M/EEG Preprocessing

MfD 10th May 2023

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M/EEG frequencies

- ➢EEG and MEG signal is usually acquired at a high temporal sampling frequency
  - e.g., 250Hz to several kHz
- ➢Not all frequencies in data reflect underlying neural sources
  - e.g., motion can generate low frequencies, muscular activity generates high frequencies
  - Useful to filter out these frequencies during preprocessing
- ➢Relevant frequencies would depend on study design/question

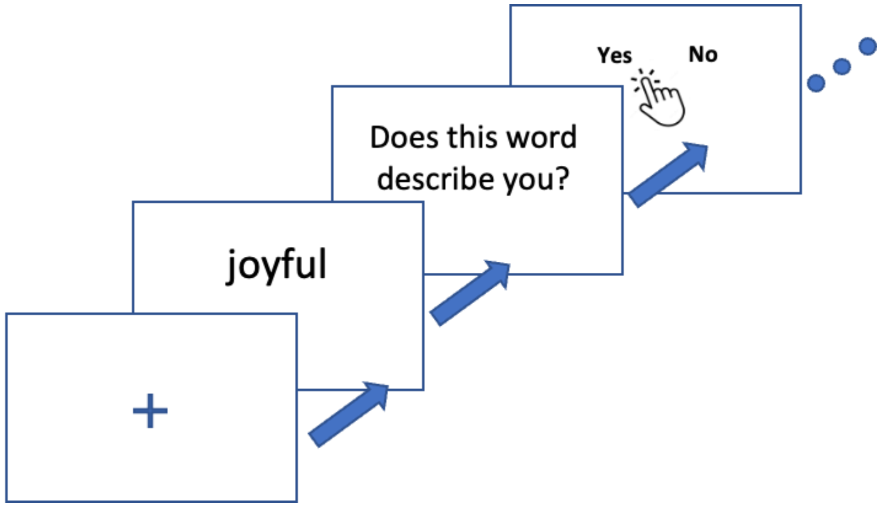
Different M/EEG study designs

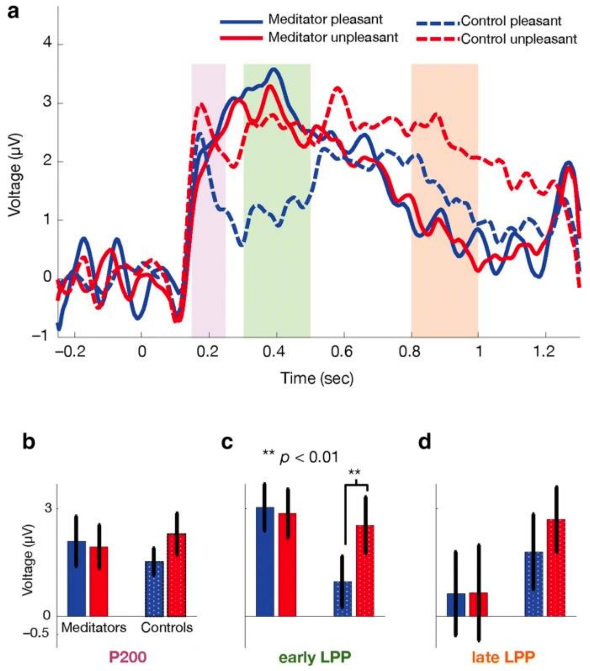
- Evoked/event-related potentials
- Spontaneous activity / Oscillations
- Time-frequency
- Steady-state evoked potentials

Evoked/event-related potentials

- ➢Large number of trials
- ➢Time-locked average
- ➢Typically seen in 1—10Hz range
- ➢Components: P100, N140, P300, LPP

e.g., affective self-referential processing in meditators

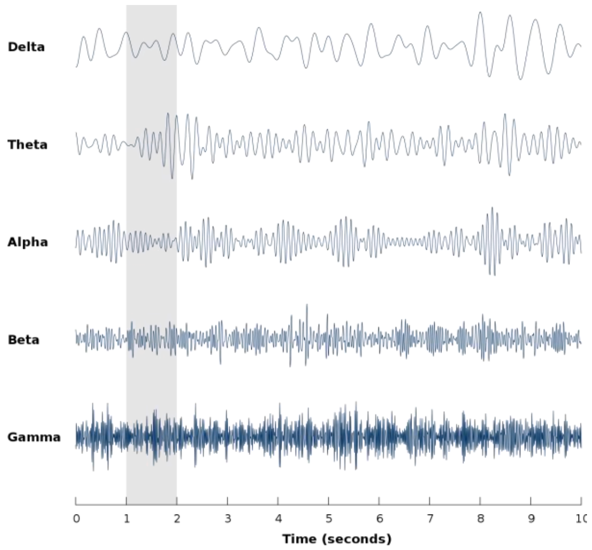


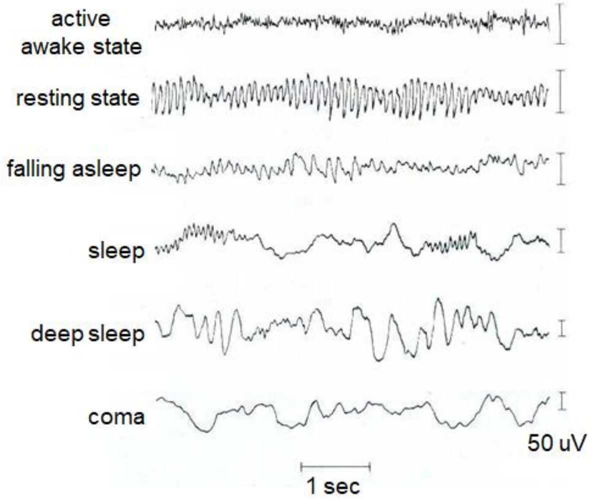


Katyal, S., et al (2020). Event-related potential and behavioural differences in affective self-referential processing in long-term meditators versus controls. *Cognitive, Affective & Behavioral Neuroscience*, *20*(2), 326–339.

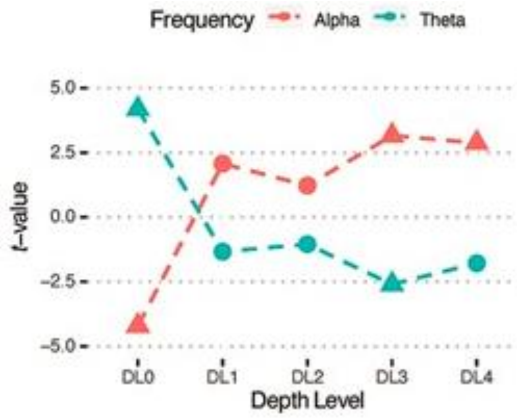
Oscillations / spontaneous activity

- Continuous activity
- Extract different frequency bands corresponding to mental functions
  - Delta: 1–3 Hz
  - Theta: 4–7 Hz
  - Alpha: 7–13 Hz
  - Beta: 15–25 Hz
  - Gamma: >30 Hz





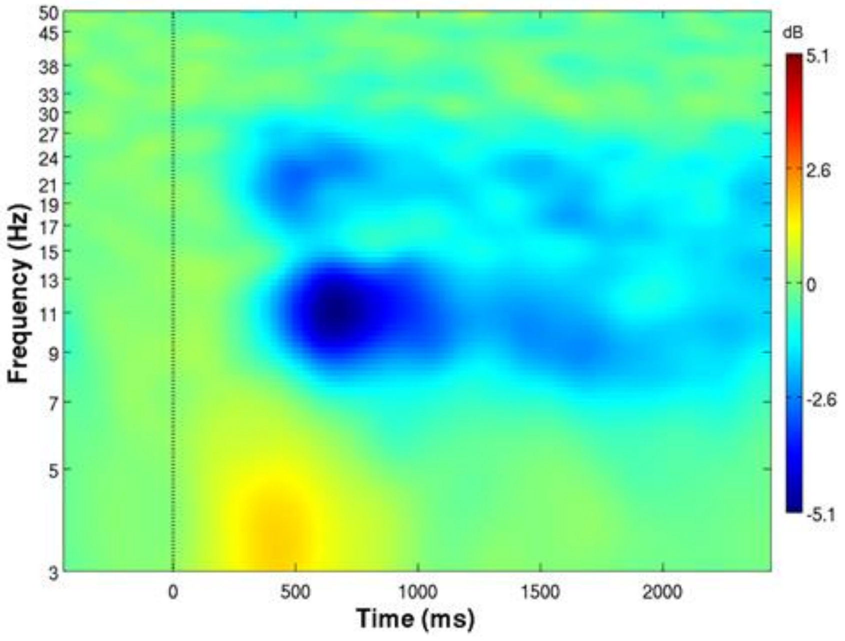
- e.g., modulation alpha and theta oscillations with depth of meditation



Katyal, S., & Goldin, P. (2021). Alpha and theta oscillations are inversely related to progressive levels of meditation depth. *Neuroscience of Consciousness*, *2021*(1), niab042.

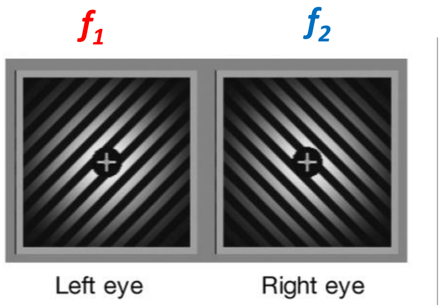
Time-frequency

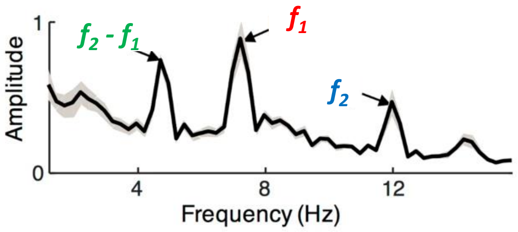
– Combination of time-locked and spectral analysis

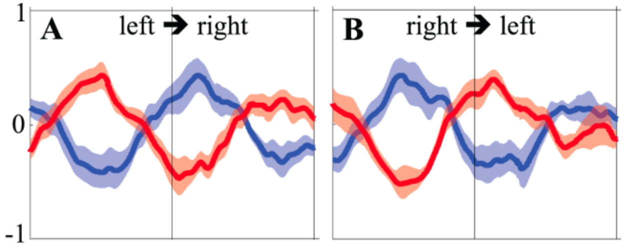


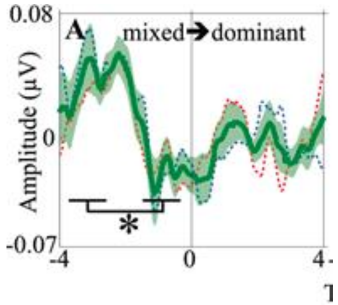
Steady-state evoked potentials

- ➢Continuous stimulus contains repeated frequencies
  - – obtain response by filtering signal at those frequencies and linear combinations of those frequencies







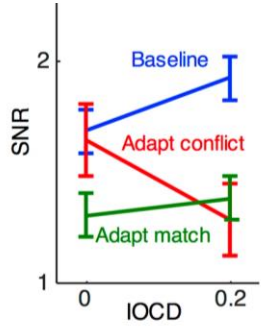


Katyal, S., Engel, S. A., He, B., & He, S. (2016). Neurons that detect interocular conflict during binocular rivalry revealed with EEG. *Journal of Vision*, *16*(3), 18–18.

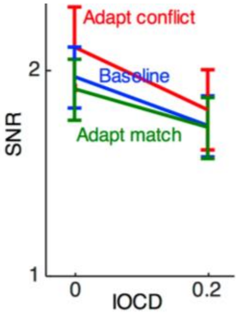
Katyal, S., Vergeer, M., He, S., He, B., & Engel, S. A. (2018). Conflict-sensitive neurons gate interocular suppression in human visual cortex. *Scientific Reports*, *8*(1), 1239.

e.g., ocular opponency neurons in visual perception

- mixed rivalry perception related to *f2-f1* signal
- *f2-f1* signal specifically adapt in exposure to rivalry/interocular conflict



$f_2 - f_1$



f1 and *f2*

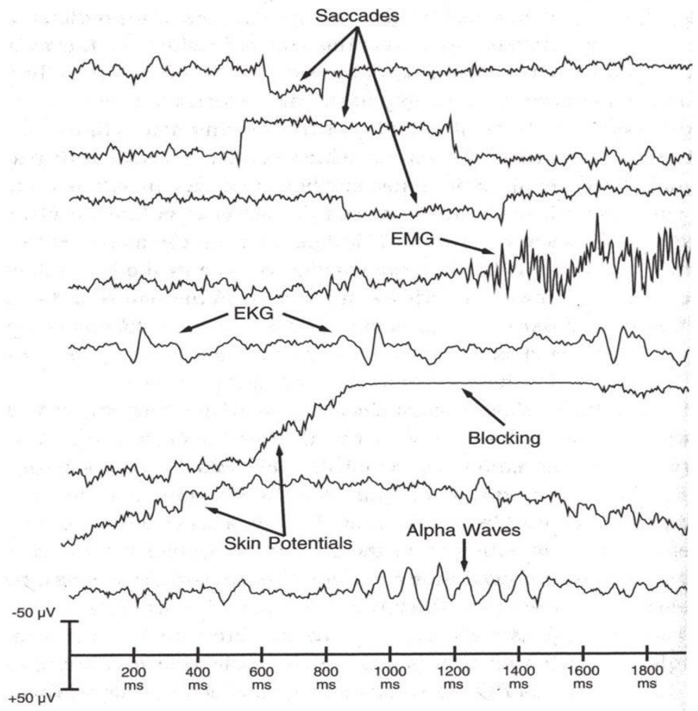
Unexpected features of M/EEG data

- Eye movements
- Heartbeat
- Participant head movement
- Muscle Artefact

Physiological

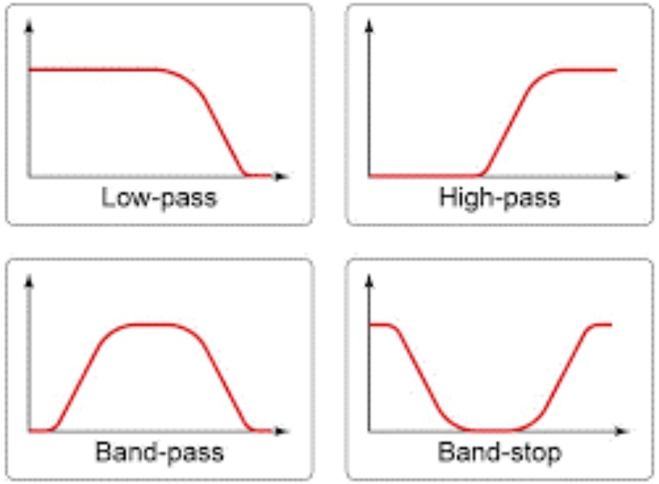
- Poorly attached EEG electrode
- SQUID Jump
- 50/60Hz Line Noise

Non-physiological

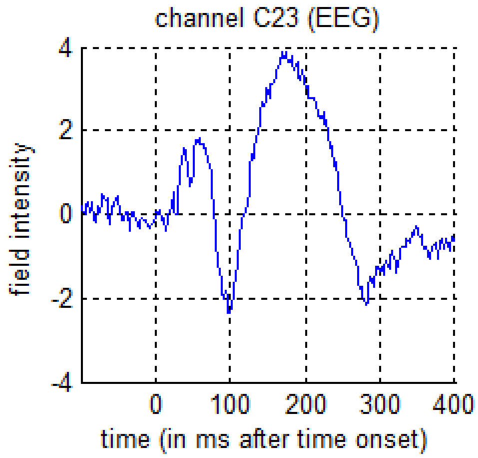


Filtering

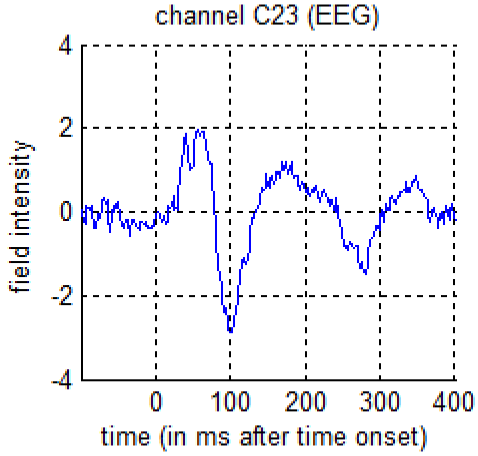
- Removing frequencies not expected in the study
  - **Low-pass** – remove high-frequency noise.
  - **High-pass** – remove the DC offset and slow trends in the data.
  - **Notch (band-stop)** – remove artefacts limited in frequency, most commonly line noise and its harmonics.
  - **Band-pass** – focus on the frequency of interest and remove the rest. More suitable for relatively narrow frequency ranges.



