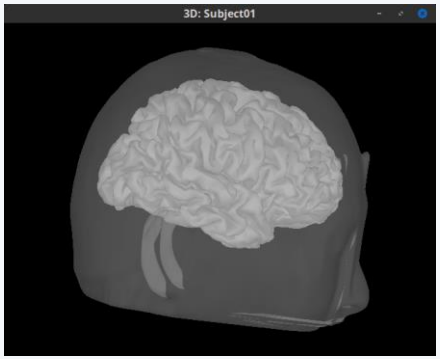
Median nerve stimulation

- Right arm stimulation: monophasic square-wave duration 0.3 ms at 2.8 Hz
- 1 participant / 1 run / 336 stimuli

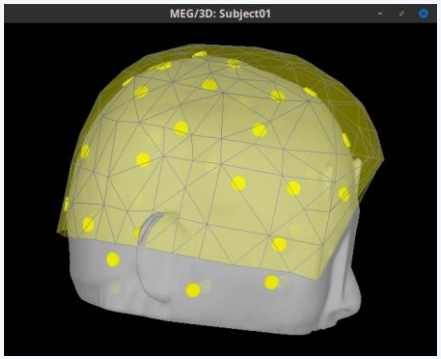
- Individual MRI, processed with CAT12
- MEG: Yokogawa 160 axial gradiometers @ 2000 Hz
- EEG: Nihon Kohden 41 electrodes @ 2000 Hz



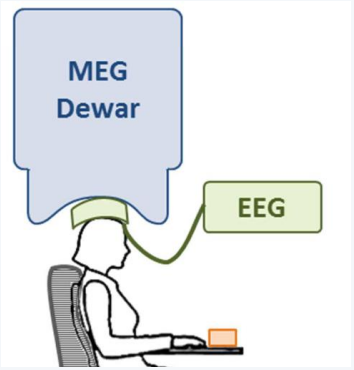
Median nerve percutaneous stimulation



Scalp and cortical surface



EEG electrodes and MEG helmet



Simultaneous MEG and EEG acquisition