



Sensor Level Analysis ERP

EEGLAB

Romain Grandchamp, PhD

Johanna Wagner, PhD

Ramon Martinez-Cancino, PhD

Arnaud Delorme, PhD

Human Electrophysiology

Some EEG milestones

1926 ~1st first EEG recordings

1938 1st EEG spectral analysis

1962 1st computer for EP averaging (CAT)

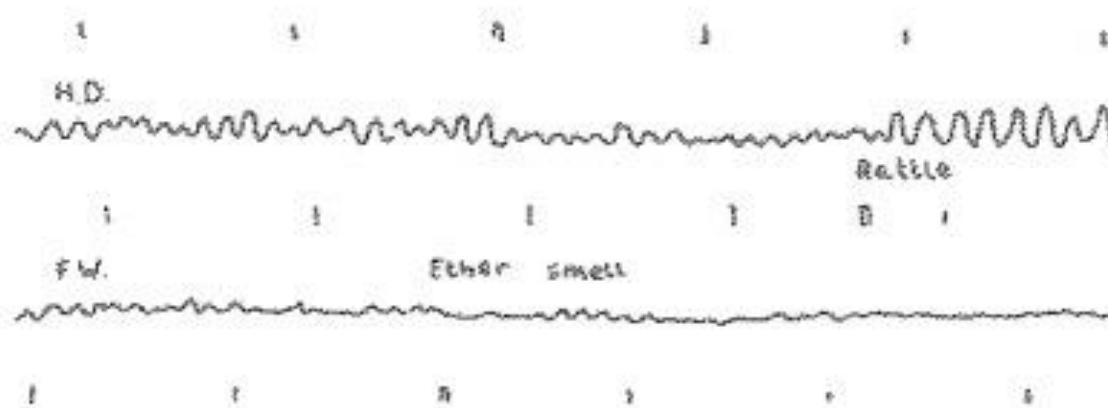
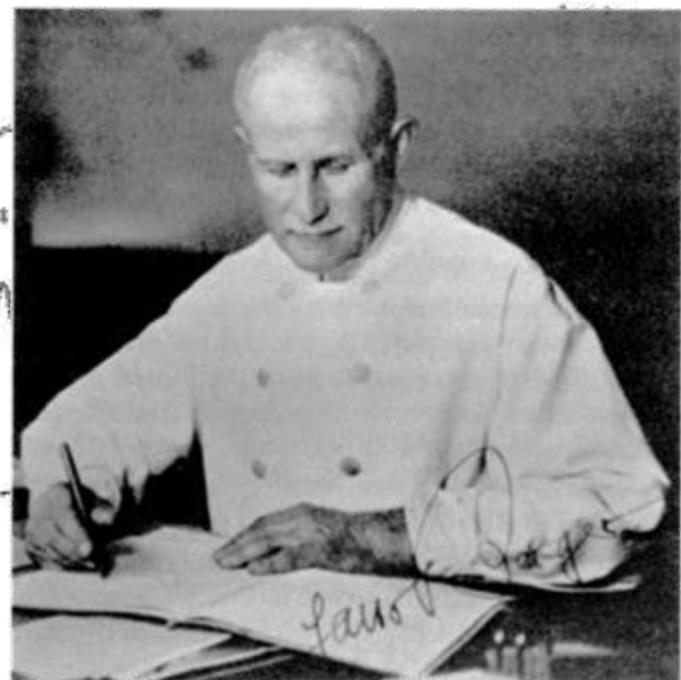
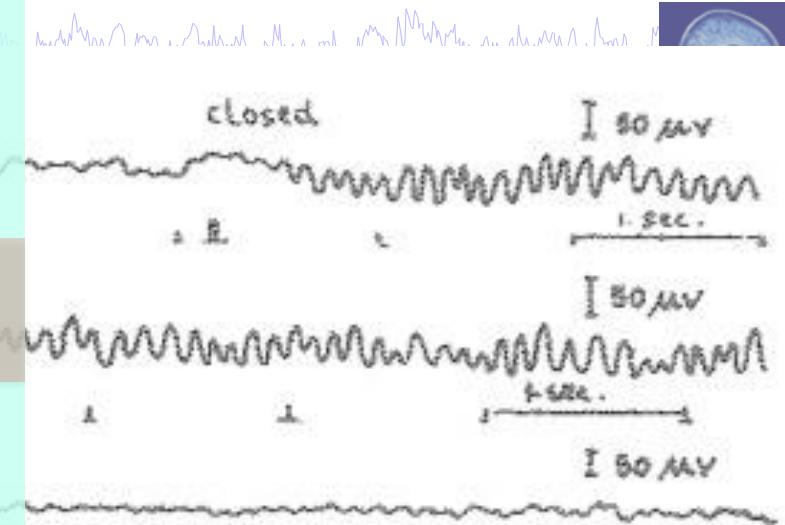
Event-related potential (ERP) averaging

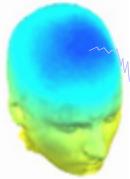
1979 1st source localization of EEG/MEG

Functional EEG brain imaging

1995 1st multisource EEG filtering by ICA

2009 ~1st commercial dry electrode devices

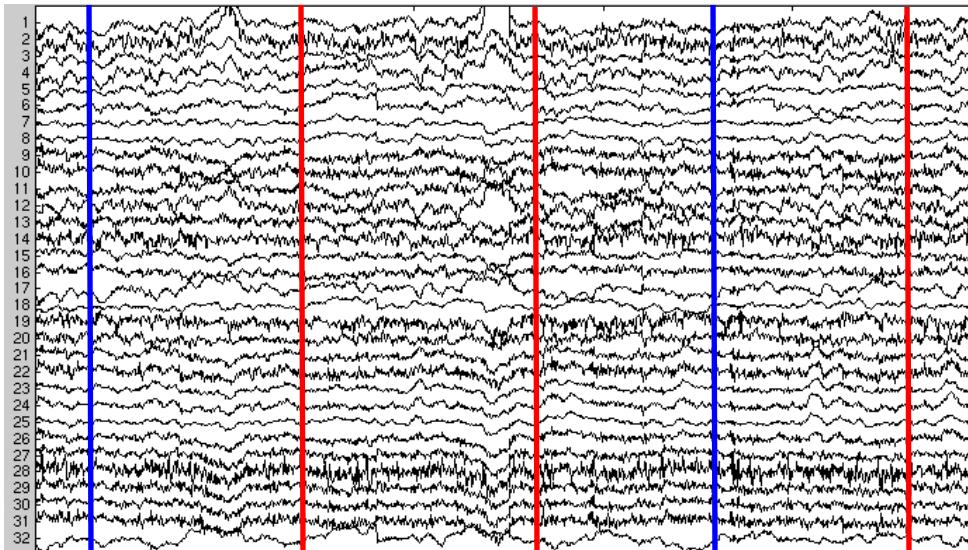




ERP Experiment

Recording

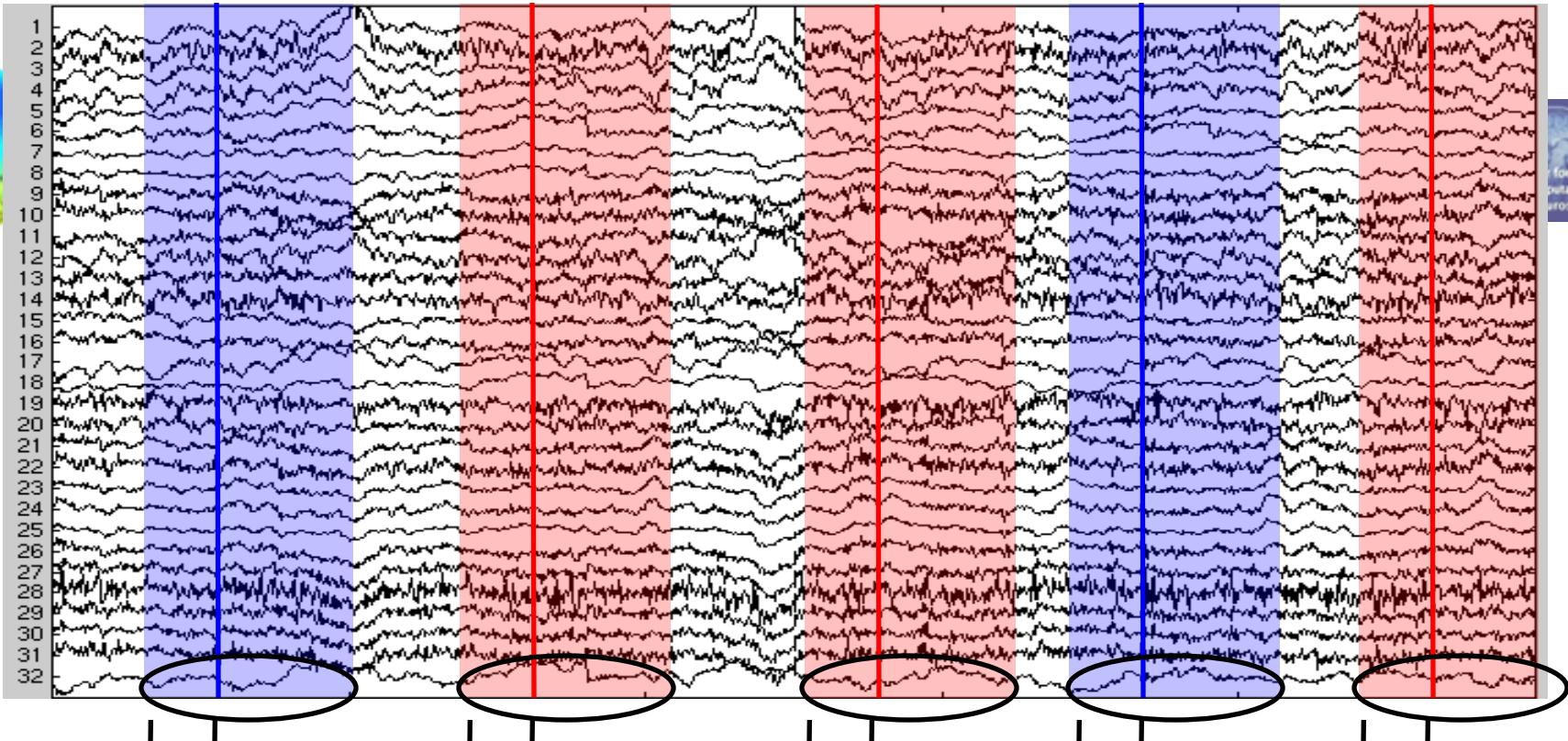
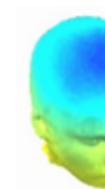
Electrodes



Time (ms)