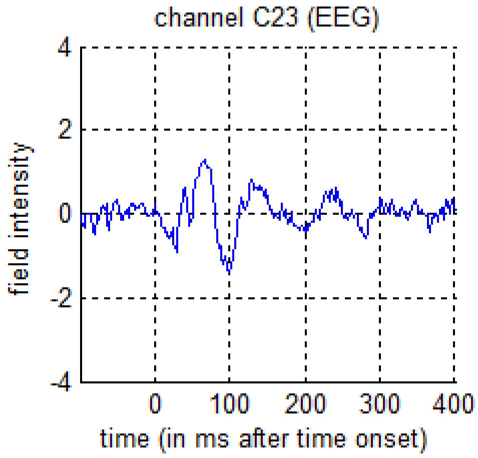
Filtering examples



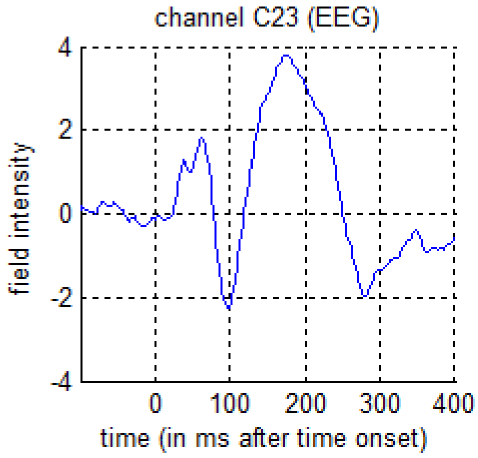
Unfiltered



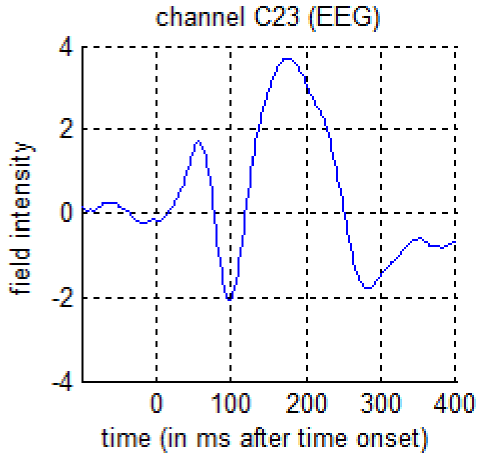
5Hz high-pass



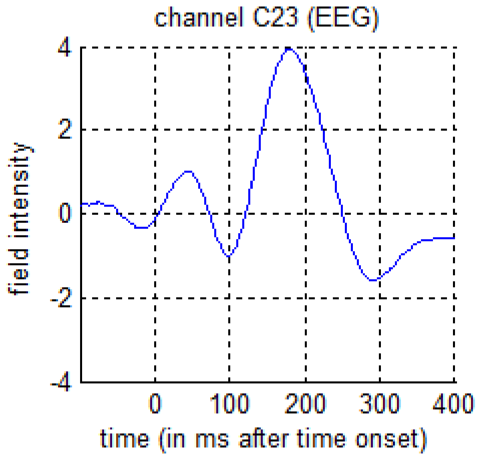
10Hz high-pass



45Hz low-pass



20Hz low-pass



10Hz low-pass

Downsampling

- Sampling rate: speed at which your data is recorded/sampled

- PROS:
  - Speeds up analysis
- CONS:
  - Aliasing: an effect that causes different signals to become indistinguishable (or aliases of one another) when sampled
  - Nyquist Frequency: Highest frequency that can be resolved without alisasing= ½ of sampling rate

Epoching

Extracting segments around events

- What: event type, coded event value
- When: onset/offset time of events

Need to define:

- Segment borders
- Trial type (can be different triggers => single trial type)
- Shift of time zero of the trial with respect to the trigger (no shift by default)

Note for SPM:

- only supports fixed length trials
- Performs baseline correction during epoching using negative times

Re-referencing

- In EEG, voltages recorded at each electrode are relative to voltages recorded at other electrodes.

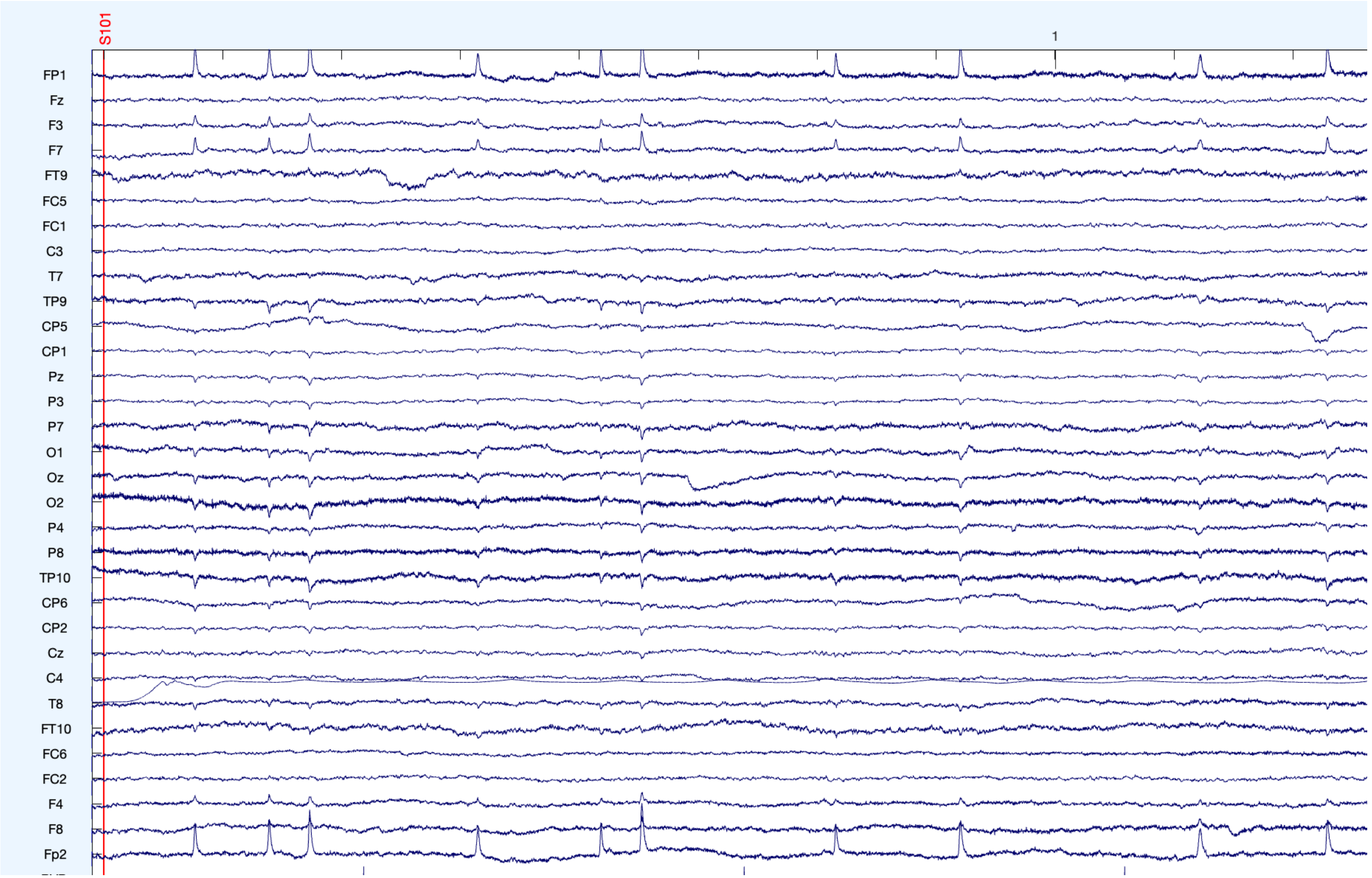
- Best practice to use a common electrode to reference all electrodes E.g. (average of) mastoids or Cz
- Can also use average of all channels, but harder to detect subtler voltage changes

- Montage function can apply any linear weighting to the channels & has a wider range of applications.

Independent component analysis

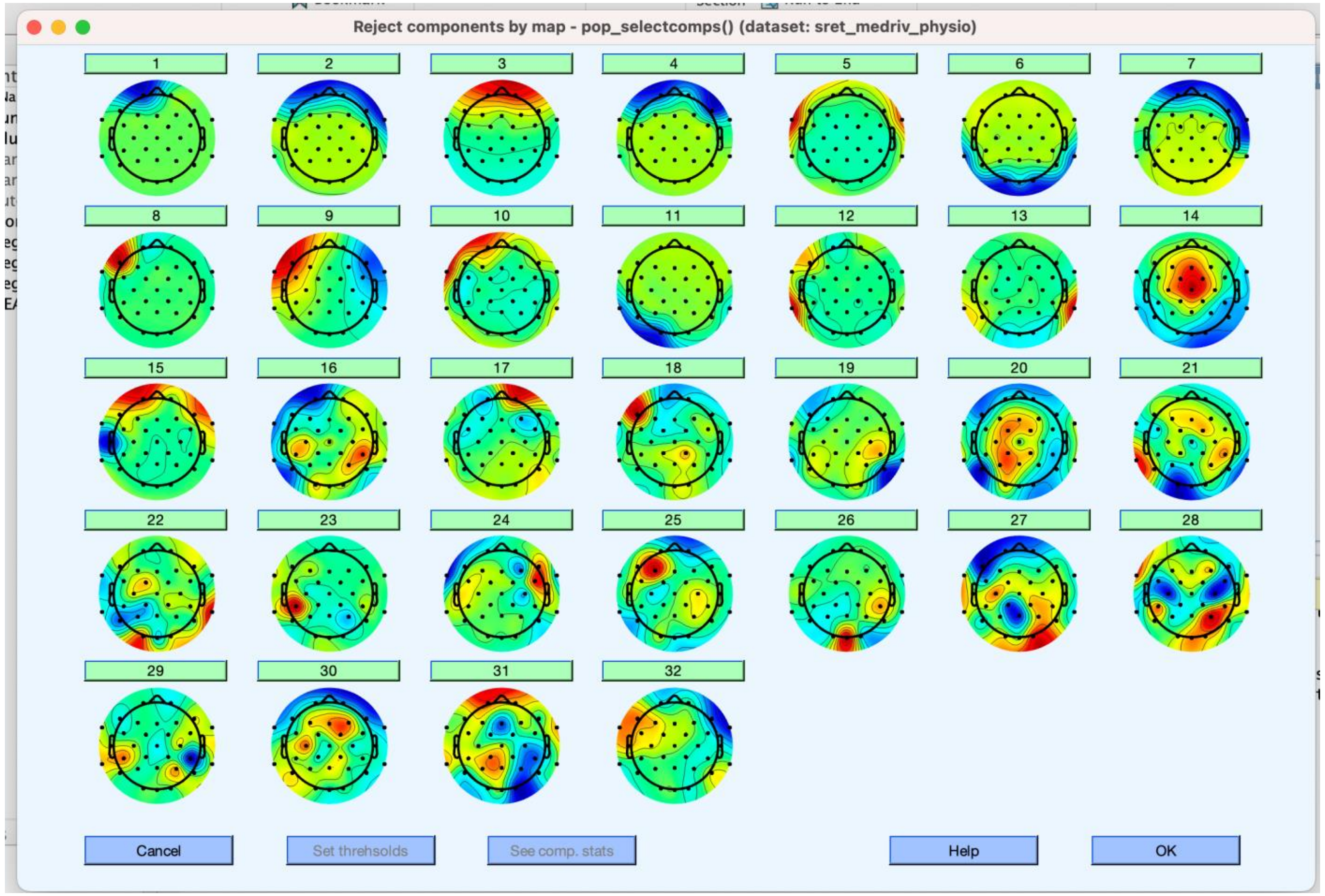
- Decompose data into different components

- Option not available in SPM



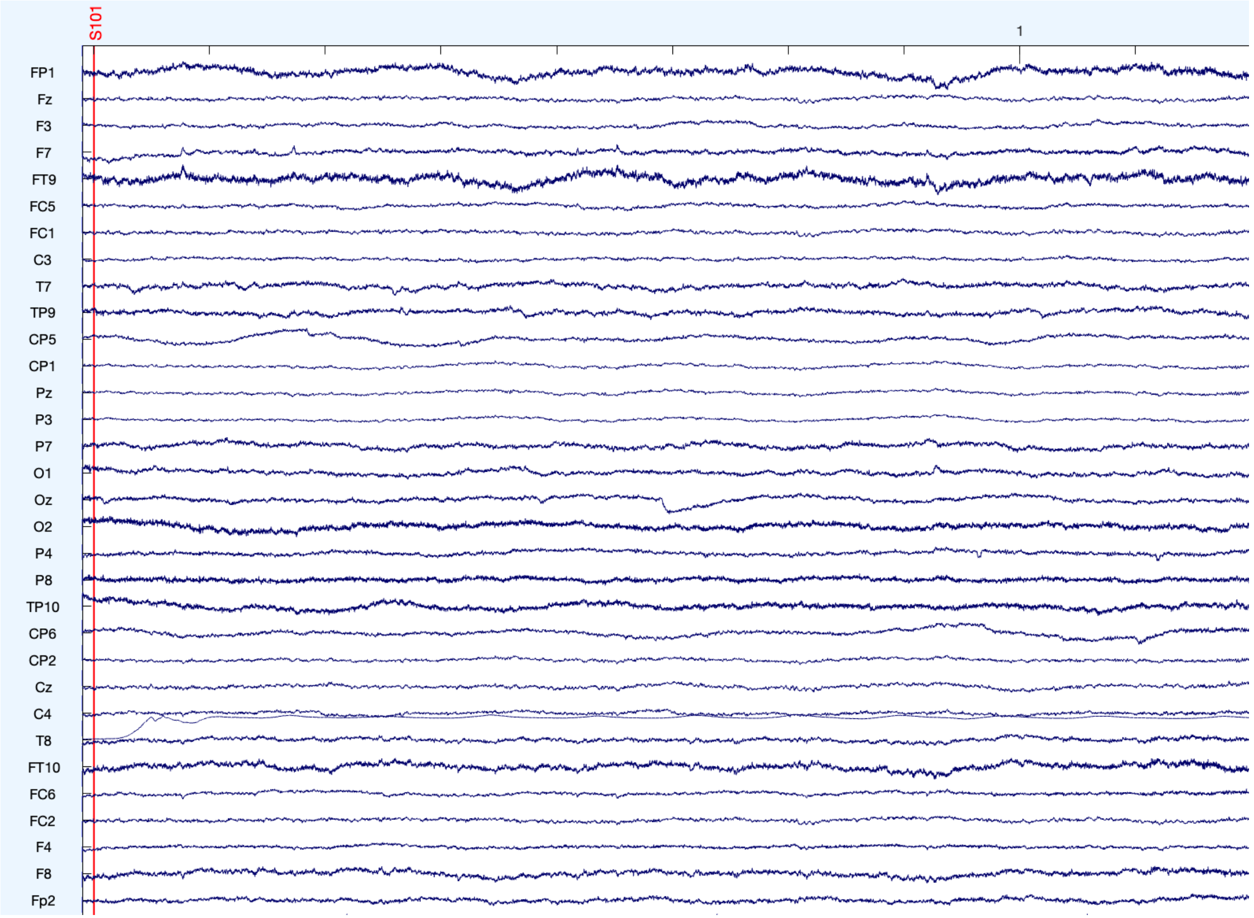
Independent component analysis

- Identify components to reject
- e.g., eye blinks are observed at frontal electrodes



Independent component analysis

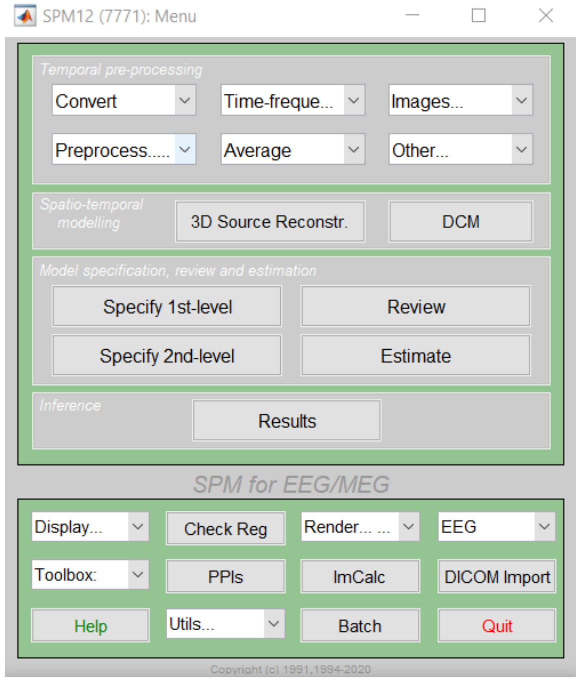
- After eye blink component removal



An Introduction to the SPM Interface

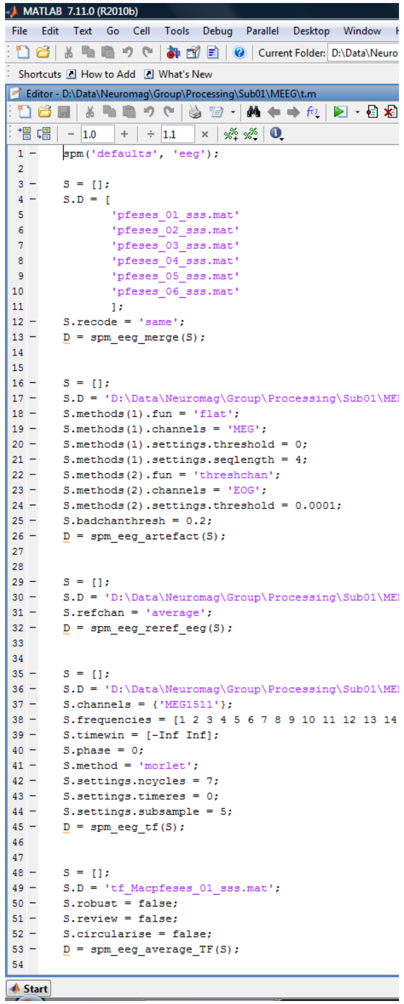
SPM interfaces

GUI

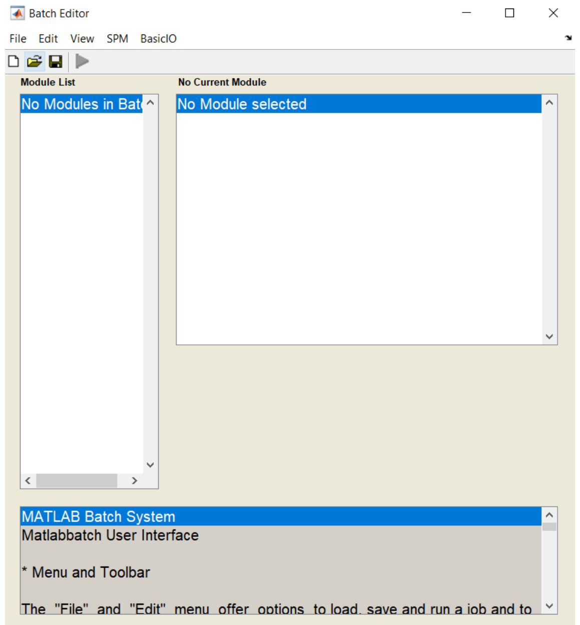


spm eeg

Script

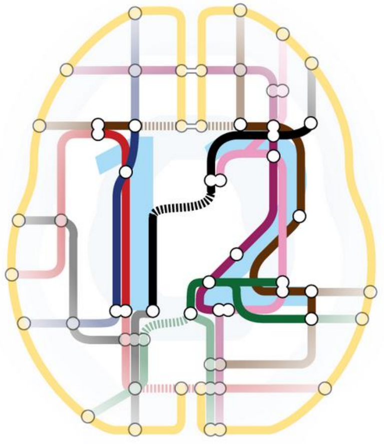


Batch



Accessed via GUI

Can be saved and run within MATLAB script

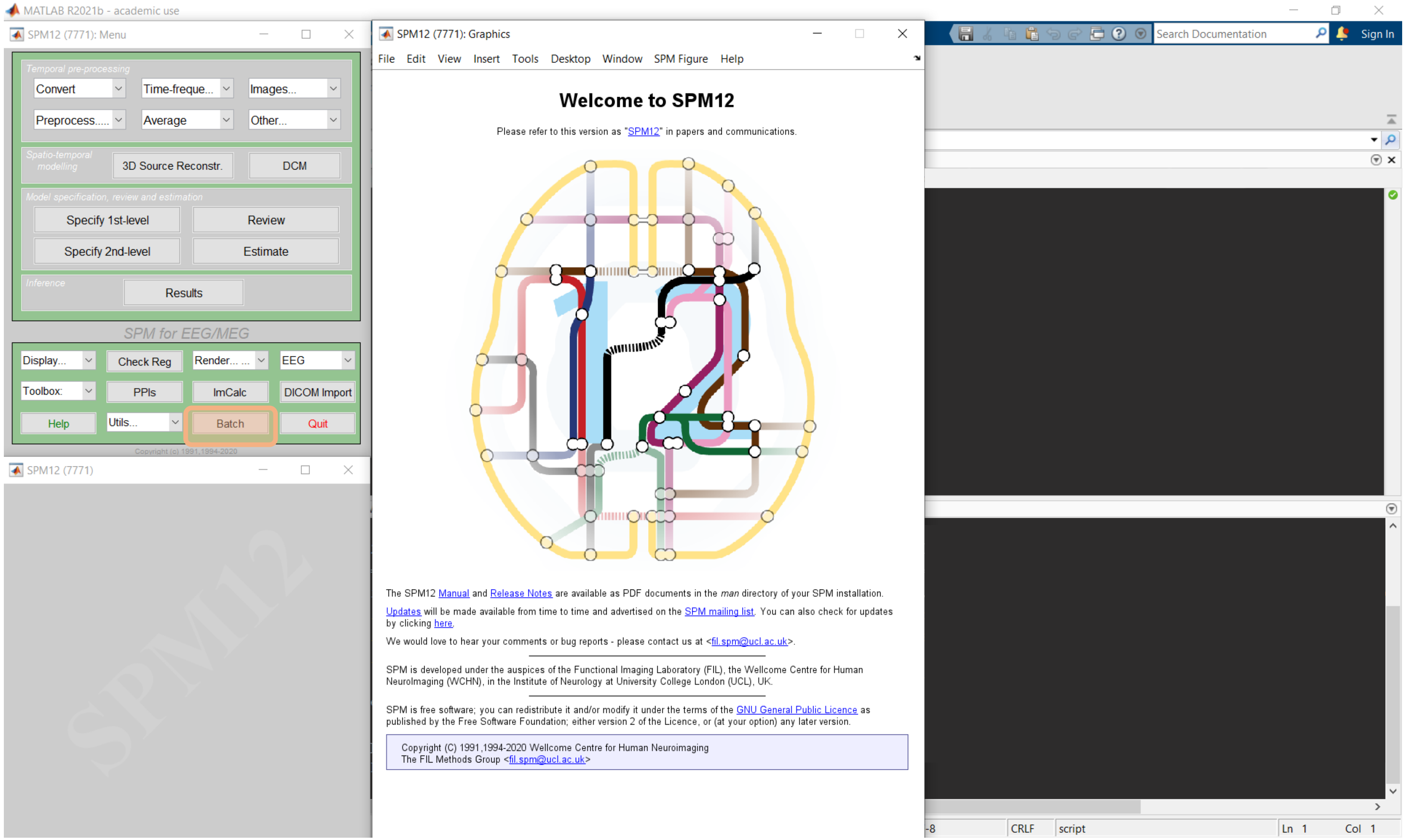


Add SPM to your MATLAB path

- SPMpath = ‘D:\spm12’;
- addpath(SPMpath);
- spm (‘defaults’, ‘eeg’)
- spm eeg

- IMPORTANT→ Make sure your path has just been cleared and do not put different imaging toolboxes in the same folder as they might interfere – causing crashes!

Open SPM



MATLAB R2021b - academic use
SPM12 (7771): Menu
Temporal pre-processing
Convert
Time-freque...
Images...
Preprocess.....
Average
Other...
Spatio-temporal modelling
3D Source Reconstr.
DCM
Model specification, review and estimation
Specify 1st-level
Review
Specify 2nd-level
Estimate
Inference
Results
SPM for EEG/MEG
Display...
Check Reg
Render... ...
EEG
Toolbox:
PPIs
ImCalc
DICOM Import
Help
Utils...
Batch
Quit
SPM12 (7771)
SPM12
SPM12 (7771): Graphics
File Edit View Insert Tools Desktop Window SPM Figure Help
Welcome to SPM12
Please refer to this version as "SPM12" in papers and communications.
The SPM12 Manual and Release Notes are available as PDF documents in the man directory of your SPM installation.
Updates will be made available from time to time and advertised on the SPM mailing list. You can also check for updates by clicking here.
We would love to hear your comments or bug reports - please contact us at <fil.spm@ucl.ac.uk>.
SPM is developed under the auspices of the Functional Imaging Laboratory (FIL), the Wellcome Centre for Human NeuroImaging (WCHN), in the Institute of Neurology at University College London (UCL), UK.
SPM is free software; you can redistribute it and/or modify it under the terms of the GNU General Public Licence as published by the Free Software Foundation; either version 2 of the Licence, or (at your option) any later version.
Copyright (C) 1991,1994-2020 Wellcome Centre for Human Neuroimaging
The FIL Methods Group <fil.spm@ucl.ac.uk>
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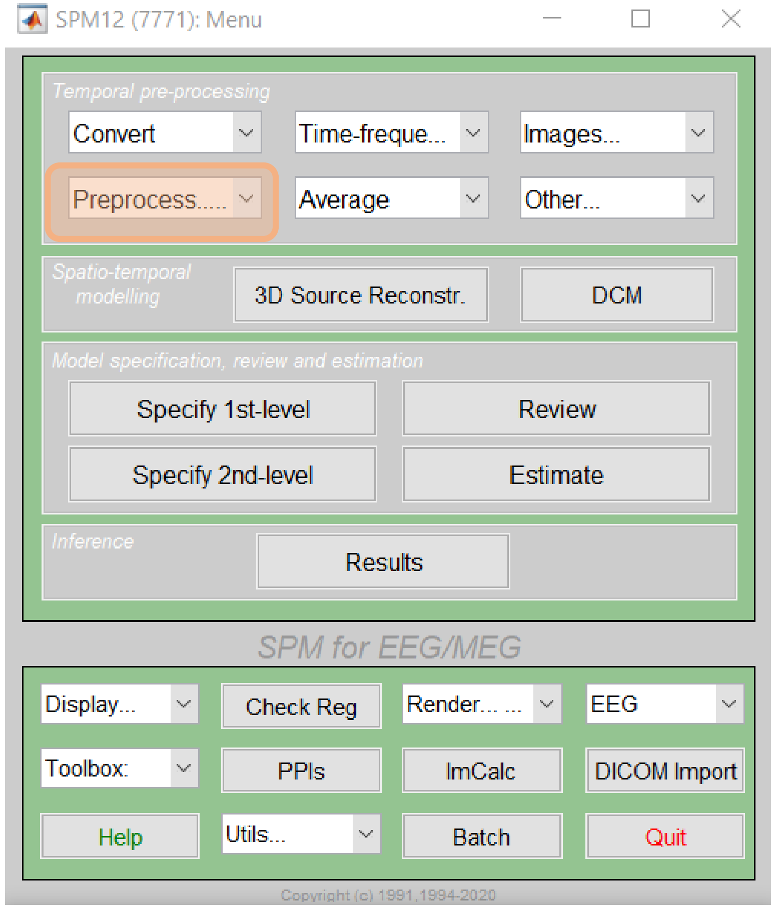
script
Ln 1
Col 1

Steps to cover

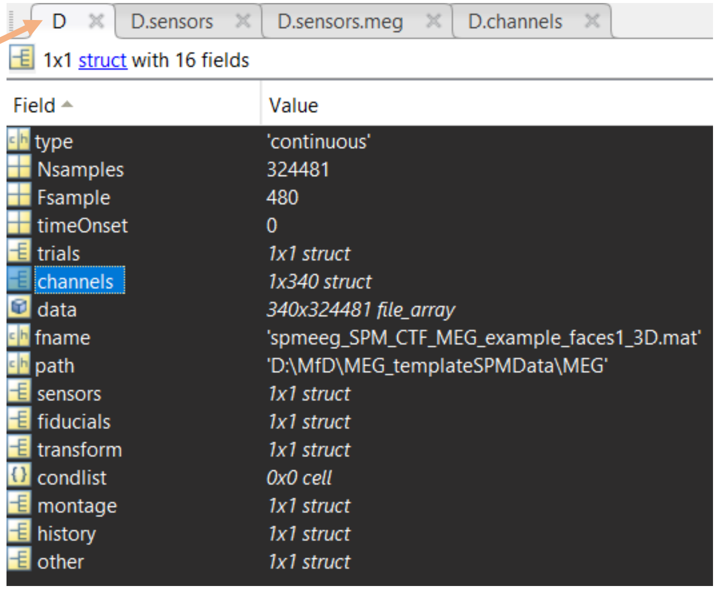
1. Conversion
2. Filtering
3. Downsampling
4. Epoching
5. Re-referencing for EEG
6. Artefacts correction
7. Averaging

spm_eeg_convert



Properties of M/EEG dataset

– The *.mat file contains a struct, named D, which is converted to an meeg object by **spm_eeg_load.**
  – Contains header information – sampling rate, channel information, trial information, etc.