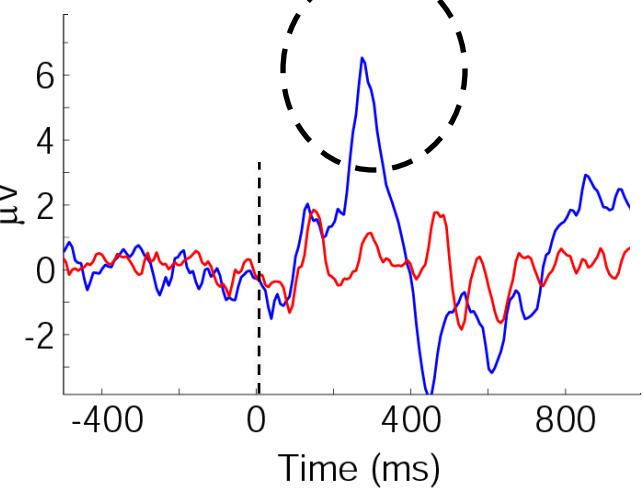


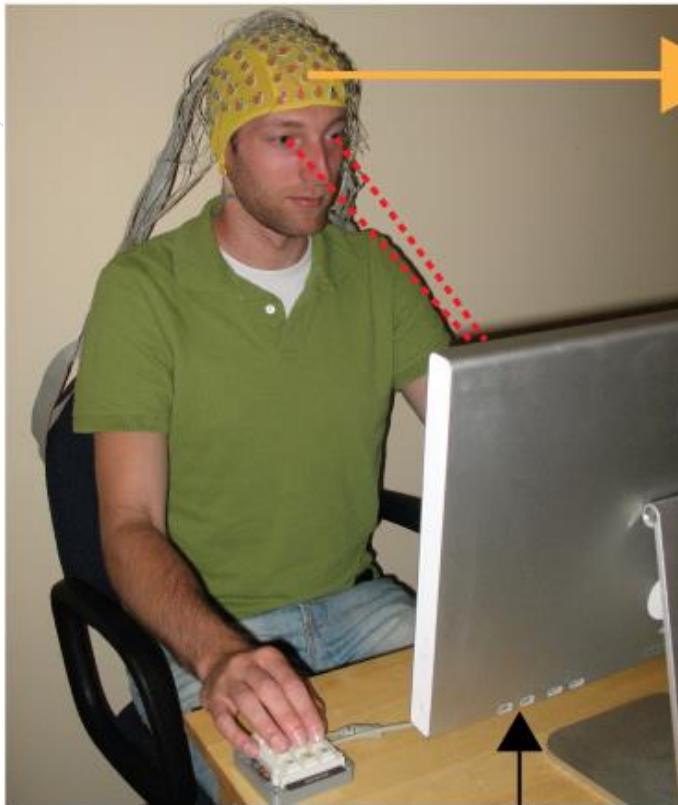
*Offline
processing*



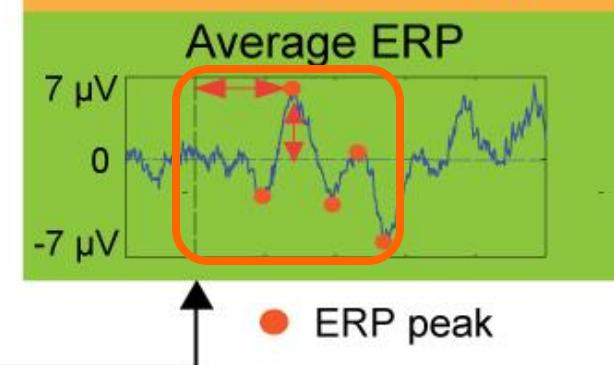
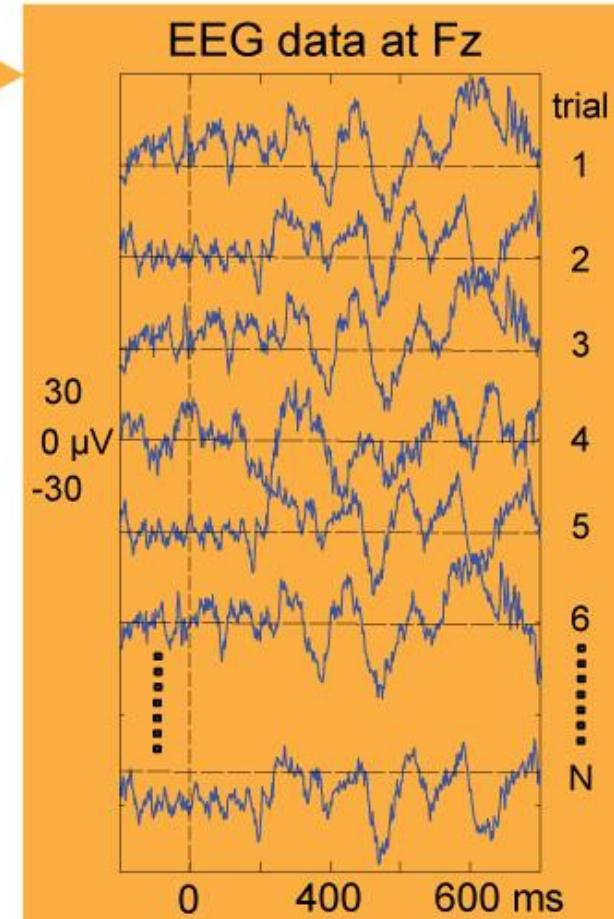
Electrode X

Baseline removal → Average

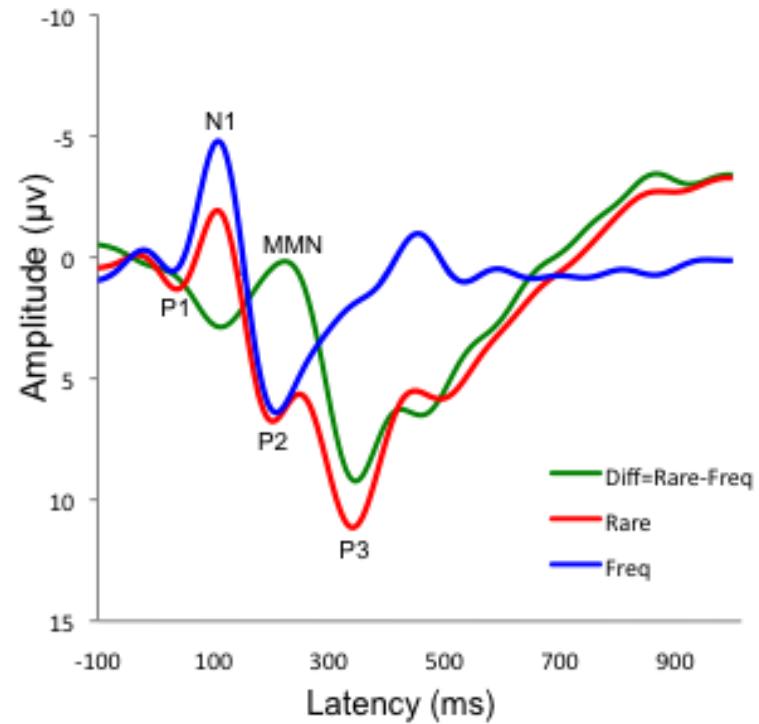
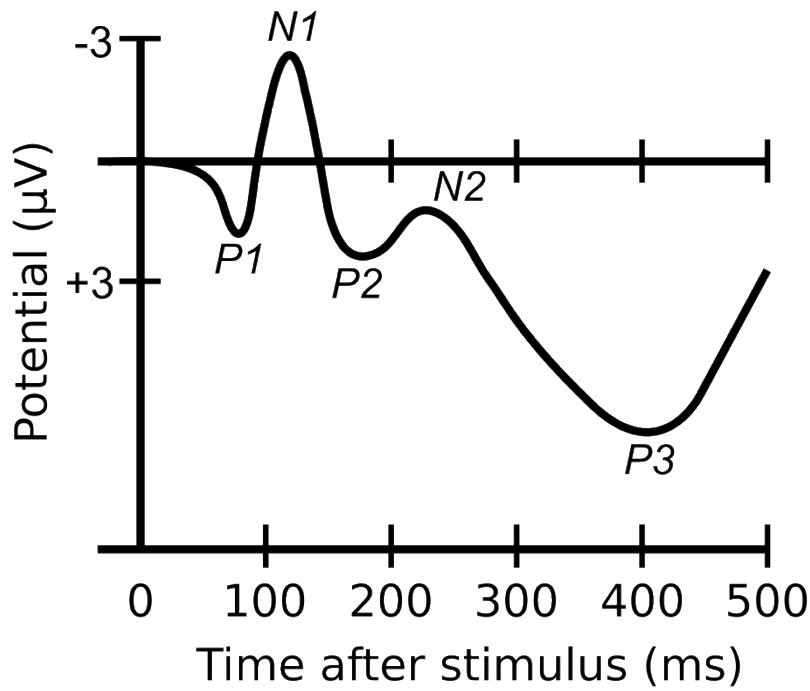
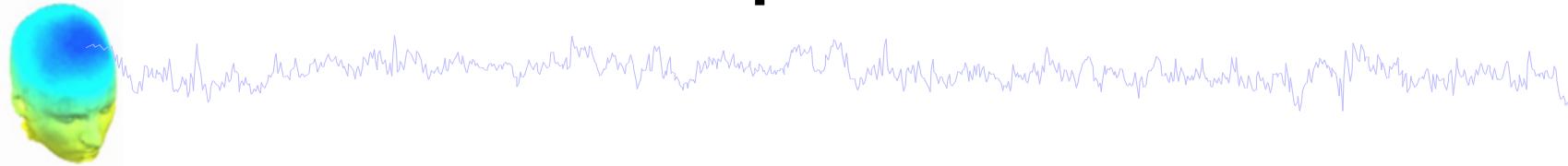


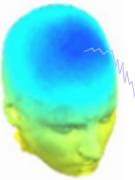


Typical EEG experiment



Examples of ERPs





Limitations of the ERP model



Data \equiv Average + “Background”

EEG

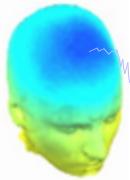
ERP

EEG “noise”

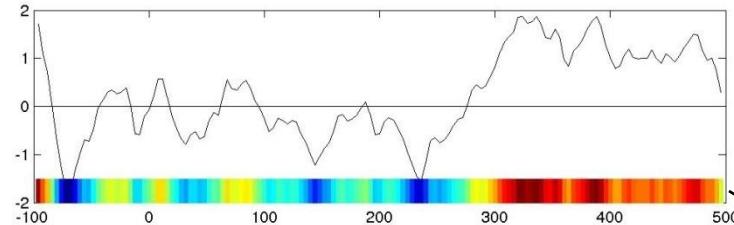
But, this linear decomposition is veridical if and only if:

1. The **Average** appears in each trial.
 2. The **Background** is not perturbed in other ways by the time locking events.
- 