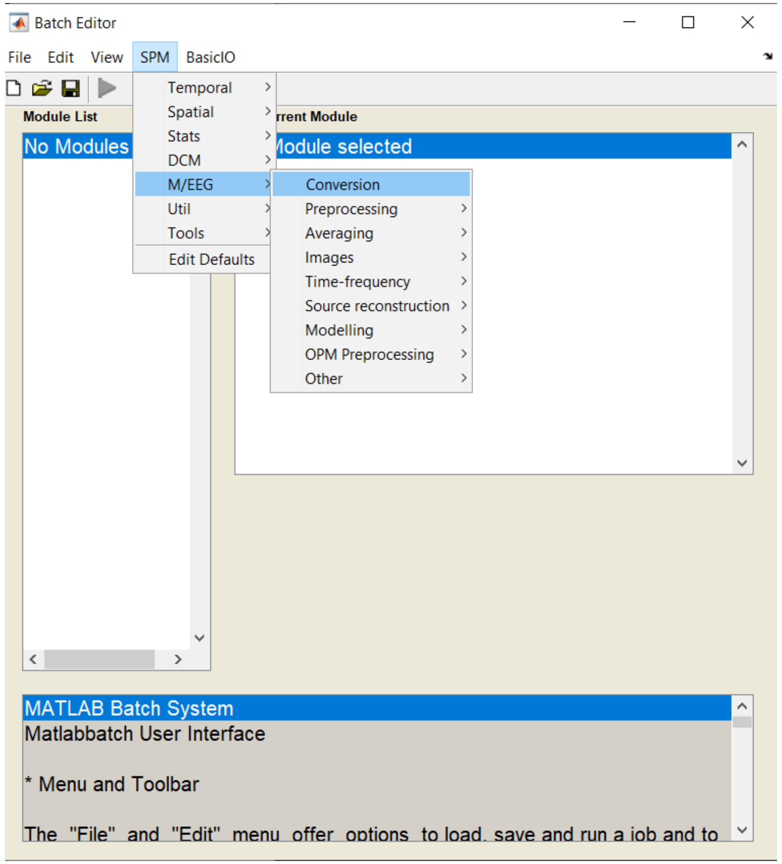
D | D.sensors | D.sensors.meg | D.channels

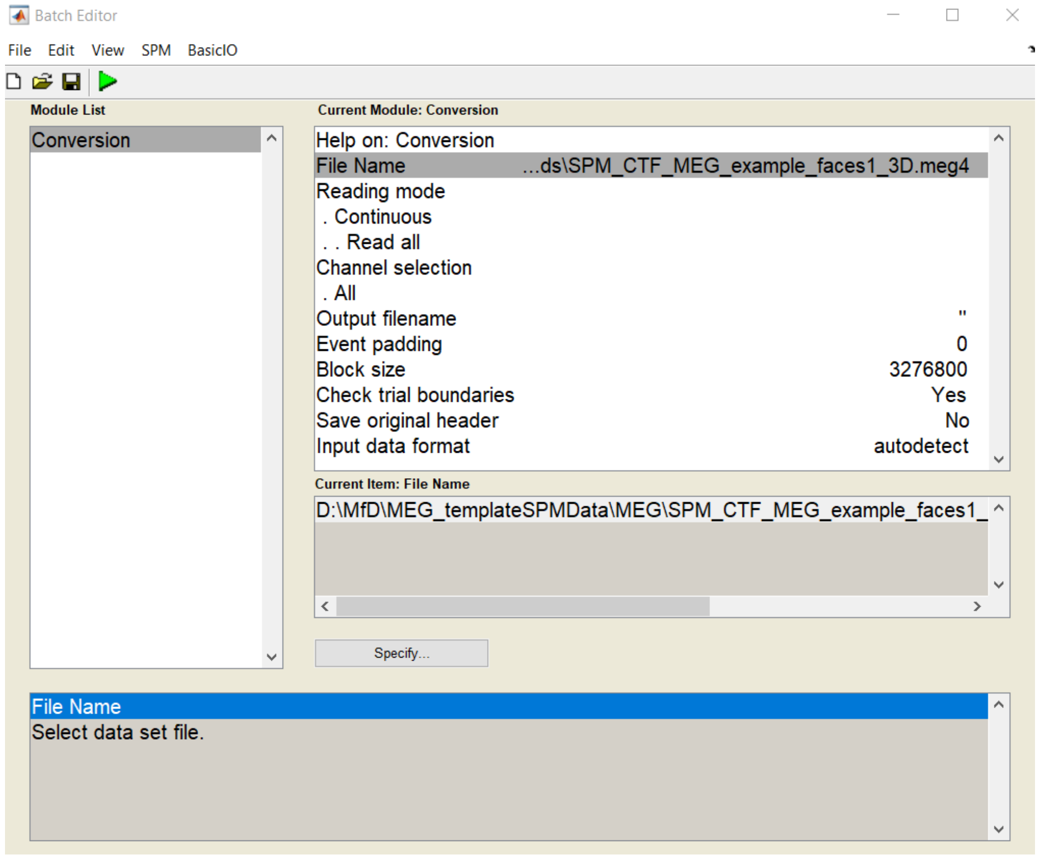
1x1 struct with 16 fields

Field	Value
type	'continuous'
Nsamples	324481
Fsample	480
timeOnset	0
trials	*1x1 struct*
channels	*1x340 struct*
data	*340x324481 file_array*
fname	'spmeeg_SPM_CTF_MEG_example_faces1_3D.mat'
path	'D:\MfD\MEG_templateSPMData\MEG'
sensors	*1x1 struct*
fiducials	*1x1 struct*
transform	*1x1 struct*
condlist	*0x0 cell*
montage	*1x1 struct*
history	*1x1 struct*
other	*1x1 struct*

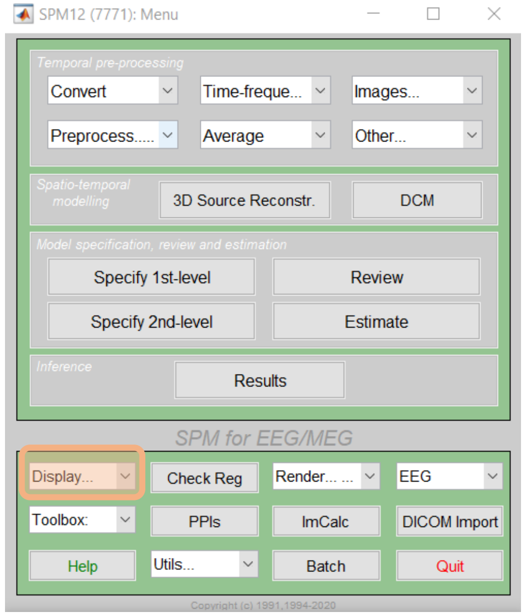
– The *.dat file contains the raw binary data, is memory-mapped and linked to the object in order to save memory.

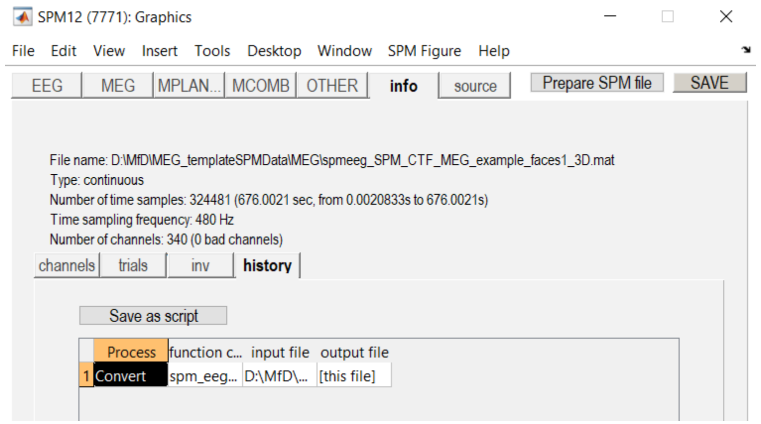
Conversion

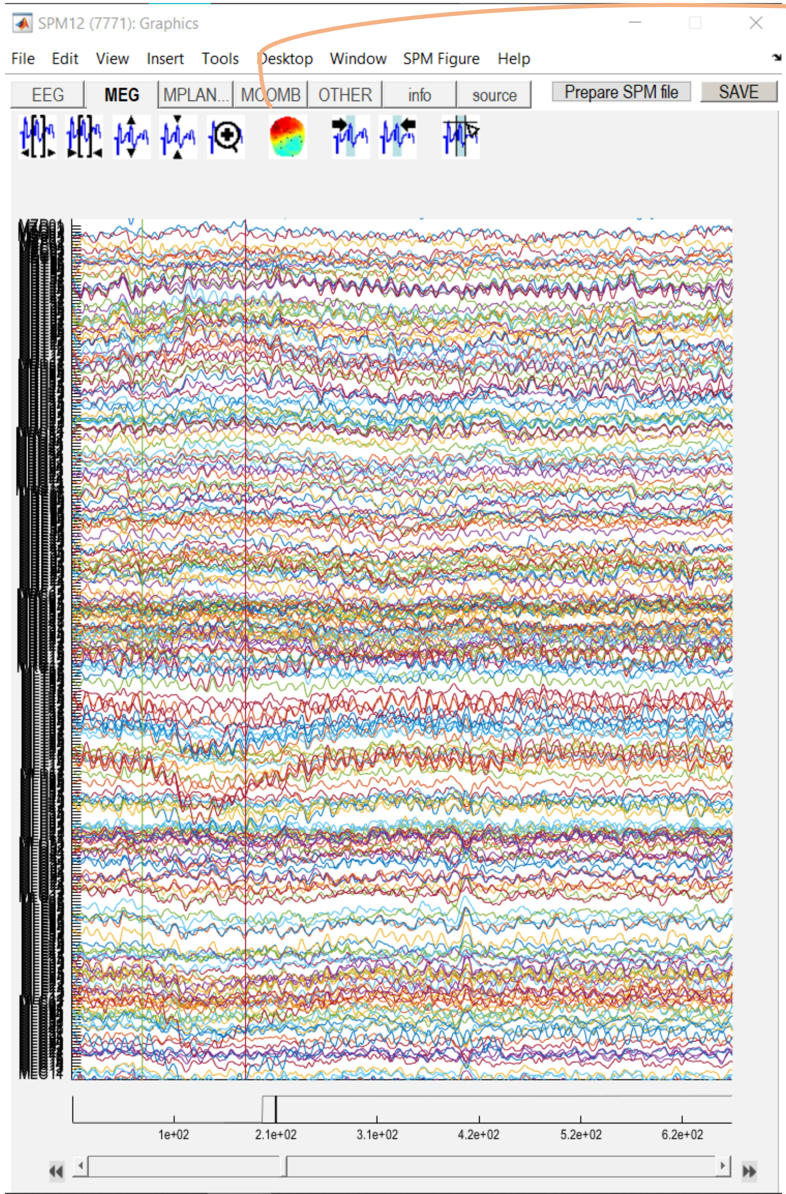

Batch Editor
File Edit View SPM BasicIO
Temporal
Spatial
Stats
DCM
M/EEG
Util
Tools
Edit Defaults
Conversion
Preprocessing
Averaging
Images
Time-frequency
Source reconstruction
Modelling
OPM Preprocessing
Other
Module List
No Modules
rrent Module
Module selected
MATLAB Batch System
Matlabbatch User Interface
* Menu and Toolbar
The "File" and "Edit" menu offer options to load, save and run a job and to

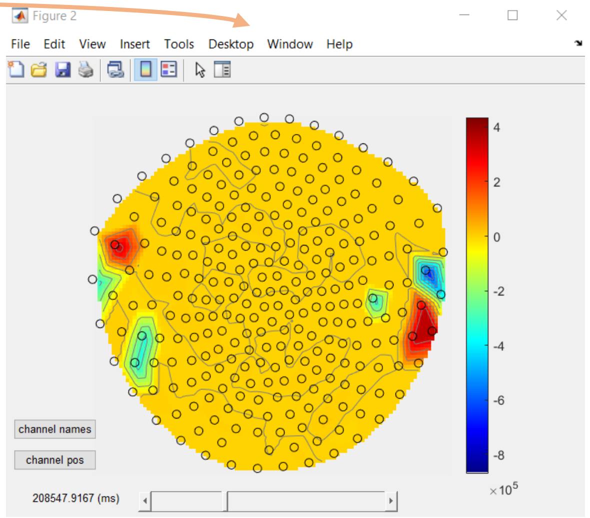

Batch Editor
File Edit View SPM BasicIO
Module List
Conversion
Current Module: Conversion
Help on: Conversion
File Name ...ds\SPM_CTF_MEG_example_faces1_3D.meg4
Reading mode
. Continuous
. . Read all
Channel selection
. All
Output filename ''
Event padding 0
Block size 3276800
Check trial boundaries Yes
Save original header No
Input data format autodetect
Current Item: File Name
D:\MfD\MEG_templateSPMData\MEG\SPM_CTF_MEG_example_faces1_
Specify...
File Name
Select data set file.

Data visualisation





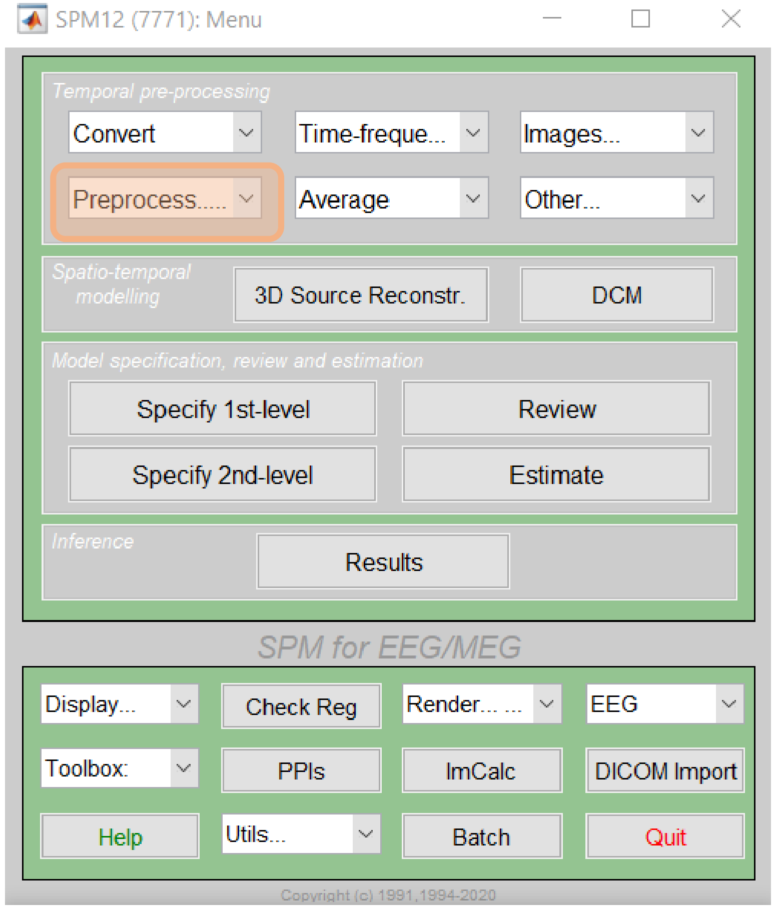




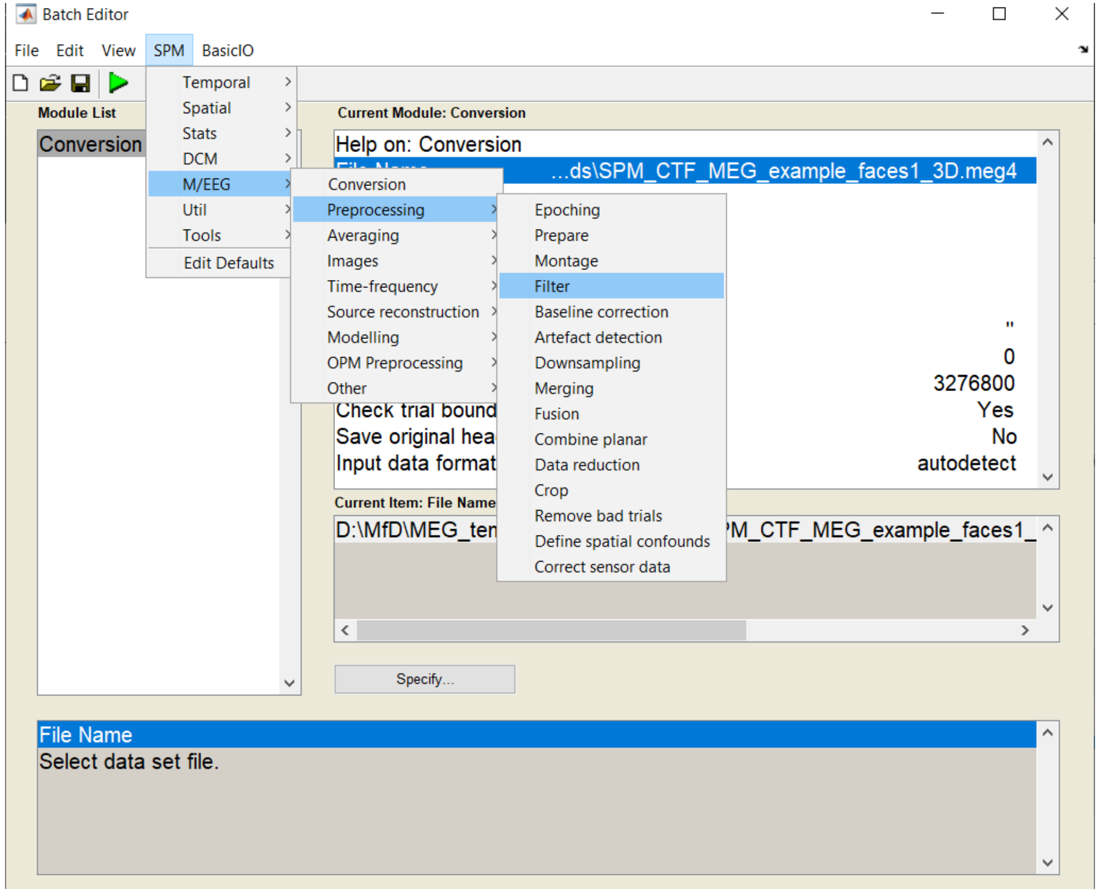
Filtering

1. Conversion
2. **Filtering**
3. Downsampling
4. Epoching
5. Re-referencing for EEG
6. Artefacts correction
7. Averaging

spm_eeg_filter



Filtering


Batch Editor
File Edit View SPM BasicIO
Module List
Conversion
Temporal
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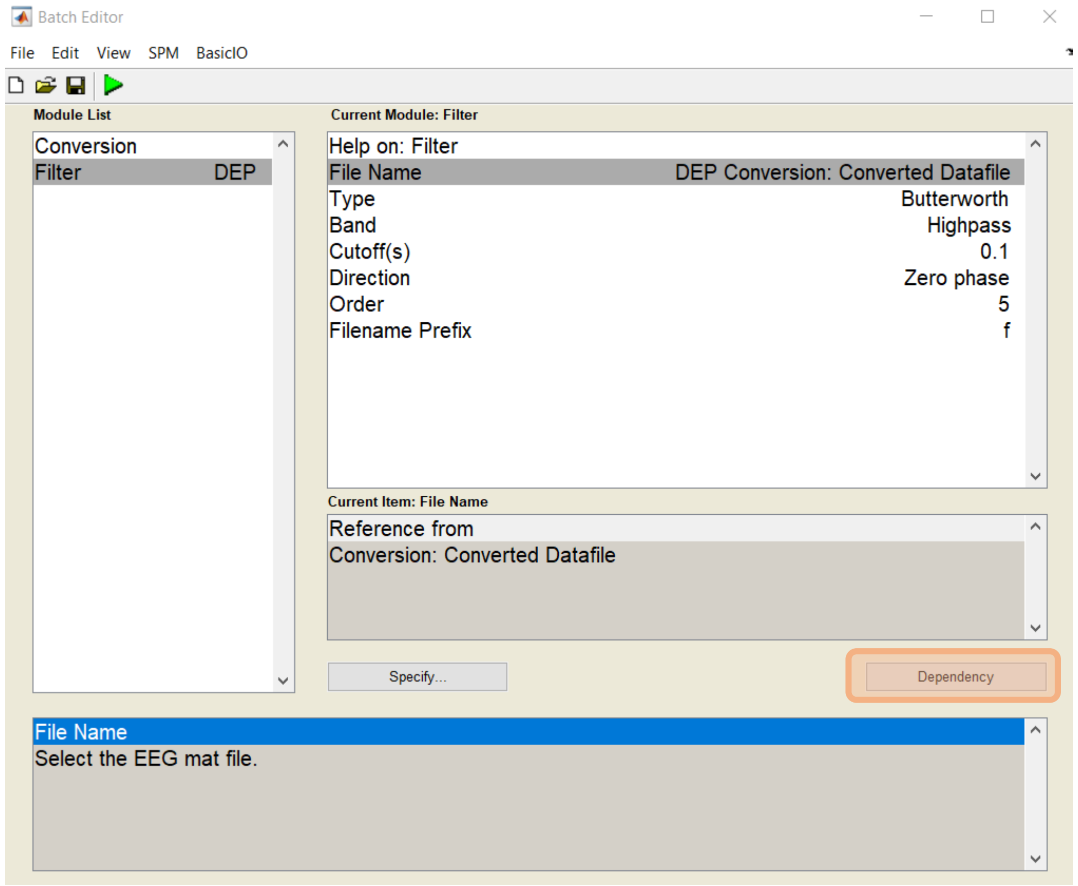
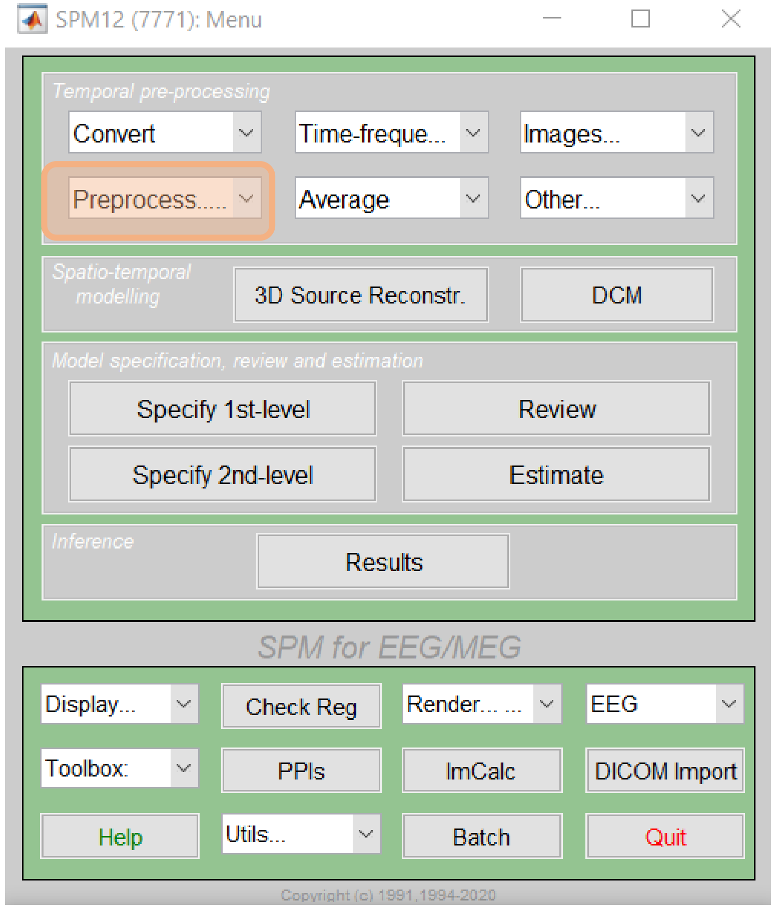
M/EEG
Util
Tools
Edit Defaults
Conversion
Preprocessing
Averaging
Images
Time-frequency
Source reconstruction
Modelling
OPM Preprocessing
Other
Epoching
Prepare
Montage
Filter
Baseline correction
Artefact detection
Downsampling
Merging
Fusion
Combine planar
Data reduction
Crop
Remove bad trials
Define spatial confounds
Correct sensor data
Current Module: Conversion
Help on: Conversion
...ds\SPM_CTF_MEG_example_faces1_3D.meg4
0
3276800
Check trial bound
Yes
Save original hea
No
Input data format
autodetect
Current Item: File Name
D:\MfD\MEG_ten
M_CTF_MEG_example_faces1_
Specify...
File Name
Select data set file.


Batch Editor
File Edit View SPM BasicIO
Module List
Conversion
Filter DEP
Current Module: Filter
Help on: Filter
File Name DEP Conversion: Converted Datafile
Type Butterworth
Band Highpass
Cutoff(s) 0.1
Direction Zero phase
Order 5
Filename Prefix f
Current Item: File Name
Reference from
Conversion: Converted Datafile
Specify...
Dependency
File Name
Select the EEG mat file.

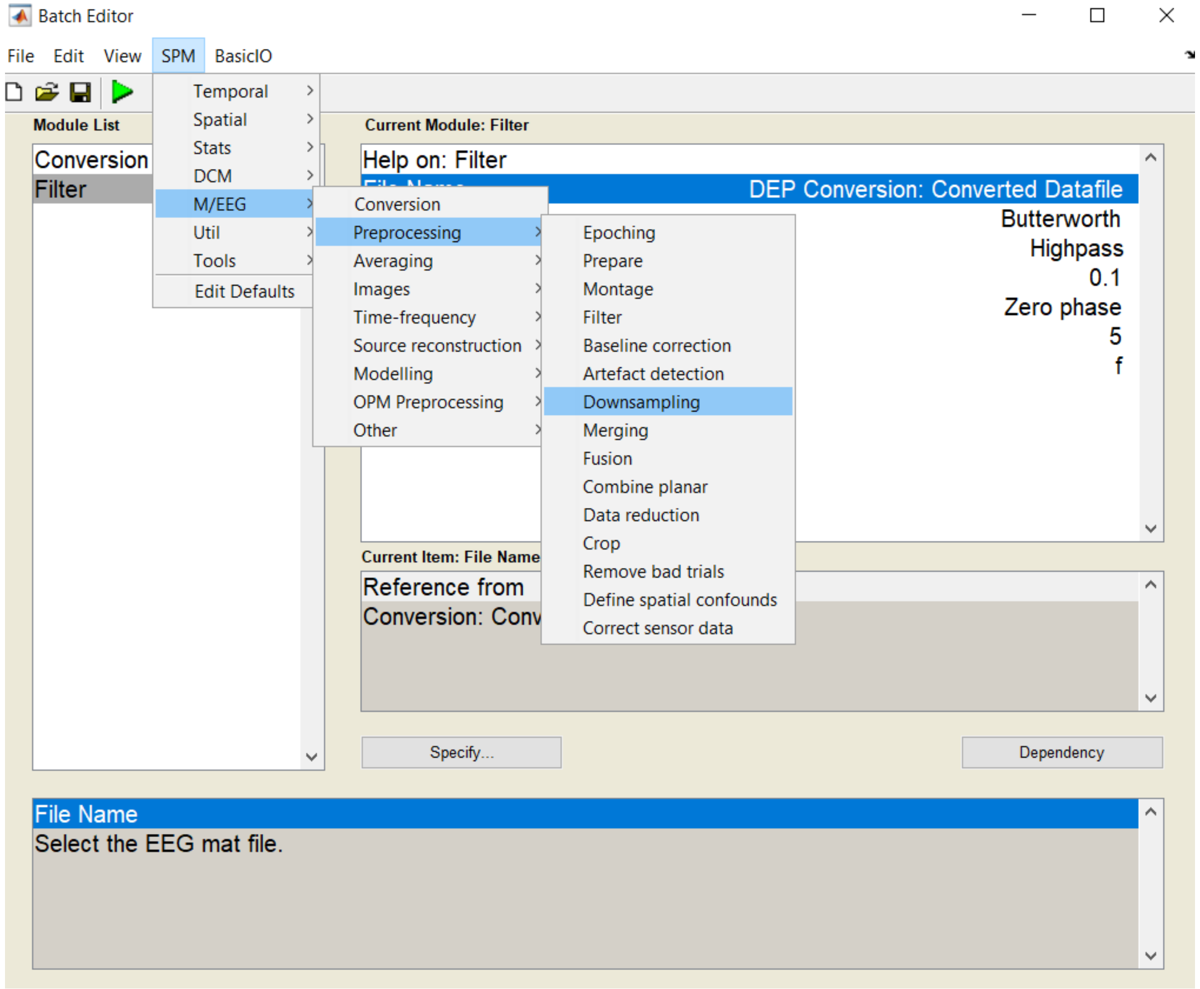
Downsampling

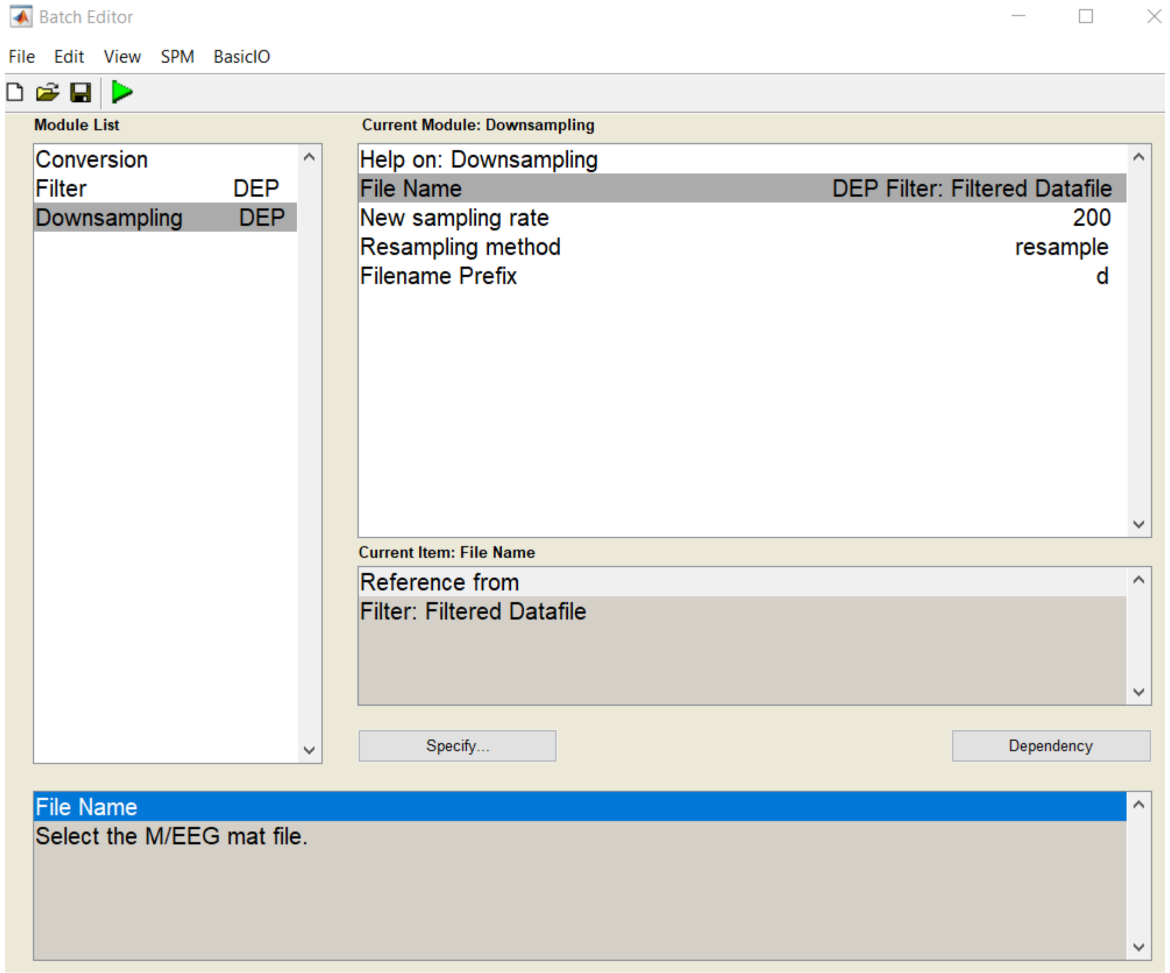
1. Converting
2. Filtering
3. **Downsampling**
4. Epoching
5. Re-referencing for EEG
6. Artefacts correction
7. Averaging