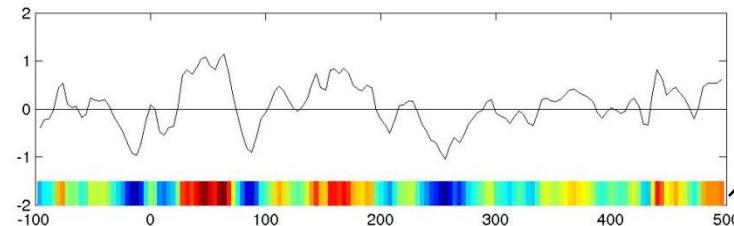
ERP Image



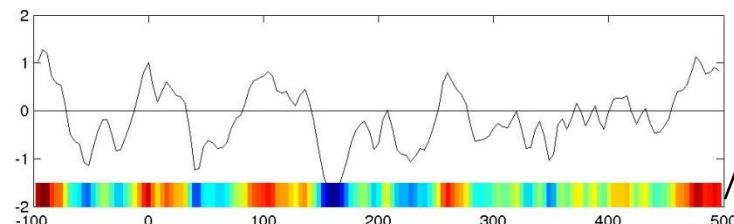
Trial 1



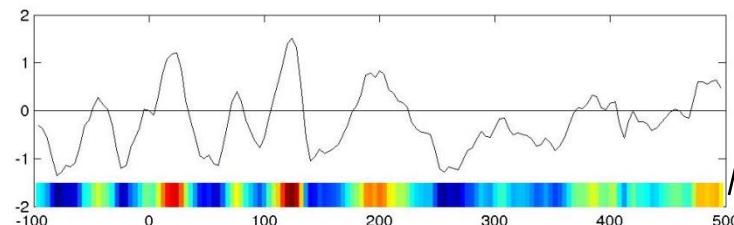
Trial 2



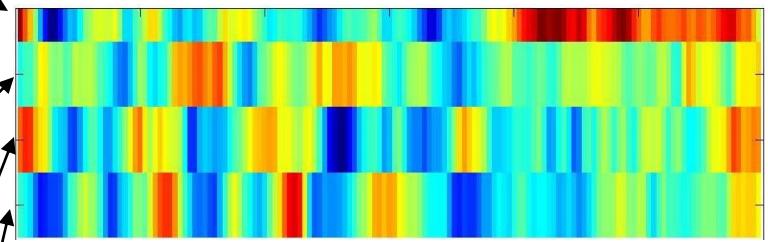
Trial 3



Trial 4

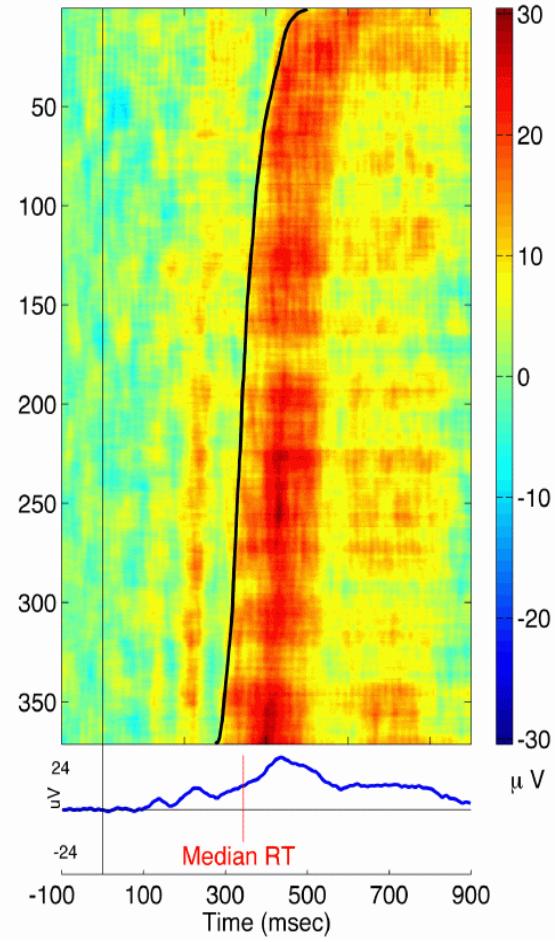
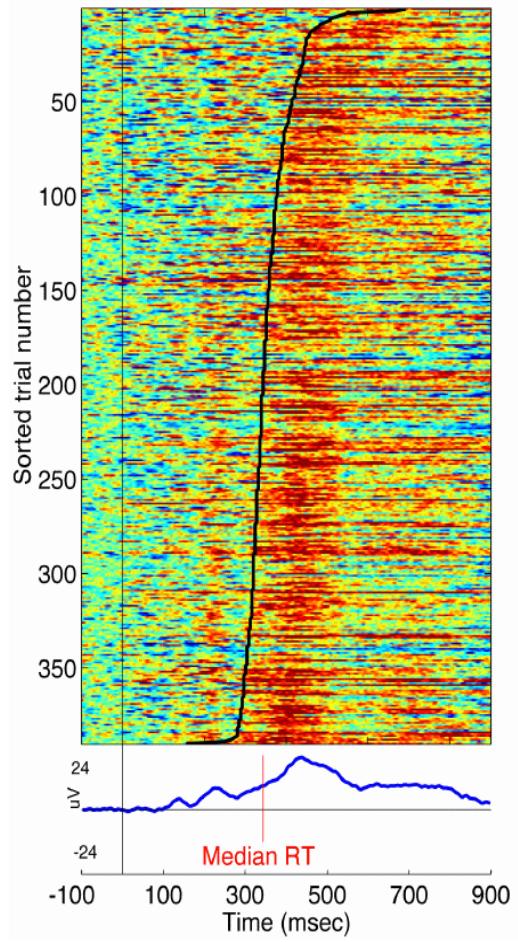
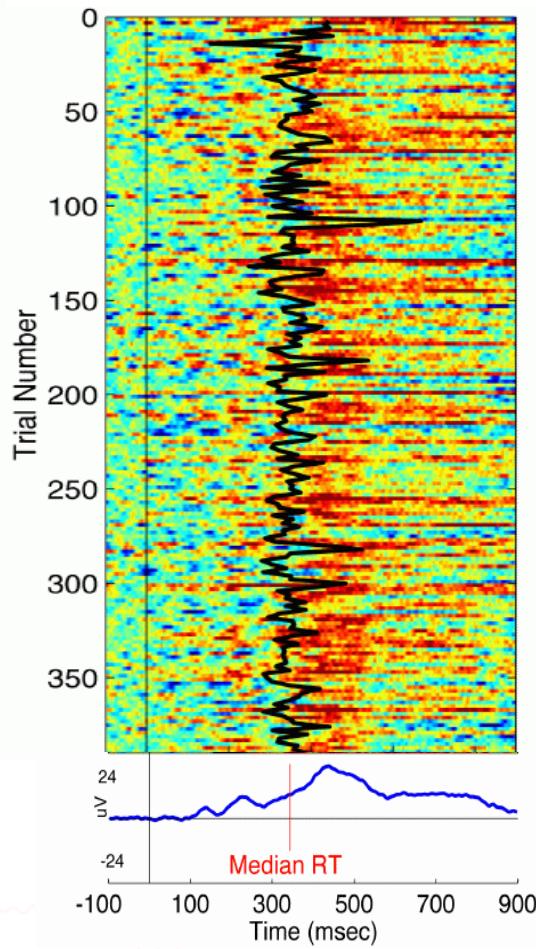
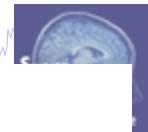


ERP Image

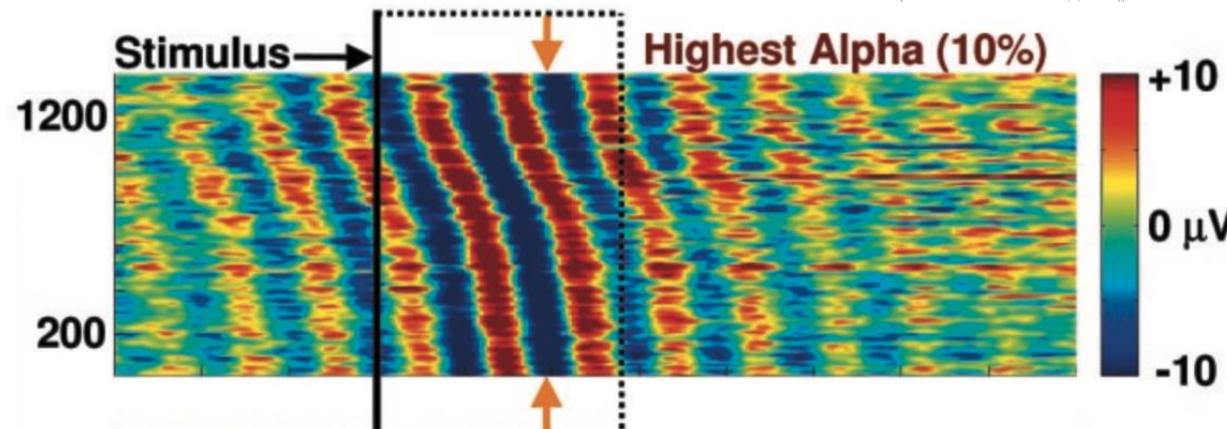


by default, sorted by
time-on-task
(1st trial, 2nd trial, ...)

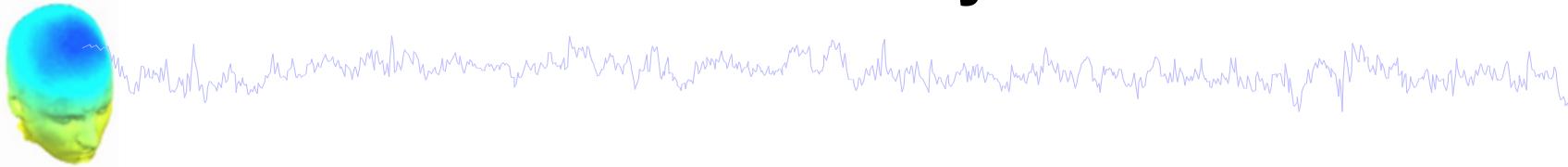
ERP Image



Phase synchronization and ERP



EEG Analysis



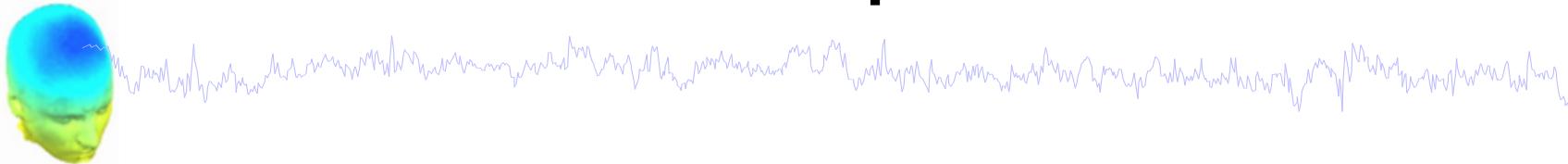
Goals

- Describe dynamic characteristics of brain activity
- Describe relation between different regions of brain

Approaches

- Time domain
- Frequency domain
- Time/Frequency

Load Example Dataset

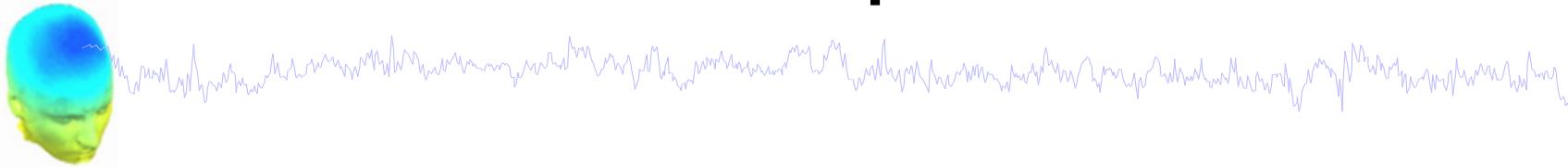


```
filename = 'wh_S01_run_01_preprocessing_data_session_1_out.set';
```

```
EEG = pop_loadset('filename', filename, 'filepath', path2data)
```

The screenshot shows the EEGLAB v2022.1 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, Export, Load existing dataset (which is highlighted), 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 / Clear all, Preferences, History scripts, Manage EEGLAB extensions, and Quit. A tooltip for 'Load existing dataset' provides a detailed description of the function. To the right, a file browser window is open, showing a list of files in a folder named 'sub-01'. The files listed are 'wh_S01_run_01_ERP_Analysis_Session_2_unfamiliar_out.set', 'wh_S01_run_01_ERP_Analysis_Session_2_famous_out.set', 'wh_S01_run_01_preprocessing_data_session_1_out.set' (which is selected and highlighted in blue), 'sub-01_ses-meg_coordsystem.json', and 'Johanna'...'. The file browser includes standard OS X-style navigation buttons and search functionality.

Load Example Dataset



EEGLAB v2022.1

File Edit Tools Plot Study Datasets Help

#1: sub-01_preprocessed

Filename:	...sing data session 1 out.set
Channels per frame	64
Frames per epoch	48362
Epochs	1
Events	263
Sampling rate (Hz)	100
Epoch start (sec)	-0.000
Epoch end (sec)	483.610
Reference	average
Channel locations	Yes
ICA weights	Yes
Dataset size (Mb)	25.6



Extract epochs

The image shows the EEGLAB v2022.1 software interface. On the left, there's a brain topography map and a waveform plot. The main window has a menu bar with File, Edit, Tools, Plot, Study, Datasets, and Help. Under the Tools menu, a dropdown menu is open with options like Change sampling rate, Filter the data, Re-reference the data, Interpolate electrodes, Inspect/reject data by eye, Reject data using Clean Rawdata and ASR, Decompose data by ICA, Inspect/label components by map, Classify components using ICLabel, Remove components from data, Extract epochs (which is highlighted in blue), Remove epoch baseline, Source localization using DIPFIT, Run AMICA, and post AMICA utility.

Event types:

- Famous
- Unfamiliar
- Scrambled

A yellow arrow points from the "Extract epochs" menu item in the Tools dropdown to the "Extract data epochs - pop_epoch()" dialog box. Another yellow arrow points from the "Famous" option in the list of event types to the "Ok" button in the dialog box. The dialog box contains fields for Time-locking event type(s) (set to all), Epoch limits [start, end] in seconds (-1 2), Name for the new dataset (sub-01 Famous), and Out-of-bounds EEG limits if any [min max]. It also has Help, Cancel, and Ok buttons.

(use shift|ctrl to select several)

Famous
Scrambled
Unfamiliar
boundary
left_nonsym
right_sym

Cancel Ok

Extract data epochs - pop_epoch()

Time-locking event type(s) ([]=all)

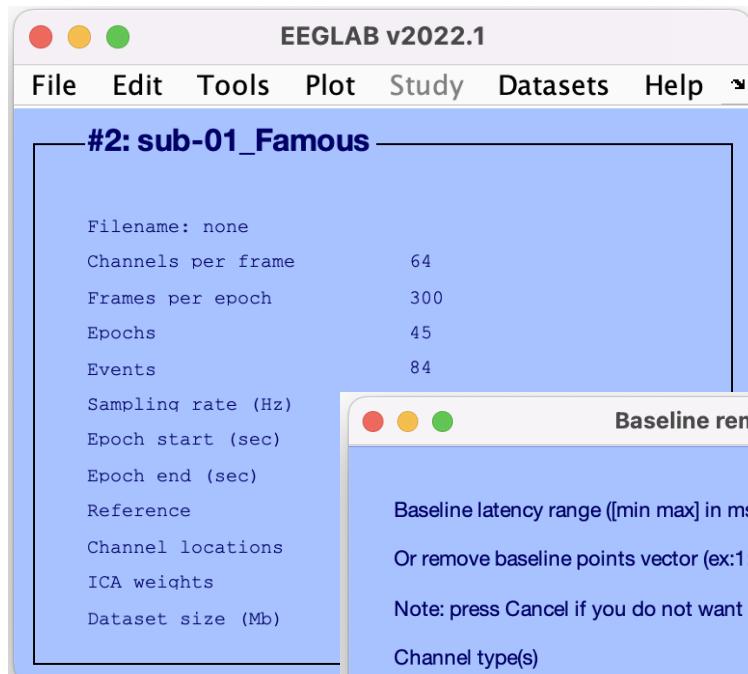
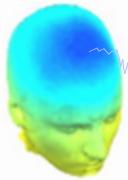
Epoch limits [start, end] in seconds

Name for the new dataset

Out-of-bounds EEG limits if any [min max]

Help Cancel Ok

Extract epochs



Remove baseline

Long baseline or no baseline

Baseline removal - pop_rmbase()

Baseline latency range ([min max] in ms) ([] = whole epoch):

Or remove baseline points vector (ex:1:56):

Note: press Cancel if you do not want to remove the baseline

Channel type(s)

OR channel(s) (default all)

Help Cancel Ok

Dataset info -- pop_newset()

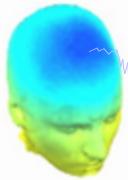
with the new dataset? Edit description

been saved. What do you want to do with the old dataset?

Save it as file:

Cancel Ok

Extract epochs



EEGLAB v2022.1

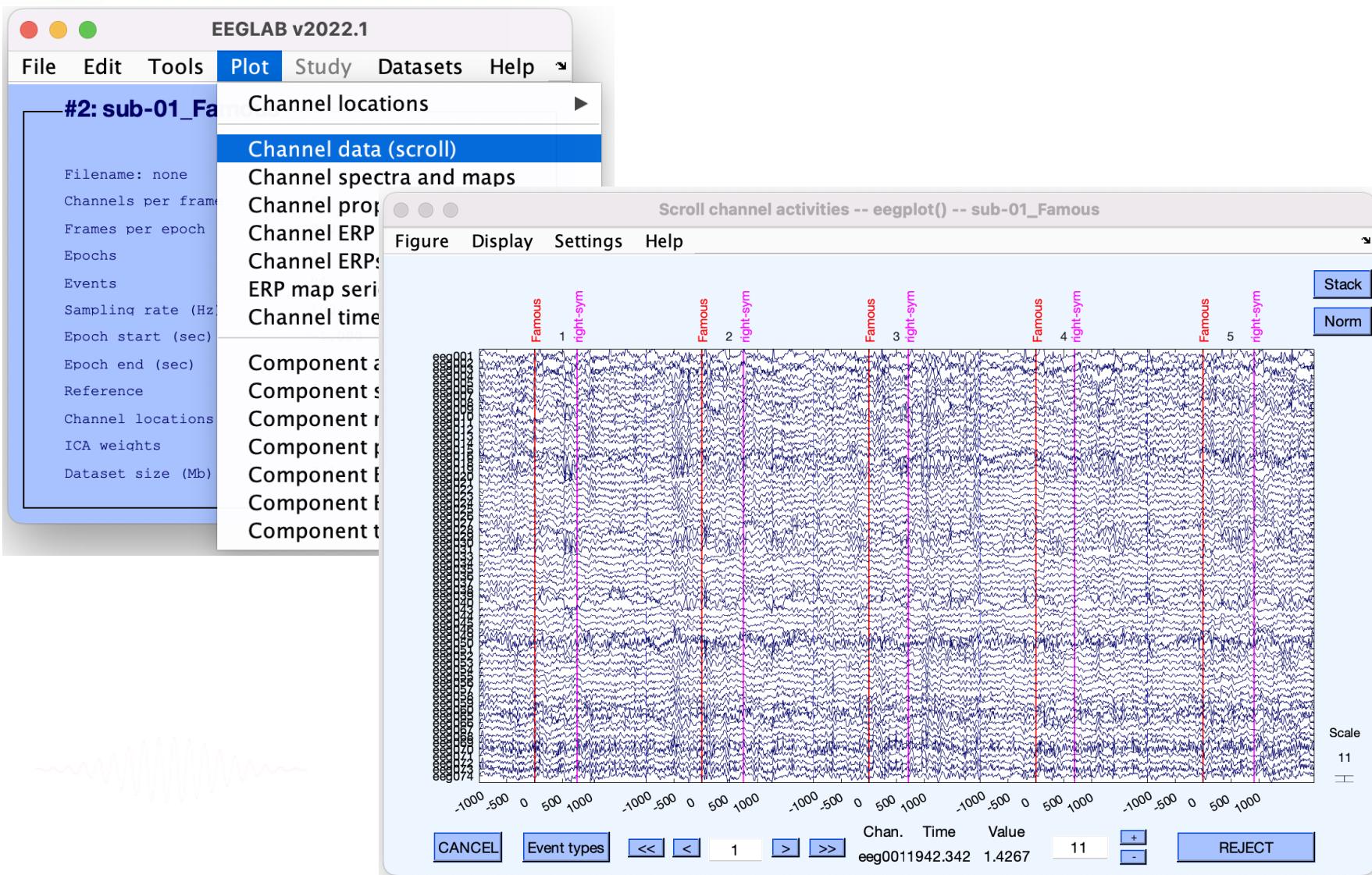
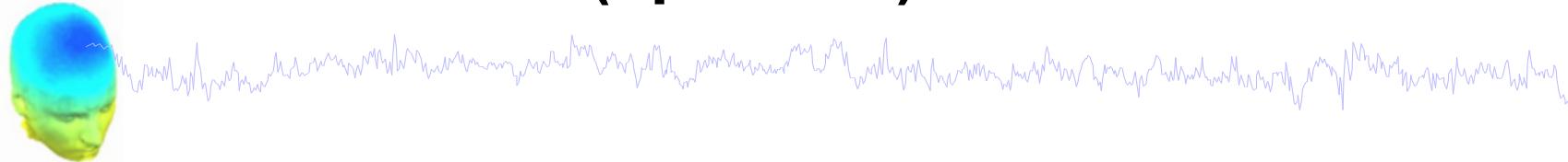
File Edit Tools Plot Study Datasets Help

#2: sub-01_Famous

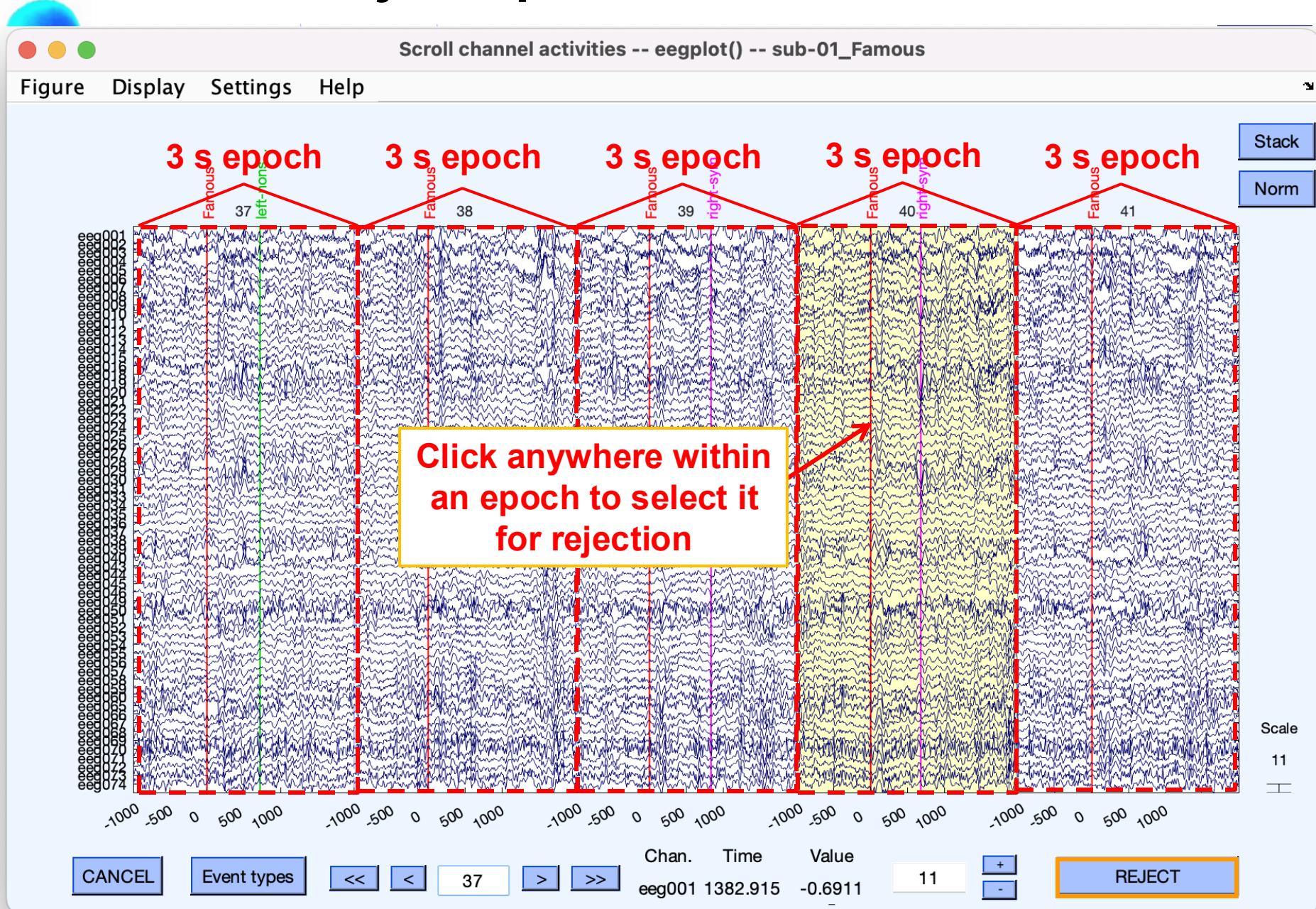
Filename:	none
Channels per frame	64
Frames per epoch	300
Epochs	45
Events	84
Sampling rate (Hz)	100
Epoch start (sec)	-1.000
Epoch end (sec)	1.990
Reference	average
Channel locations	Yes
ICA weights	Yes
Dataset size (Mb)	7.5