spm_eeg_downsample



Downsampling

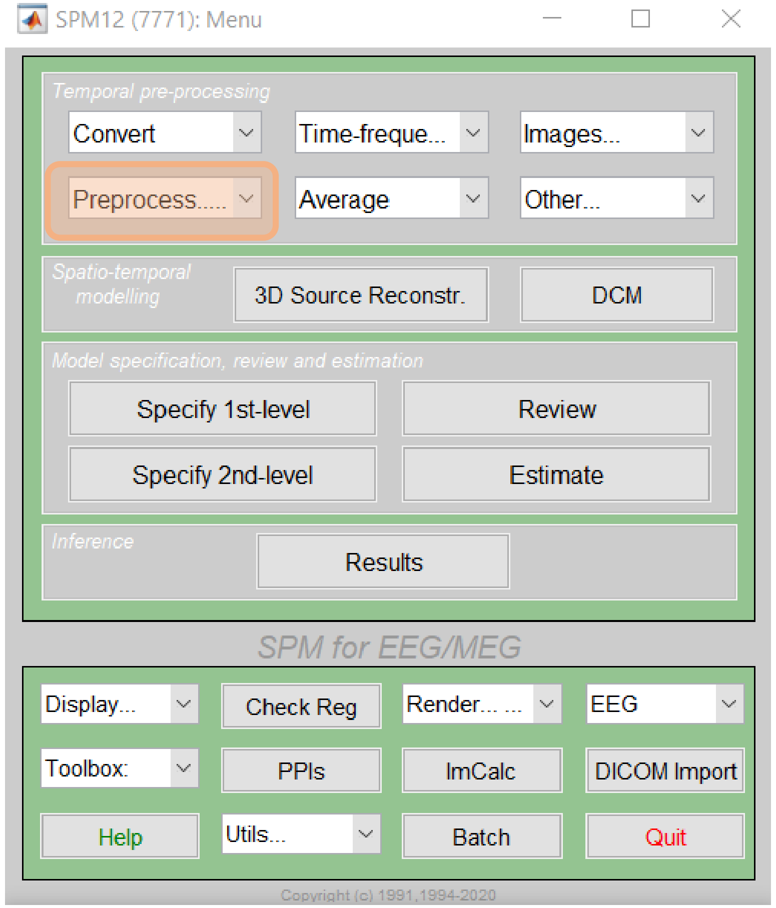




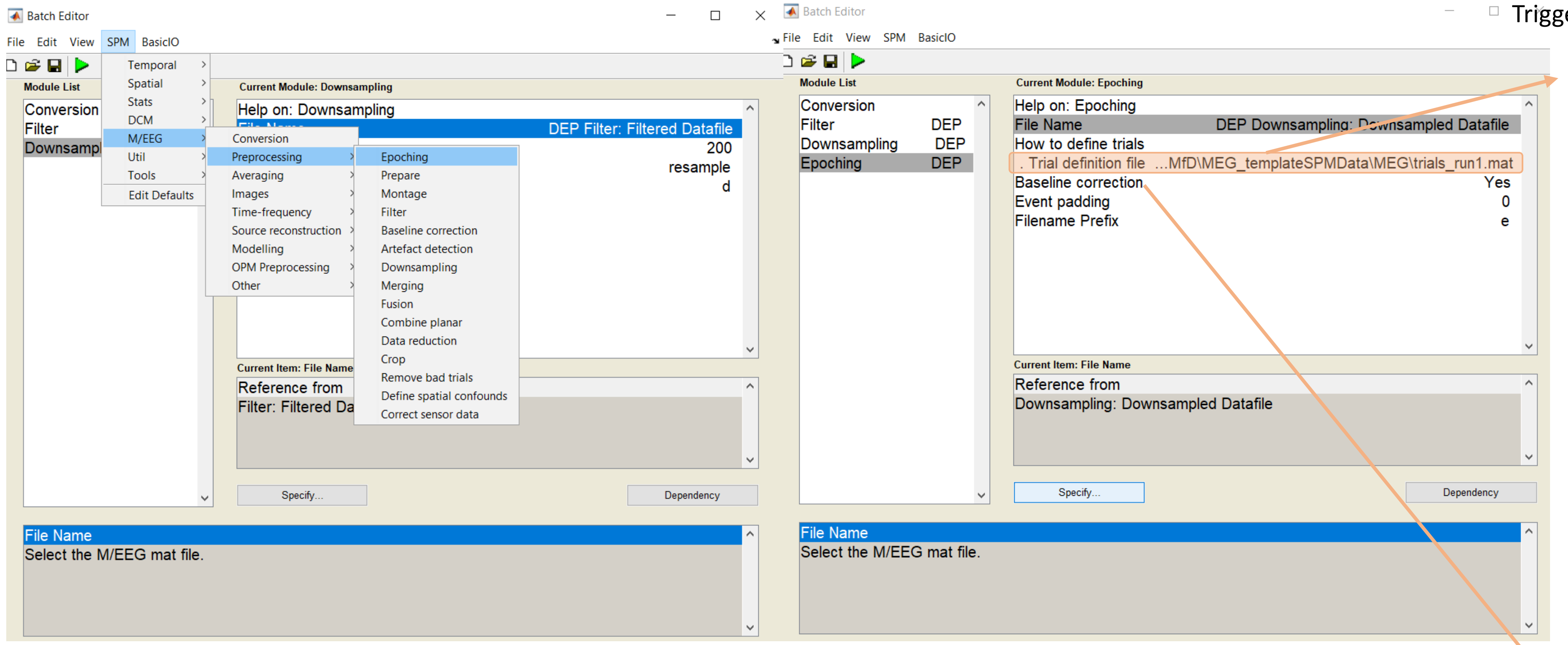
Epoching

1. Converting
2. Filtering
3. Downsampling
4. Epoching
5. Re-referencing for EEG
6. Artefacts correction
7. Averaging

spm_eeg_epochs



Epoching



Trigger start | end | offset

trl — 168x3 double

	1	2	3
1	8856	9240	-96
2	10597	10981	-96
3	12330	12714	-96
4	14063	14447	-96
5	15789	16173	-96
6	17522	17906	-96
7	19255	19639	-96
8	20988	21372	-96
9	22729	23113	-96
10	24454	24838	-96
11	26188	26572	-96
12	27929	28313	-96
13	29654	30038	-96
14	31387	31771	-96
15	33128	33512	-96
16	34862	35246	-96
17	36587	36971	-96
18	38328	38712	-96
19	40053	40437	-96
20	41794	42178	-96

conditionlabels — 168x1 cell

	1	2	3
1	faces		
2	faces		
3	scrambled		
4	scrambled		
5	faces		
6	scrambled		
7	scrambled		
8	scrambled		
9	faces		
10	scrambled		
11	scrambled		
12	scrambled		
13	scrambled		
14	scrambled		
15	scrambled		
16	scrambled		
17	faces		
18	scrambled		
19	scrambled		
20	faces		

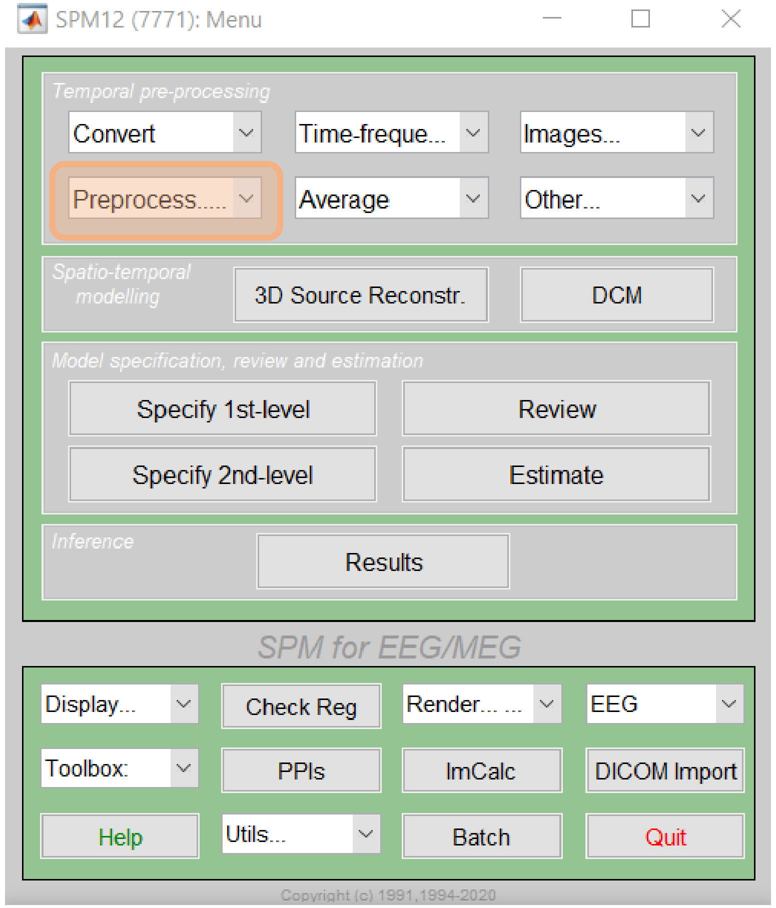
Offset - difference between the trigger value and the actual start of the trial

→ window is the baseline value (so -96 means 96 samples in each trial are considered baseline)

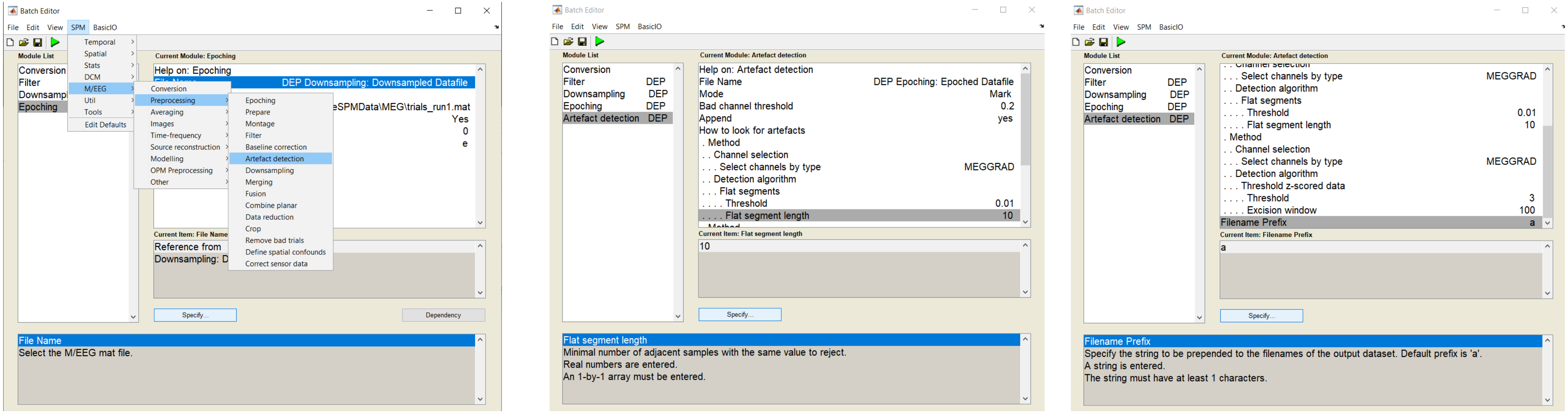
Artefacts correction

1. Converting
2. Filtering
3. Downsampling
4. Epoching
5. Re-referencing for EEG
6. **Artefacts correction**
7. Averaging

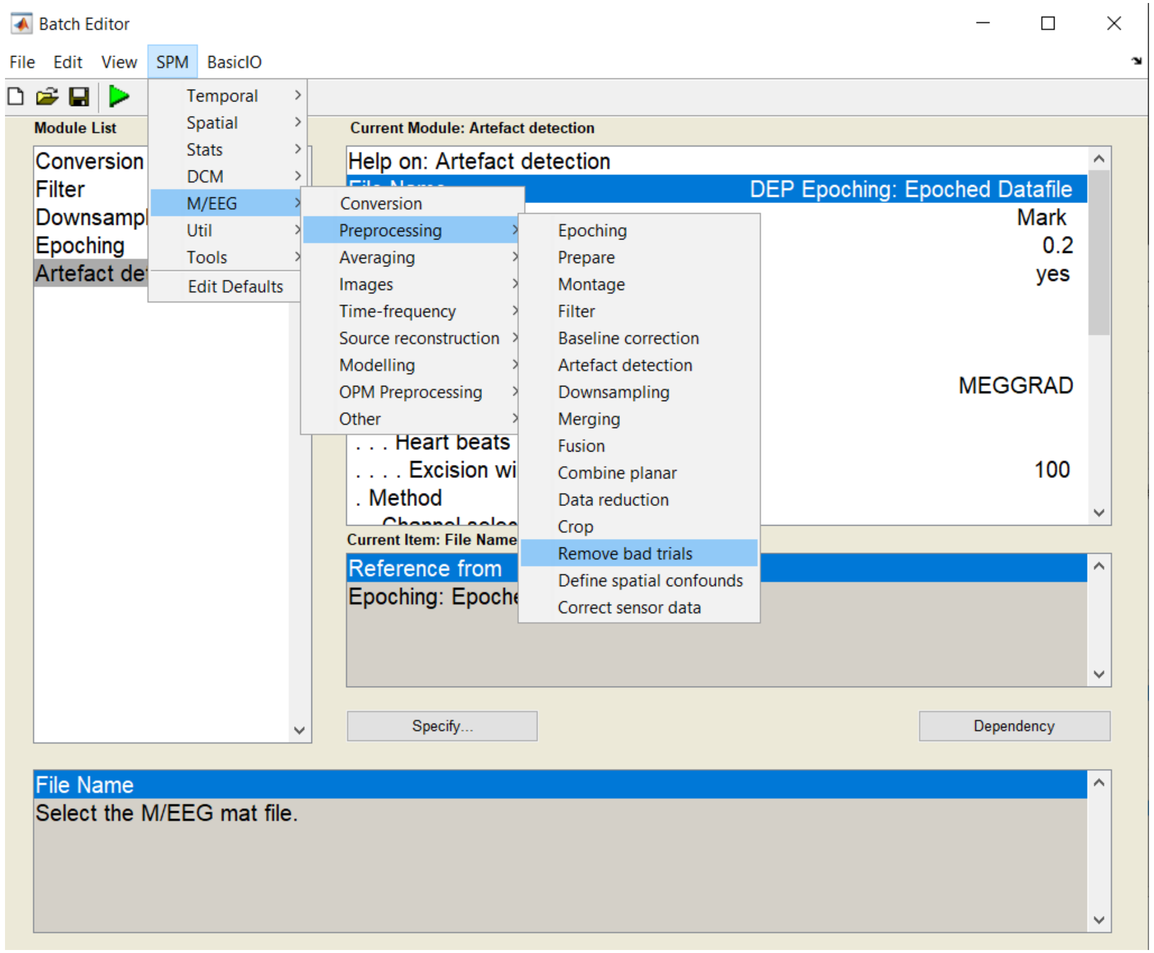
spm_eeg_artefact

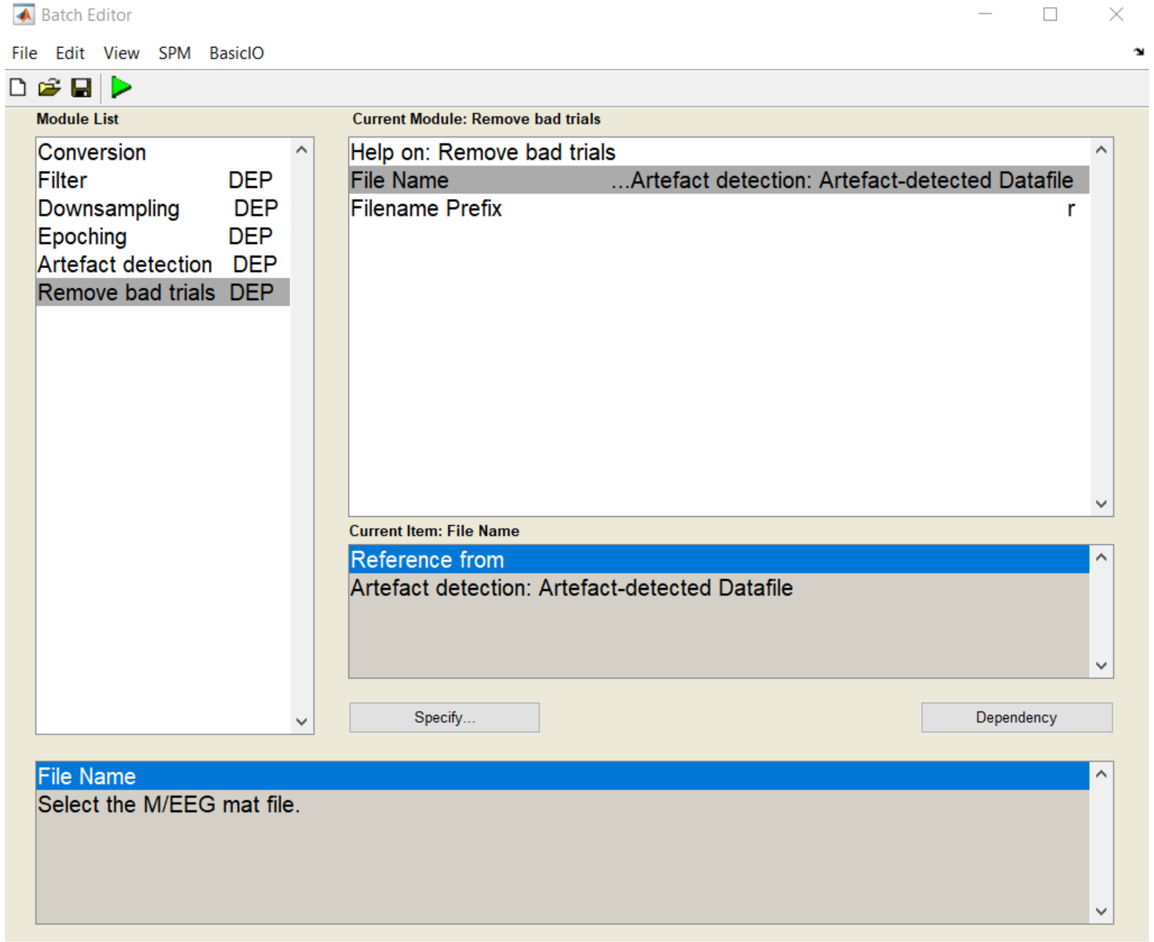


Searching for artefacts



Removing artefacts

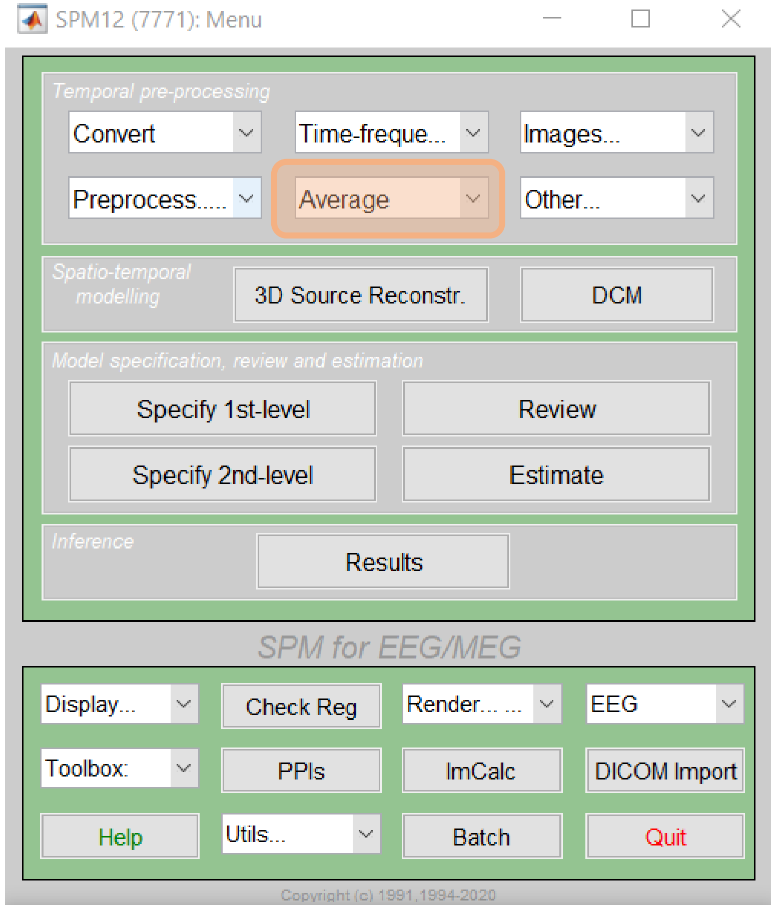




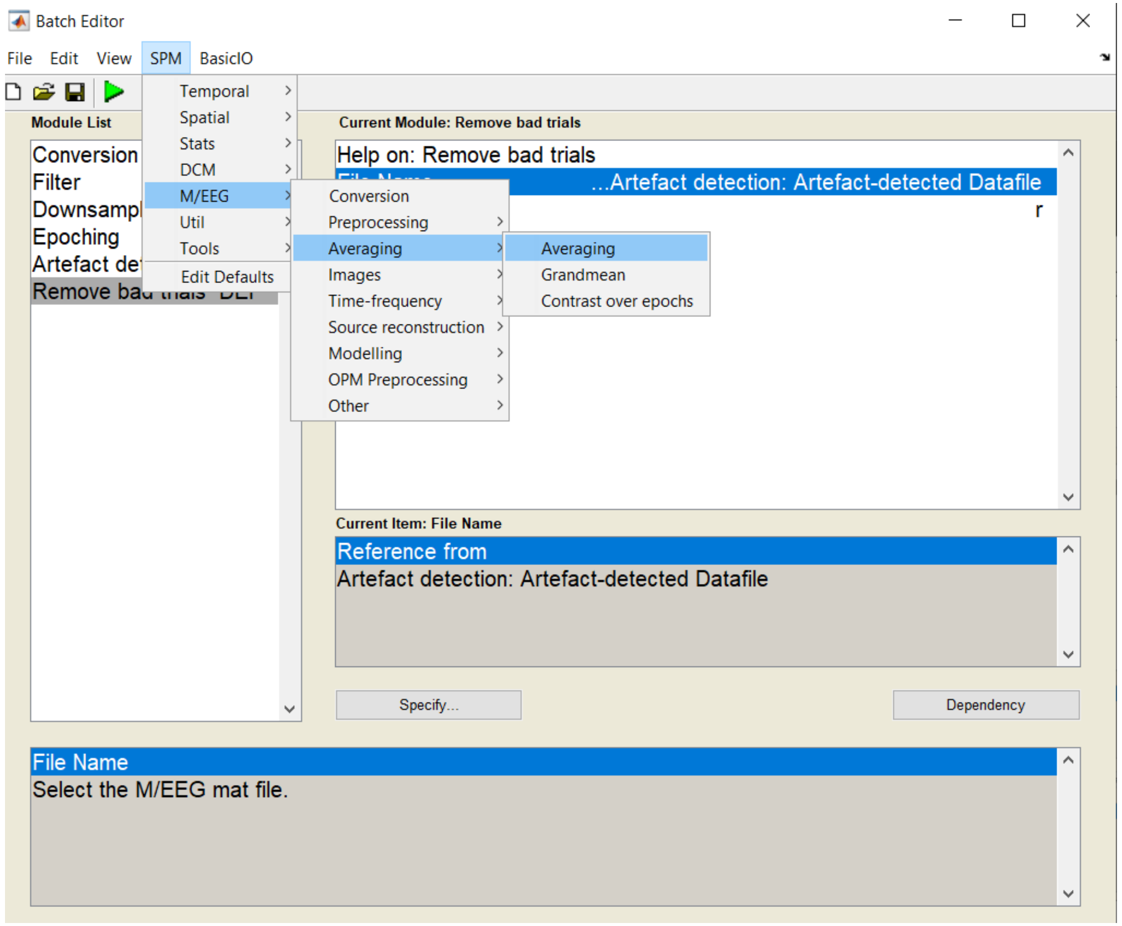
Averaging

1. Converting
2. Filtering
3. Downsampling
4. Epoching
5. Re-referencing for EEG
6. Artefacts correction
7. **Averaging**

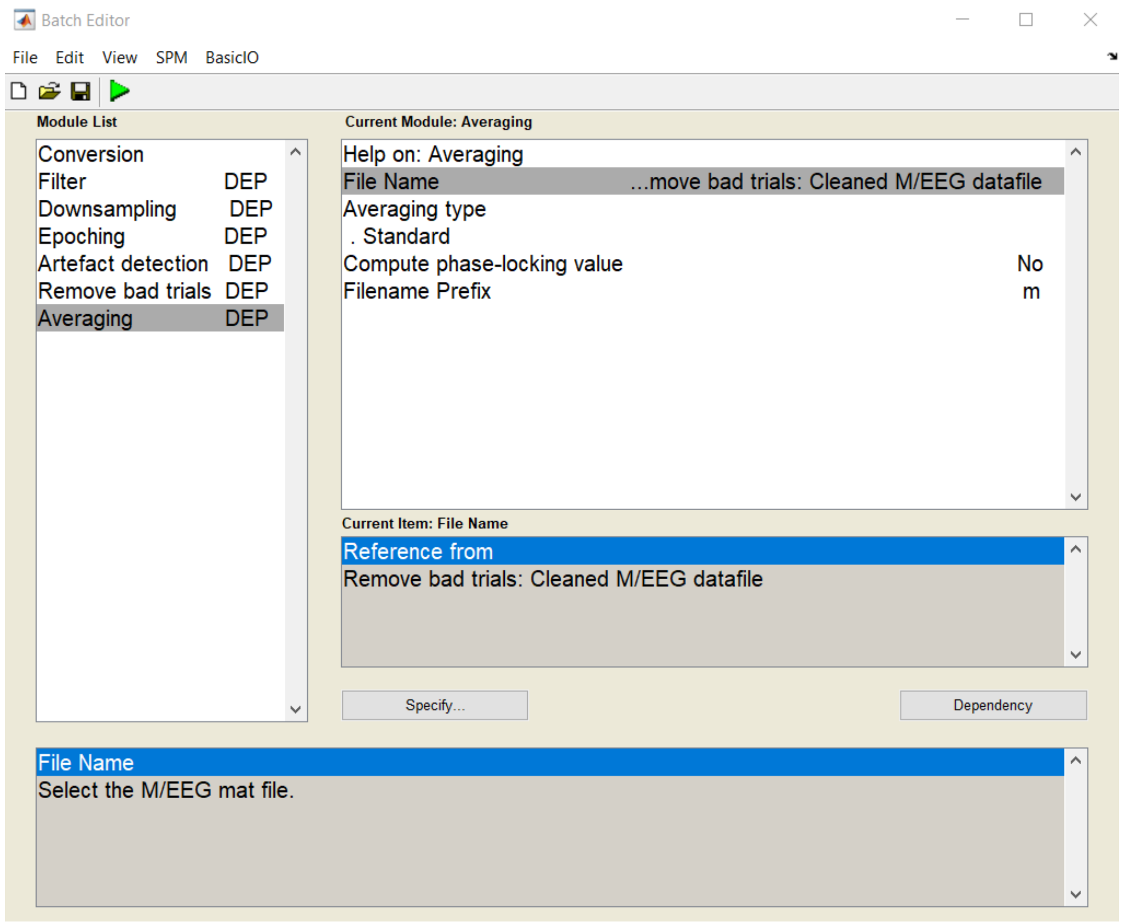
spm_eeg_average



Averaging

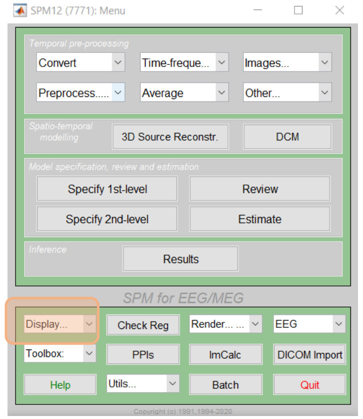


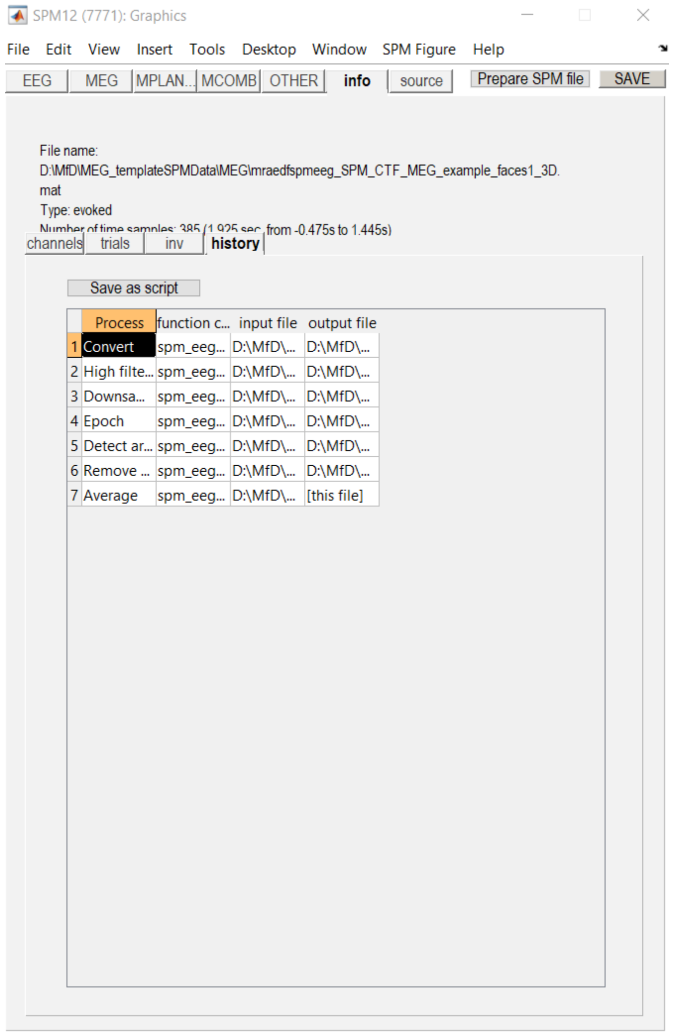
Batch Editor
File Edit View SPM BasicIO
Temporal
Spatial
Stats
DCM
M/EEG
Util
Tools
Edit Defaults
Module List
Conversion
Filter
Downsampl
Epoching
Artefact de
Remove bad trials DEP
Current Module: Remove bad trials
Help on: Remove bad trials
...Artefact detection: Artefact-detected Datafile
Conversion
Preprocessing
Averaging
Images
Time-frequency
Source reconstruction
Modelling
OPM Preprocessing
Other
Averaging
Grandmean
Contrast over epochs
Current Item: File Name
Reference from
Artefact detection: Artefact-detected Datafile
Specify...
Dependency
File Name
Select the M/EEG mat file.