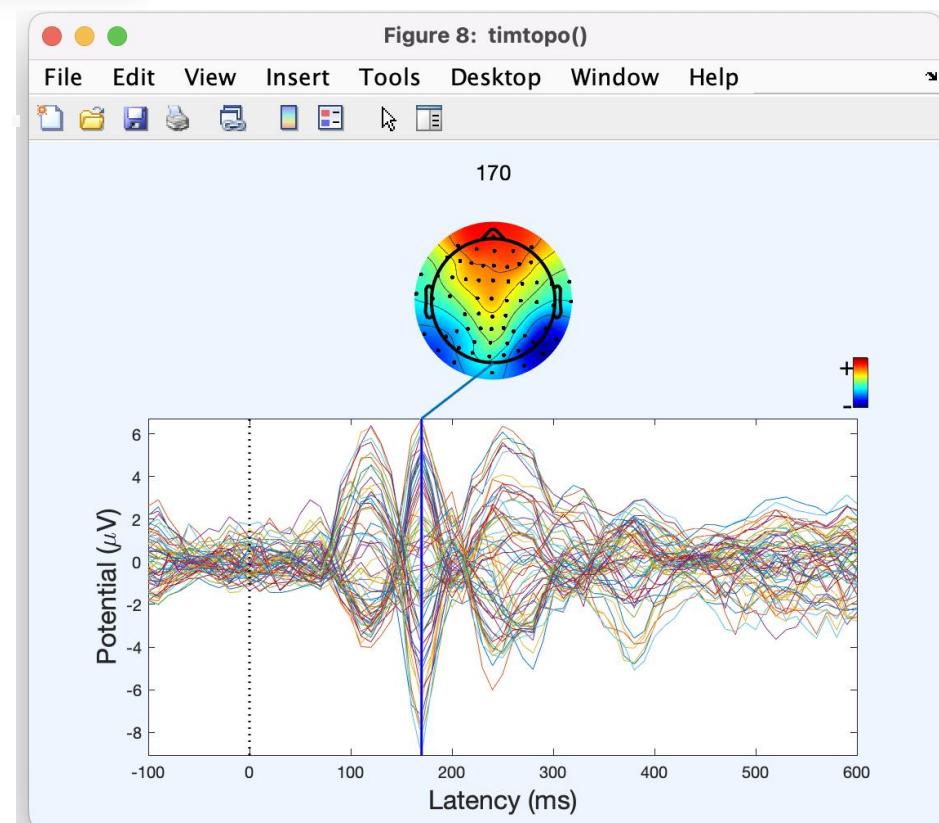
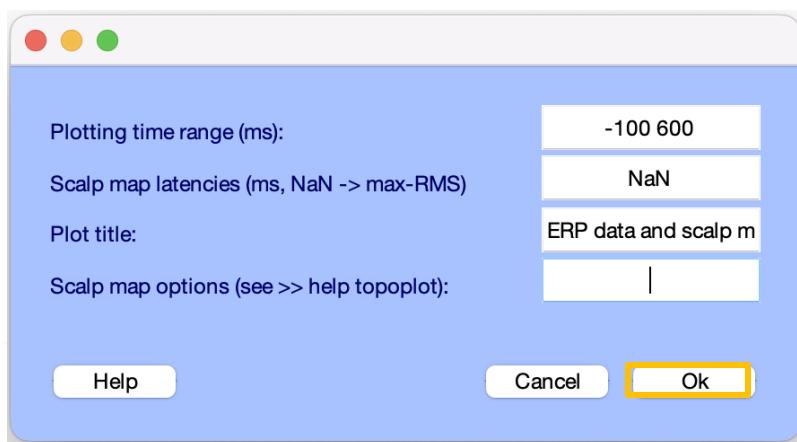
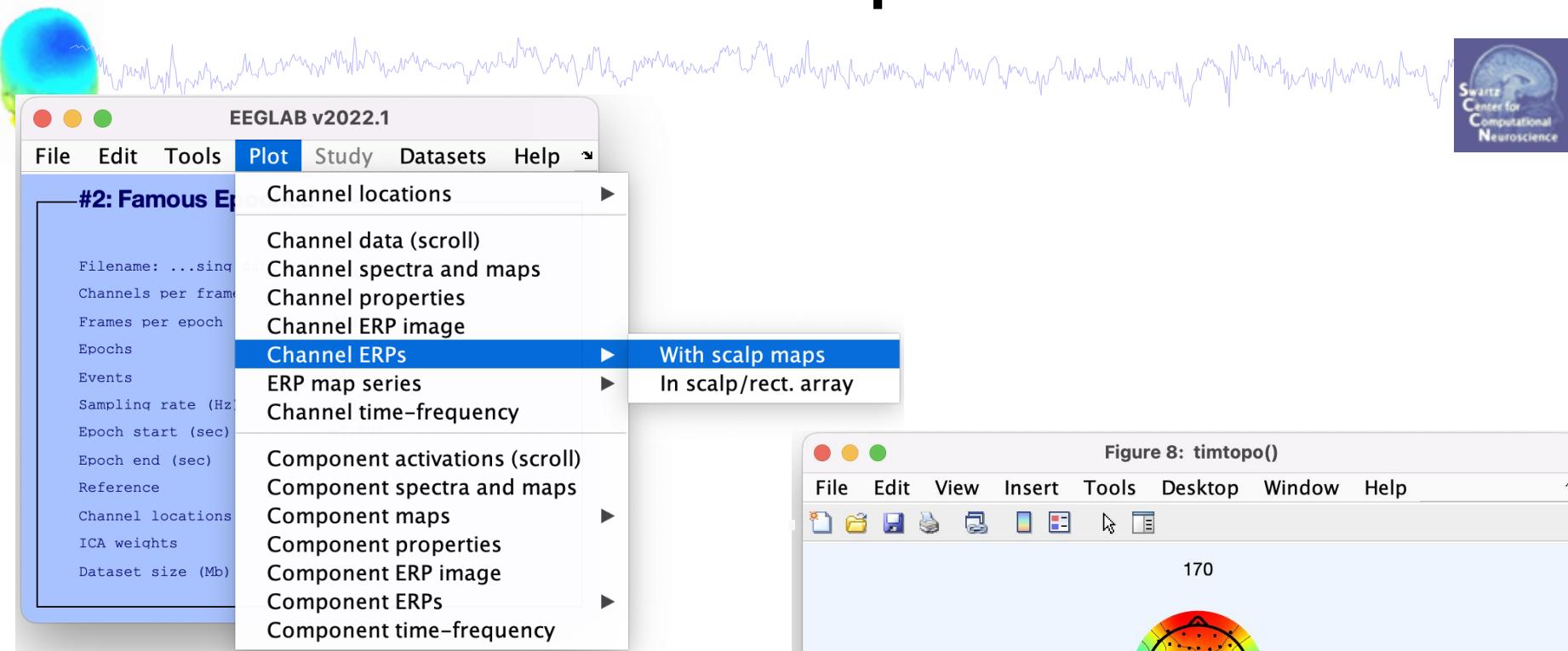
Scroll (epoched) channel data



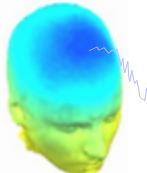
Reject epochs with artifacts



Visualize ERP scalp distribution



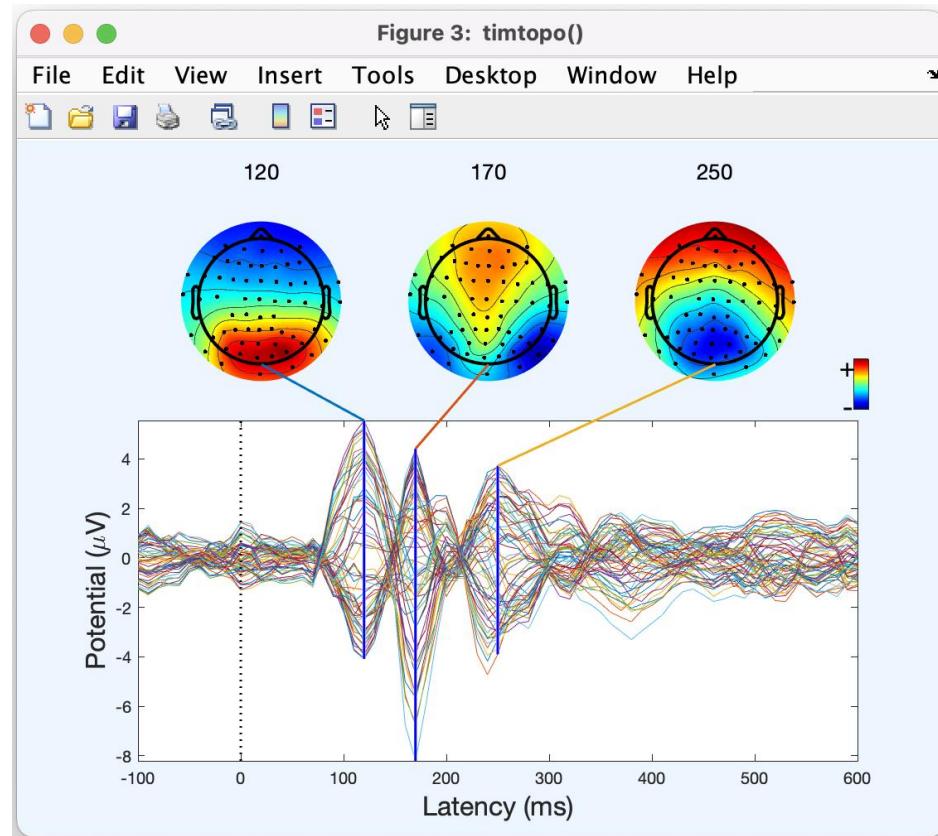
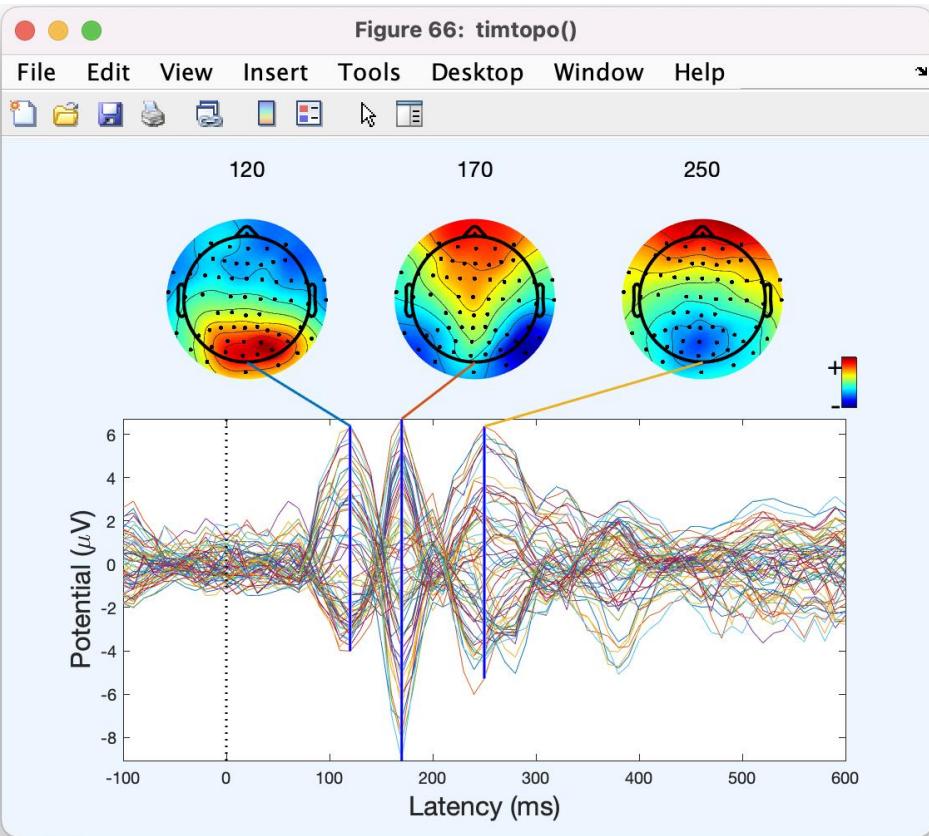
ERP scalp distribution



Before artefact IC removal



After artefact IC removal



Note slightly decreased frontal activity after artefact removal, probably due to removed eye movements

Visualize Channel ERPs in 2 D

EEGLAB v2022.1

File Edit Tools Plot Study Datasets Help

#2: Famous Ep

Channel locations

- Channel data (scroll)
- Channel spectra and maps
- Channel properties
- Channel ERP image
- Channel ERPs
- ERP map series
- Channel time-frequency
- Component activations
- Component spectra and
- Component maps
- Component properties
- Component ERP image
- Component ERPs
- Component time-frequencies

Plot ERP scalp maps in 2-D -- pop_topoplot()

Plotting ERP scalp maps at these latencies 25:25:300
(range: -1000 to 1990 ms, NaN -> empty):

Plot title Famous Epoched pruned with

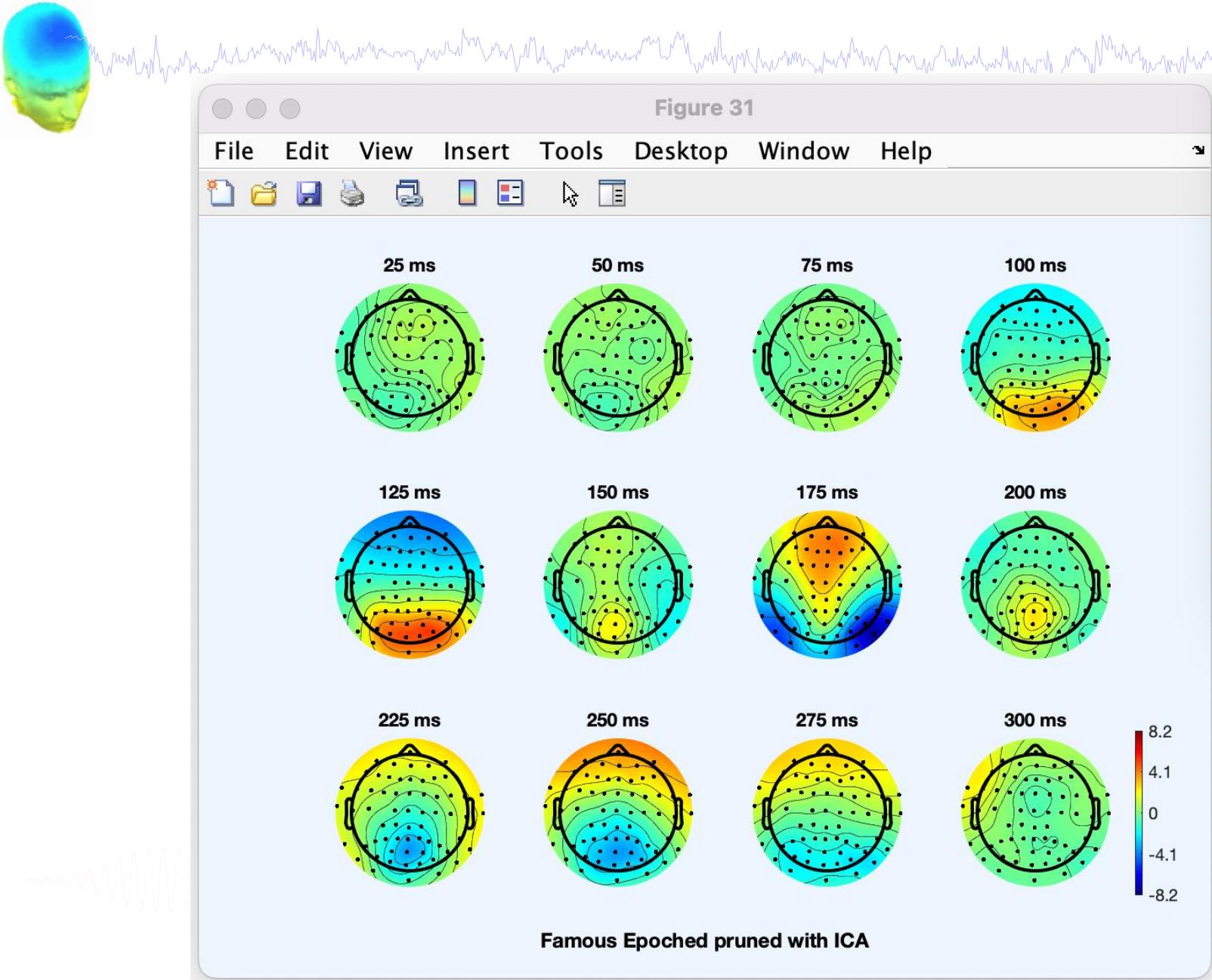
Plot geometry (rows,col.); [] -> near square []

-> Additional topoplot() options (see Help)

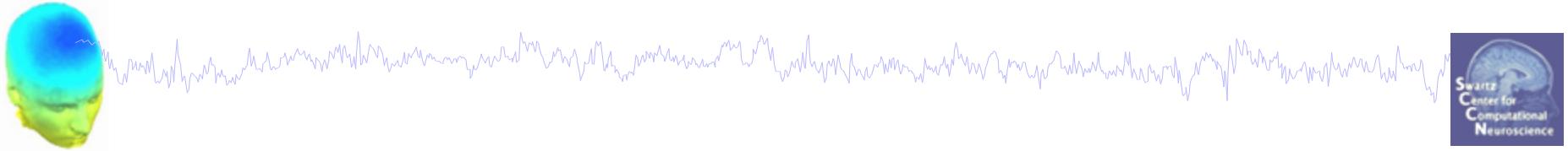
'electrodes', 'on'

Help Cancel Ok

Visualize Channel ERPs in 2 D



Visualize channel ERPs in 3D



EEGLAB v2022.1

File Edit Tools Plot Study Datasets Help

#2: Famous

Filename: ...sing
Channels per frame
Frames per epoch
Epochs
Events
Sampling rate (Hz)
Epoch start (sec)
Epoch end (sec)
Reference
Channel locations
ICA weights
Dataset size (Mb)

Channel locations

Channel data (scroll)

Channel spectra and maps

Channel properties

Channel ERP image

Channel ERPs

ERP map series

In 2-D

In 3-D

Sum/Compare ERPs

Component activations (scroll)

Component s

Component n

Component p

Component E

Component E

Sum/Compar

Data statistics

Time-frequer

ERP head plot(s) -- pop_headplot()

Co-register channel locations with head mesh and compute a mesh spline file (each scalp montage needs a headplot() spline file)

Use the following spline file or structure /Users/johanna/Library/CloudStorage/GoogleDrive-joa.wagn@
 Or (re)compute a new spline file named: /Users/johanna/Library/CloudStorage/GoogleDrive-joa.wagn@

Browse Help

3-D head mesh file mheadnew.mat Browse other

Mesh associated channel file mheadnew.xyz Browse other

Talairach-model transformation matrix Manual coreg.

Plot interpolated activity onto 3-D head

Making headplots for these latencies (from -1000 to 1990 ms):

Plot title:

Plot geometry (rows,columns): (Default [] = near square)

Other headplot options (See >> help headplot):

0

ERP scalp maps of dataset:Famous

Cancel Ok

Visualize channel ERPs in 3D



Align fiducials

coregister()

File Edit View Insert Tools Desktop Window

Labels on
Electrodes
Labels on
Electrodes
Mesh off

z
x
y

Move right {mm} 0 Pitch (rad) 0 Resize {x} 10.4 Align fiducials
Move front {mm} 0 Roll (rad) 0 Resize {y} 10.4 Warp montage
Move up {mm} 0 Yaw (rad) 0 Resize {z} 10.4 Cancel Ok

coregister()

Tools Desktop Window Help

Help me
Funct. help

z
x
y

Move right {mm} 0.5633 Pitch (rad) -0.1999 Resize {x} 9.758 Align fiducials
Move front {mm} -3.107 Roll (rad) -0.00611 Resize {y} 9.758 Warp montage
Move up {mm} -48.9 Yaw (rad) -1.374 Resize {z} 9.758 Cancel Ok

Select corresponding channels to pair in the lists below

Plot new montage Plot ref montage

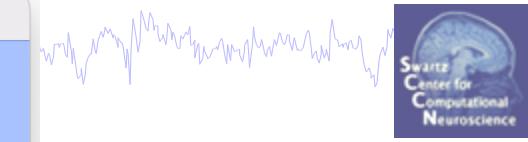
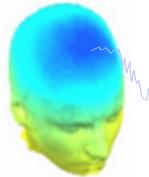
48 - eeg054
49 - eeg055
50 - eeg056
51 - eeg057
52 - eeg058
53 - eeg059
54 - eeg060
55 - eeg065
56 - eeg066
57 - eeg067
58 - eeg068
59 - eeg069
60 - eeg070
61 - eeg071
62 - eeg072
63 - eeg073
64 - eeg074
65 - Nz -> 1 - Nz
66 - RPA -> 3 - RPA
67 - LPA -> 2 - LPA

1 - Nz -> 65 - Nz
2 - LPA -> 67 - LPA
3 - RPA -> 66 - RPA

4 - LEYE
5 - REYE
6 - FP1
7 - FPZ
8 - FP2
9 - AF7
10 - AF3
11 - AFZ
12 - AF4
13 - AF8
14 - F9
15 - F7
16 - F5
17 - F3
18 - F1
19 - FZ
20 - F2

Pair channels Clear this pair
Clear all pairs Auto select
Cancel Ok

Visualize channel ERPs in 3D



coregister()

File Edit View Insert Tools Desktop Window Help

Labels on
Electrodes
Labels on
Electrodes
Mesh off

Move right {mm}	0.5633	Pitch (rad)	-0.1999	Resize {x}	9.758	Align fiducials
Move front {mm}	-3.107	Roll (rad)	-0.00611	Resize {y}	9.758	Warp montage
Move up {mm}	-48.9	Yaw (rad)	-1.374	Resize {z}	9.758	Cancel Ok

Pair channels - pop_chancoresp

Select corresponding channels to pair in the lists below

Plot new montage Plot ref montage

48 - eeg054	1 - Nz -> 65 - Nz
49 - eeg055	2 - LPA -> 67 - LPA
50 - eeg056	3 - RPA -> 66 - RPA
51 - eeg057	4 - LEYE
52 - eeg058	5 - REYE
53 - eeg059	6 - FP1
54 - eeg060	7 - FPZ
55 - eeg065	8 - FP2
56 - eeg066	9 - AF7
57 - eeg067	10 - AF3
58 - eeg068	11 - AFZ
59 - eeg069	12 - AF4
60 - eeg070	13 - AF8
61 - eeg071	14 - F9
62 - eeg072	15 - F7
63 - eeg073	16 - F5
64 - eeg074	17 - F3
65 - Nz -> 1 - Nz	18 - F1
66 - RPA -> 3 - RPA	19 - FZ
67 - LPA -> 2 - LPA	20 - F2

Pair channels Clear this pair
Clear all pairs Auto select
Cancel Ok

Warp montage

coregister()