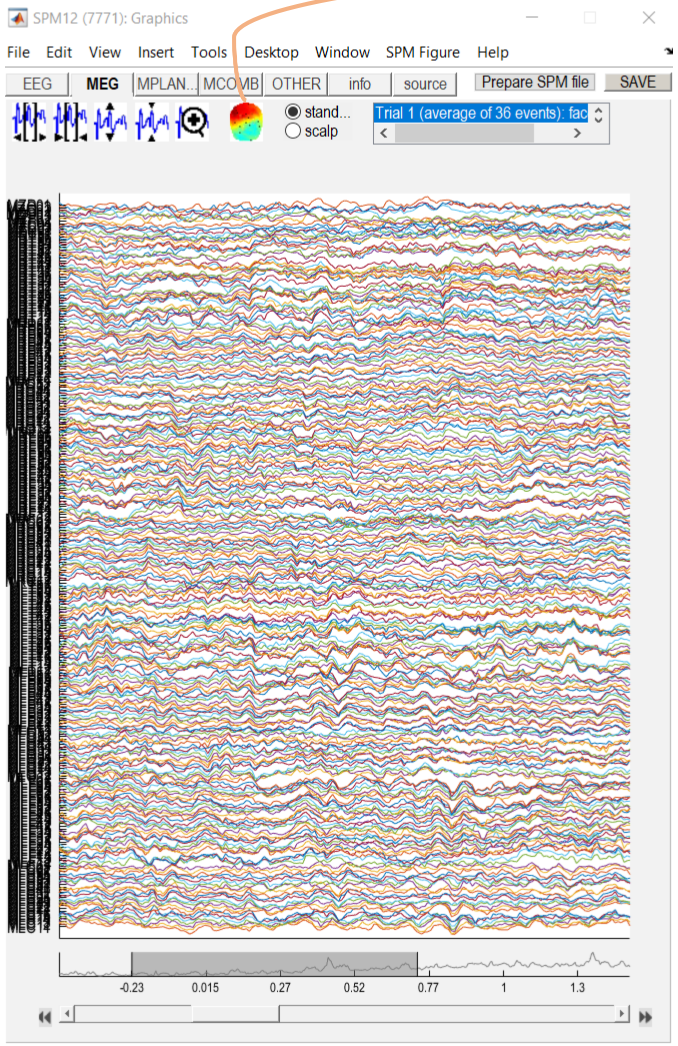


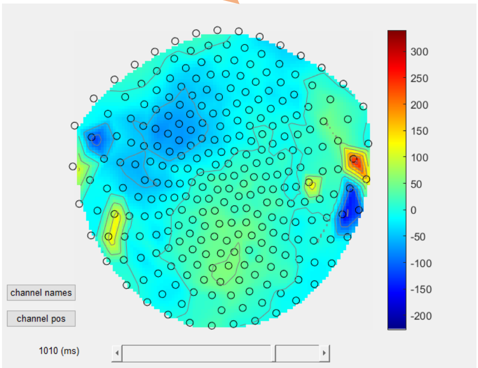
Batch Editor
File Edit View SPM BasicIO
Module List
Conversion
Filter DEP
Downsampling DEP
Epoching DEP
Artefact detection DEP
Remove bad trials DEP
Averaging DEP
Current Module: Averaging
Help on: Averaging
File Name ...move bad trials: Cleaned M/EEG datafile
Averaging type
. Standard
Compute phase-locking value No
Filename Prefix m
Current Item: File Name
Reference from
Remove bad trials: Cleaned M/EEG datafile
Specify...
Dependency
File Name
Select the M/EEG mat file.

Data visualisation

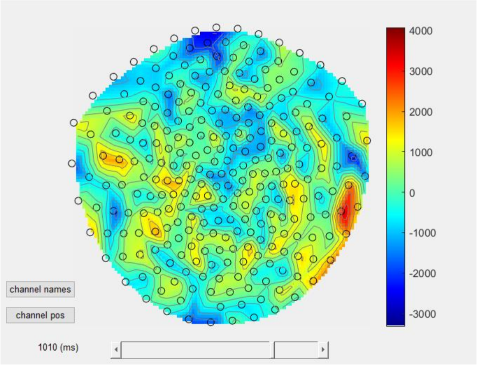






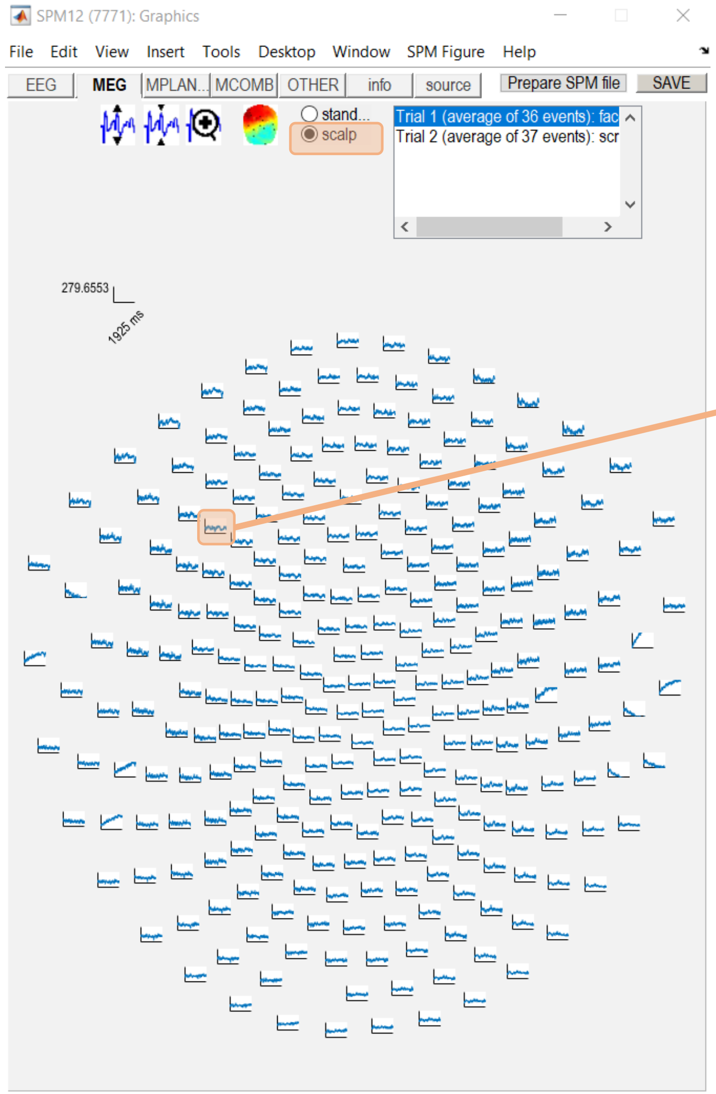


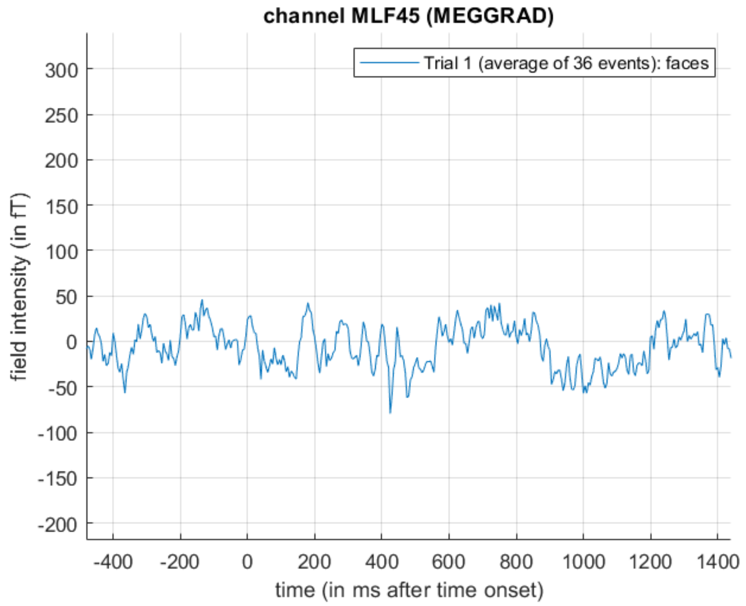
Average of faces condition at 1010ms



Average of scrambled images condition at 1010ms

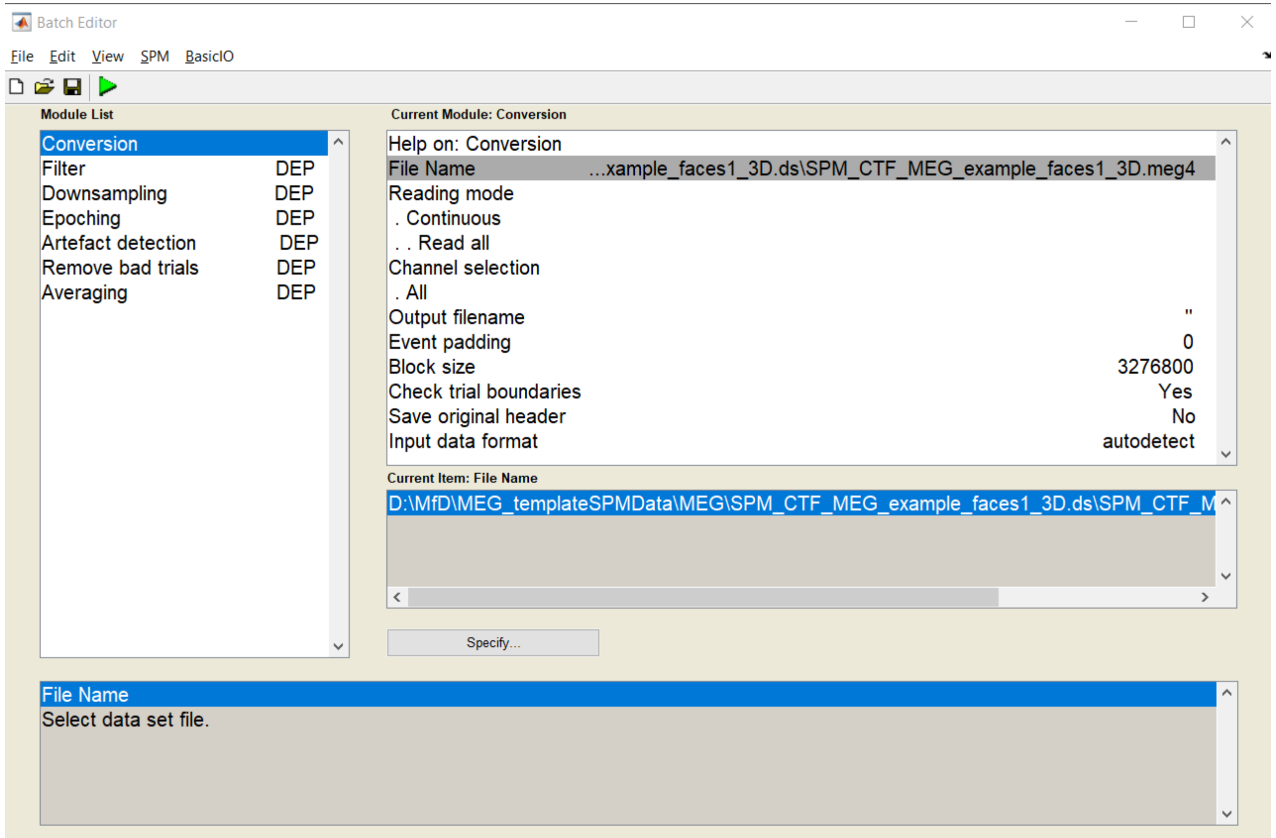
Data visualisation



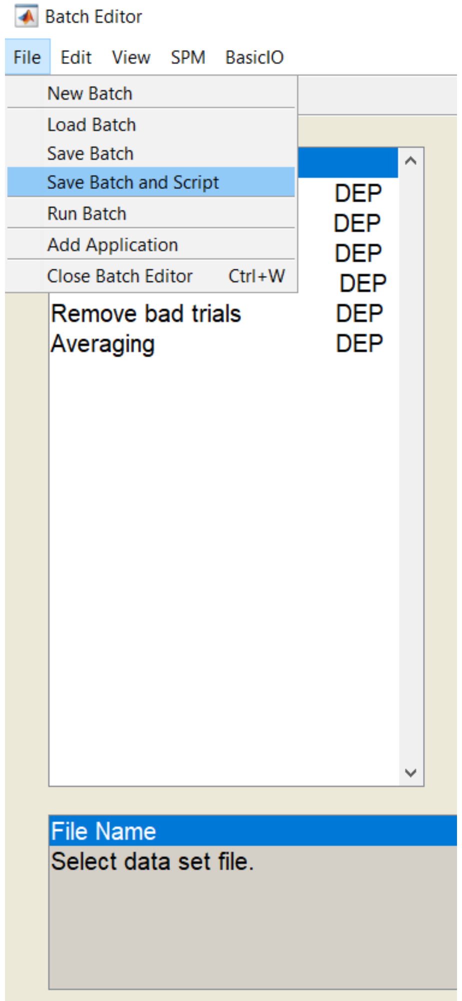


Steps to cover

1. Converting
2. Filtering
3. Downsampling
4. Epoching
5. Re-referencing for EEG
6. Artefacts correction
7. Averaging



Run preprocessing on several runs



MfD_preprocessingMEG.m

```
% List of open inputs
nrun = X; % enter the number of runs here
jobfile = {'D:\MfD\MEG_templateSPMData\MEG\MfD_preprocessingMEG_job.m'};
jobs = repmat(jobfile, 1, nrun);
inputs = cell(0, nrun);
for crun = 1:nrun
end
spm('defaults', 'EEG');
spm_jobman('run', jobs, inputs{:});
```

MfD_preprocessingMEG_job.m | MfD_preprocessingMEG.m

```
%-----------------------------------------------------------------------
% Job saved on 09-May-2023 14:38:17 by cfg_util (rev $Rev: 7345 $)
% spm SPM - SPM12 (7771)
% cfg_basicio BasicIO - Unknown
%-----------------------------------------------------------------------
matlabbatch{1}.spm.meeg.convert.dataset = {'D:\MfD\MEG_templateSPMData\MEG\SPM_CTF_MEG_example_faces1_3D.ds\SPM_CTF_MEG_example_faces1_3D.meg4'};
matlabbatch{1}.spm.meeg.convert.mode.continuous.readall = 1;
matlabbatch{1}.spm.meeg.convert.channels{1}.all = 'all';
matlabbatch{1}.spm.meeg.convert.outfile = '';
matlabbatch{1}.spm.meeg.convert.eventpadding = 0;
matlabbatch{1}.spm.meeg.convert.blocksize = 3276800;
matlabbatch{1}.spm.meeg.convert.checkboundary = 1;
matlabbatch{1}.spm.meeg.convert.saveorigheader = 0;
matlabbatch{1}.spm.meeg.convert.inputformat = 'autodetect';
matlabbatch{2}.spm.meeg.preproc.filter.D(1) = cfg_dep('Conversion: Converted Datafile', substruct('.','val', '{}',{1}, '.','val', '{}',{1}, '.','v
matlabbatch{2}.spm.meeg.preproc.filter.type = 'butterworth';
matlabbatch{2}.spm.meeg.preproc.filter.band = 'high';
matlabbatch{2}.spm.meeg.preproc.filter.freq = 0.1;
matlabbatch{2}.spm.meeg.preproc.filter.dir = 'twopass';
matlabbatch{2}.spm.meeg.preproc.filter.order = 5;
matlabbatch{2}.spm.meeg.preproc.filter.prefix = 'f';
matlabbatch{3}.spm.meeg.preproc.downsample.D(1) = cfg_dep('Filter: Filtered Datafile', substruct('.','val', '{}',{2}, '.','val', '{}',{1}, '.','va
matlabbatch{3}.spm.meeg.preproc.downsample.fsample_new = 200;
matlabbatch{3}.spm.meeg.preproc.downsample.method = 'resample';
```

Note on order of preprocessing steps

- There is no single correct order of steps, but here are some considerations for order choices
  - It is better to filter continuous data prior to epoching to avoid filter ringing artefacts in every trial. It is better to do high-pass filtering or baseline correction before other filtering steps to reduce filter ringing.
- Downsample early in the pipeline to make the subsequent steps faster.
- SPM only filters channels with physiological data. So the channel types should be set correctly before filtering.
- Some artefacts (e.g. discontinuous jumps, muscle) are more difficult to detect after filtering.

Thank you so much for listening!

Thank you to our expert Mansoureh,

- SPM MEG course 2022 materials,
- to previous MfD course slides.

Questions?