Tools Desktop Window Help

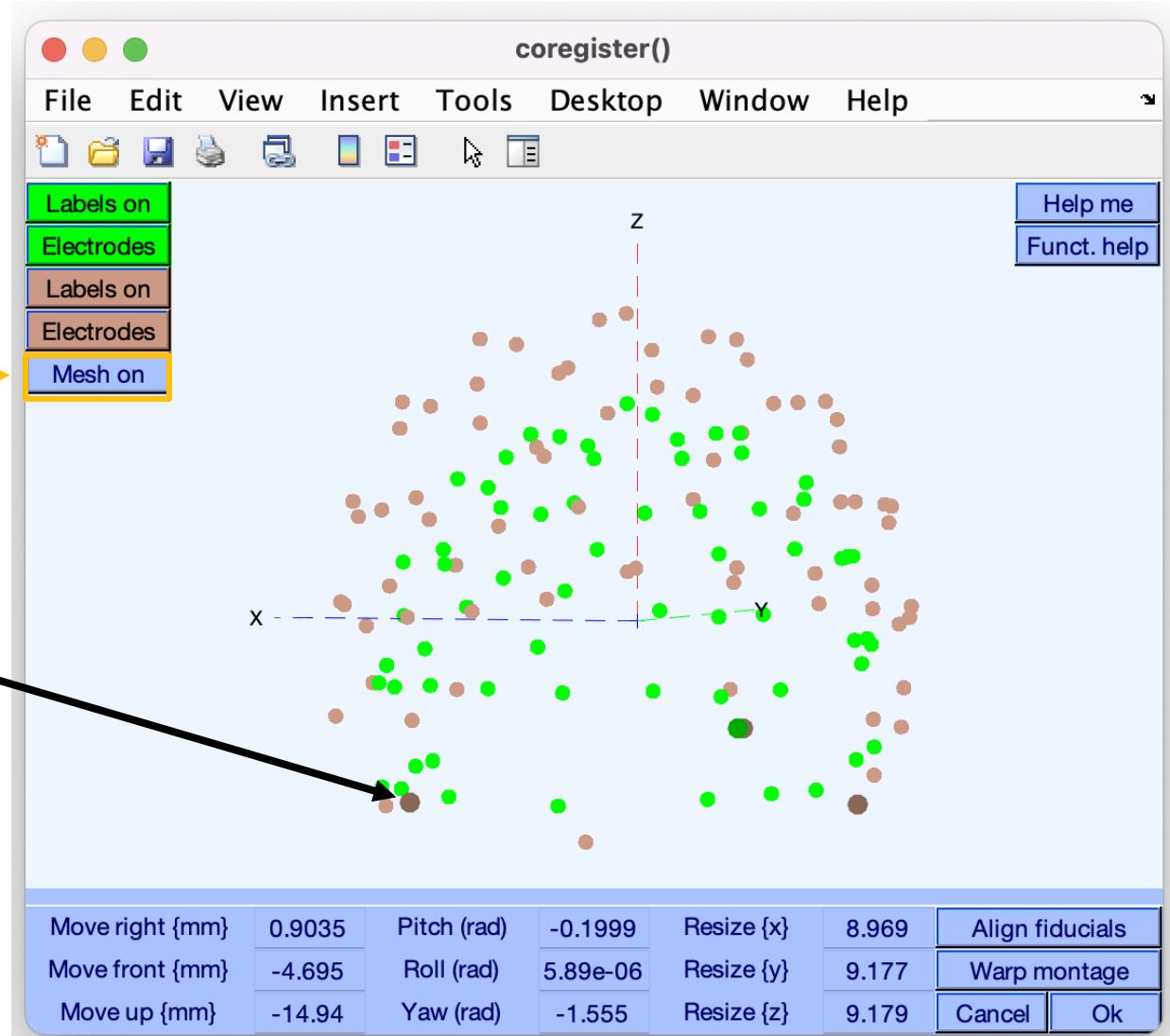
Help me Funct. help

Move right {mm}	0.9035	Pitch (rad)	-0.1999	Resize {x}	8.969	Align fiducials
Move front {mm}	-4.695	Roll (rad)	5.89e-06	Resize {y}	9.177	Warp montage
Move up {mm}	-14.94	Yaw (rad)	-1.555	Resize {z}	9.179	Cancel Ok

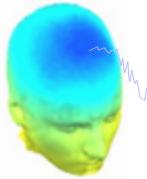
Visualize channel ERPs in 3D



Fiducials are aligned



Visualize channel ERPs in 3D



ERP head plot(s) -- pop_headplot()

Co-register channel locations with head mesh and compute a mesh spline file (each scalp montage needs a headplot() spline file)

Use the following spline file or structure /Users/johanna/Library/CloudStorage/GoogleDrive-joa.wagn@[Browse](#) [Help](#)

Or (re)compute a new spline file named: /Users/johanna/Library/CloudStorage/GoogleDrive-joa.wagn@[Browse](#) [Help](#)

3-D head mesh file mheadnew.mat [Browse other](#)

Mesh associated channel file mheadnew.xyz [Browse other](#)

Talairach-model transformation matrix 0.90355 -4.69459 -14.9446 -0.199874 5.88963e-06 [Manual coreg.](#)

Plot interpolated activity onto 3-D head

Making headplots for these latencies (from -1000 to 1990 ms): 25:25:350

Plot title: ERP scalp maps of dataset:Famous

Plot geometry (rows,columns): (Default [] = near square)

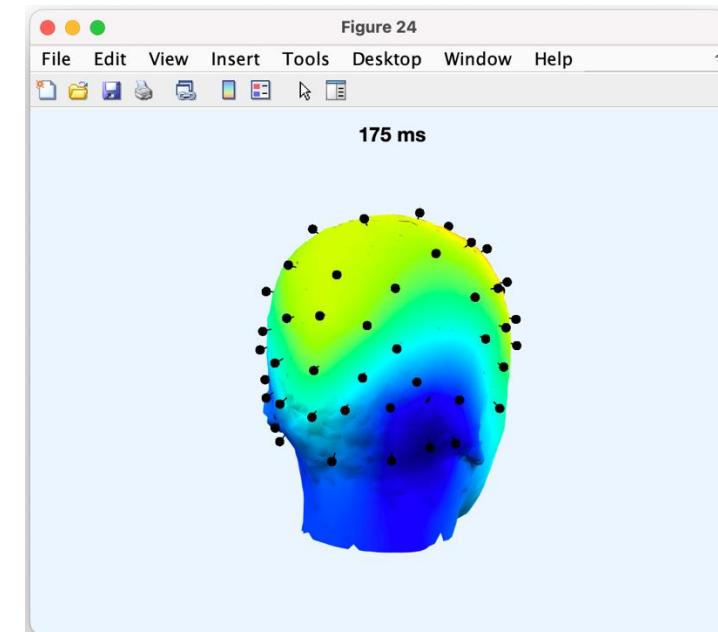
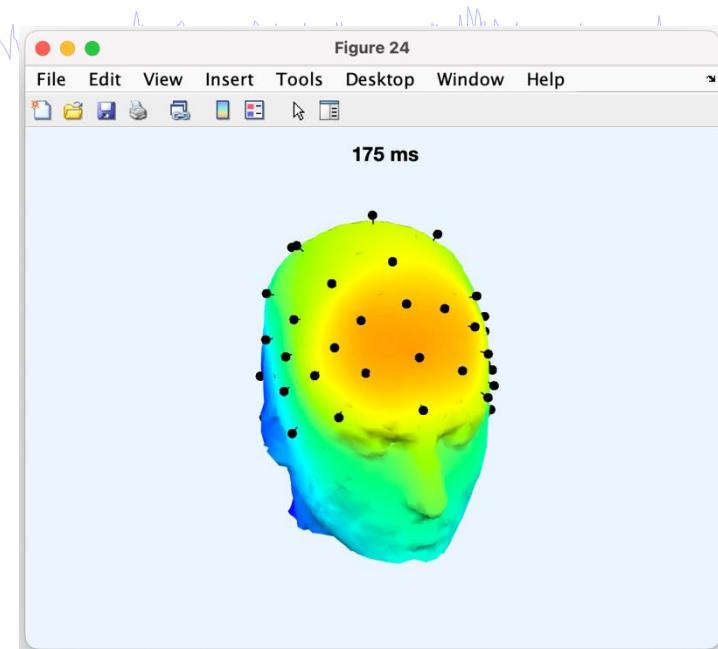
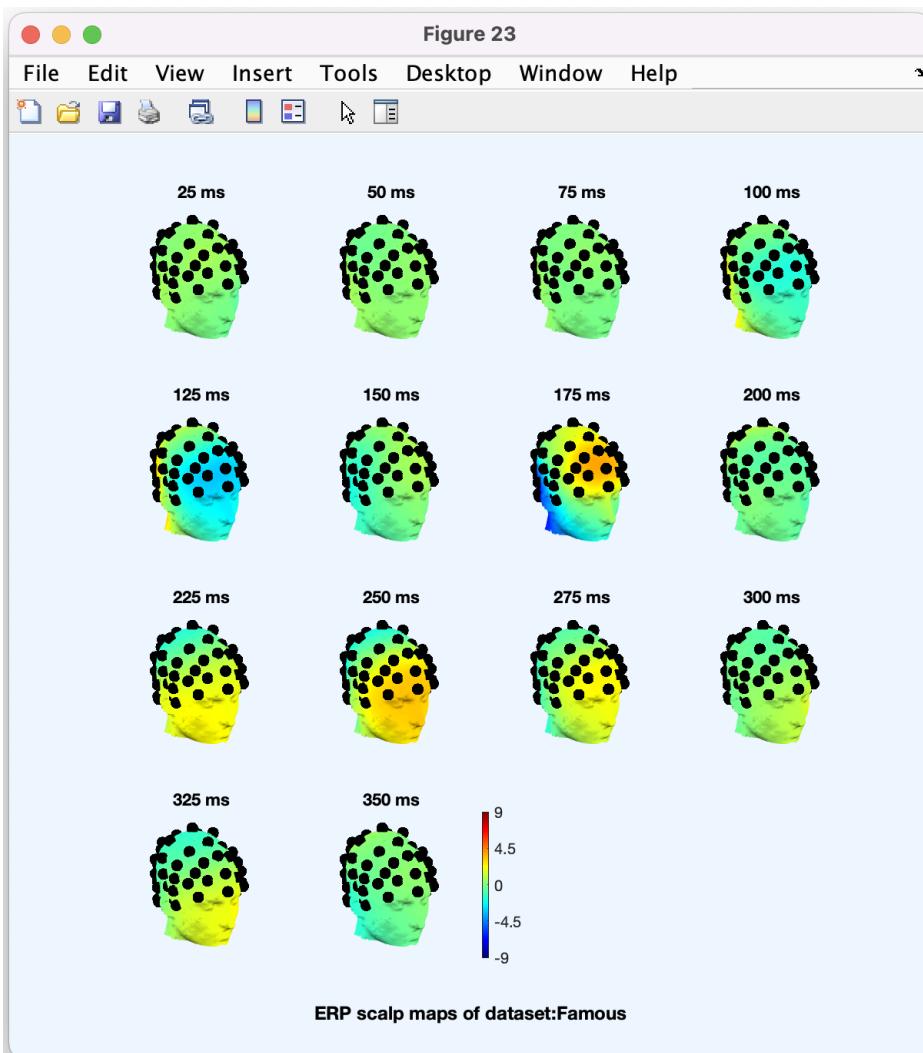
Other headplot options (See >> help headplot):

[Cancel](#) [Ok](#)

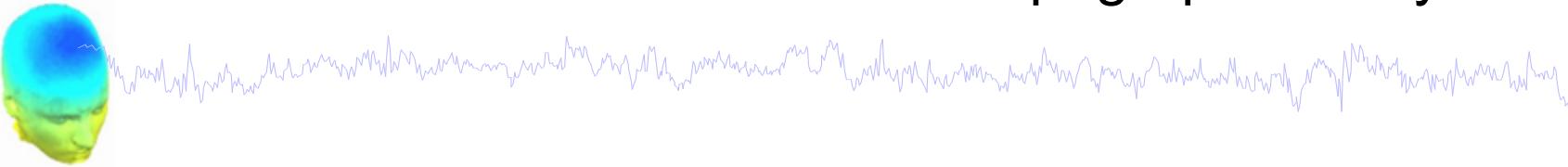
Visualize channel ERPs in 3D



Click on the head



Visualize channel ERPs in topographic array



EEGLAB v2022.1

File Edit Tools Plot Study Datasets Help

#2: Famous Epochs

Channel locations

Filename: ...sing

Channels per frame

Frames per epoch

Epochs

Events

Sampling rate (Hz)

Epoch start (sec)

Epoch end (sec)

Reference

Channel locations

ICA weights

Dataset size (Mb)

Channel data (scroll)

Channel spectra and maps

Channel properties

Channel ERP image

Channel ERPs

ERP map series

Channel time-frequency

Component activations (scroll)

Component spectra and maps

Component maps

Component properties

Component ERP image

Component ERPs

Component time-frequency

With scalp maps

In scalp/rect. array

Topographic ERP plot - pop_plottopo()

Channels to plot: 1:64

Plot title: Famous

(set=yes) Plot single trials

(set=yes) Plot in rect. array

Other plot options (see help): 'ydir', 1, 'limits', [-100 600 0 0]

Help Cancel Ok

Visualize channel ERPs in topographic array

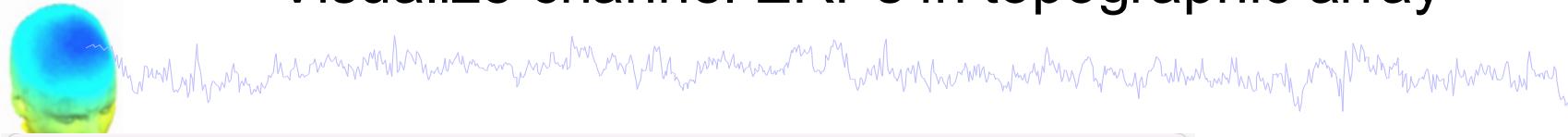


Figure 2: plottopo()

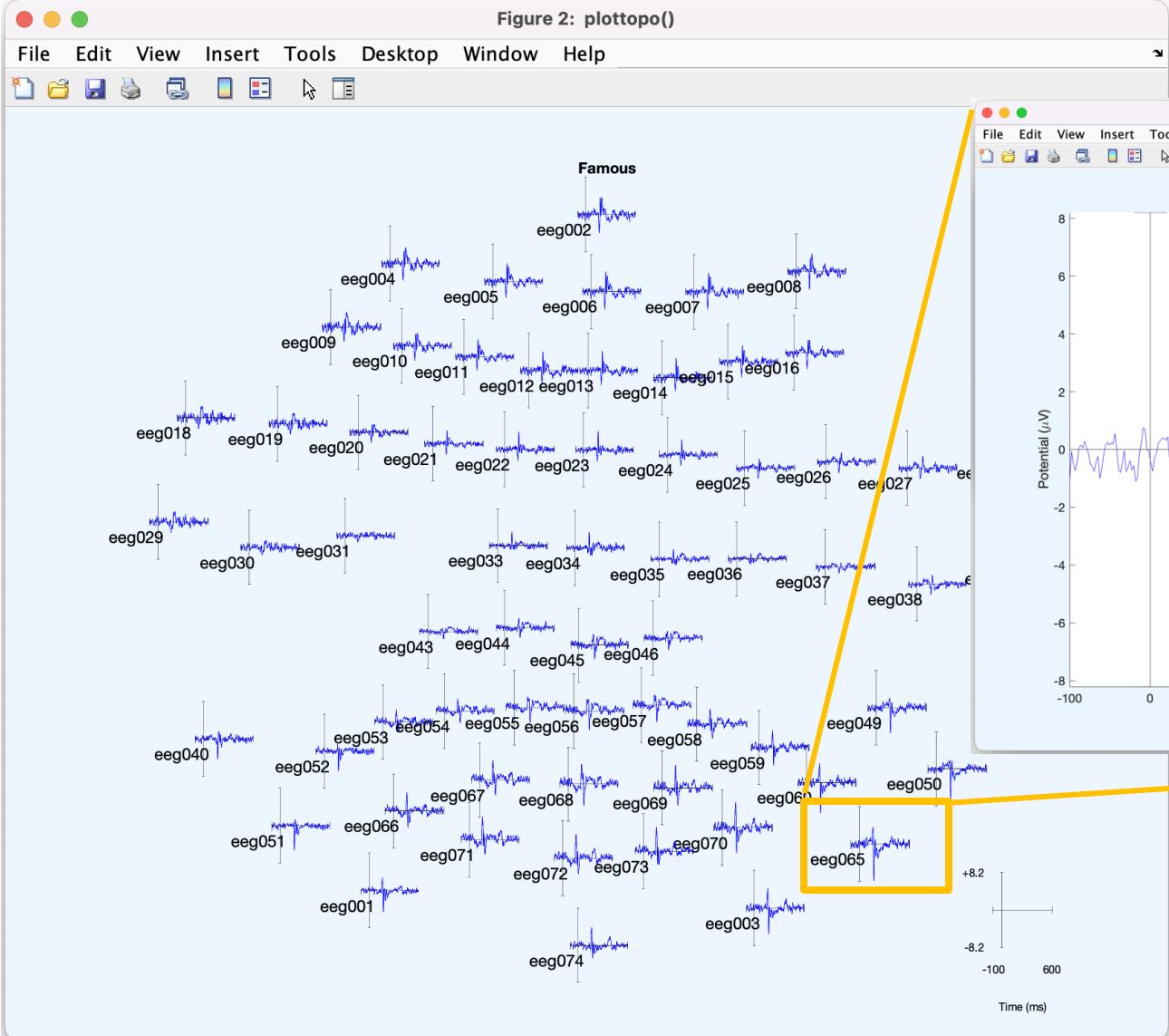
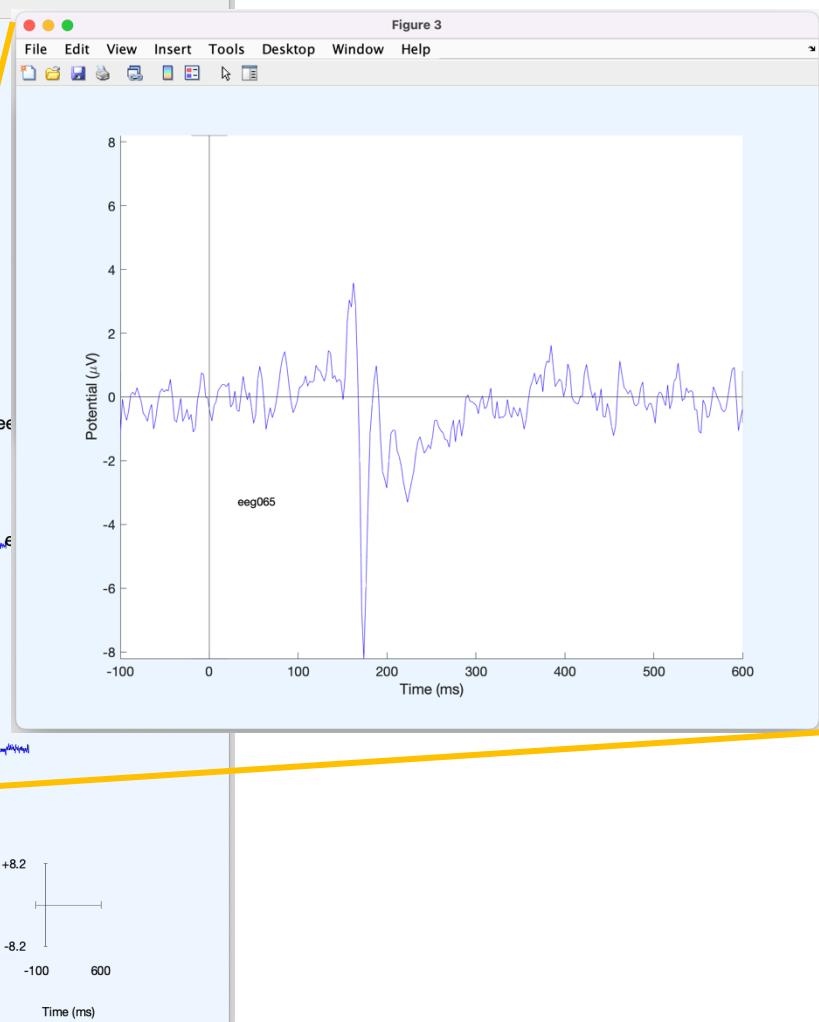


Figure 3



Component ERP image



EEGLAB v2021.0

File Edit Tools Plot Study Datasets Help

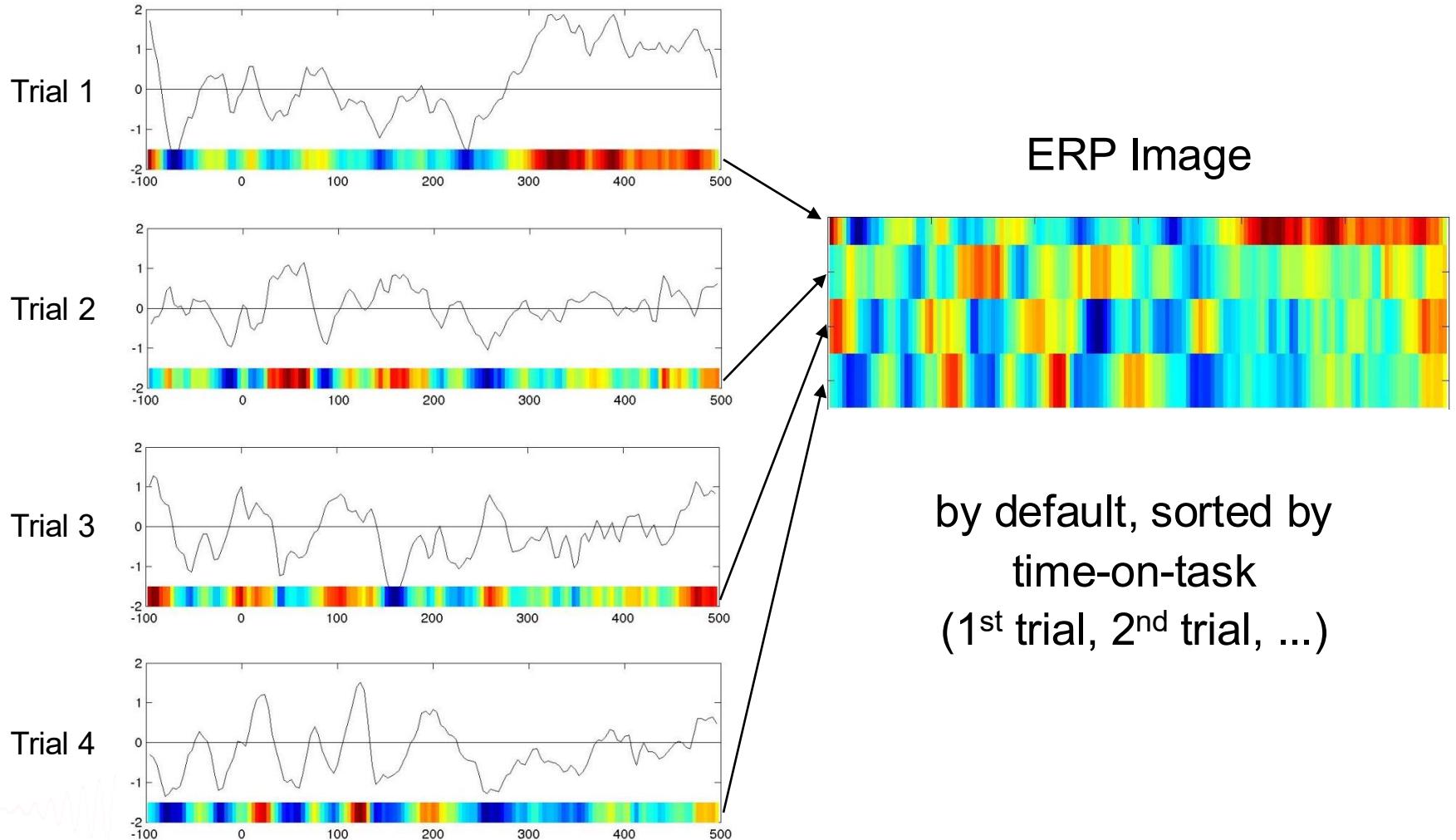
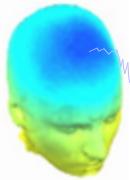
#3: Merged data

Channel locations

- Channel data (scroll)
- Channel spectra and maps
- Channel properties
- Channel ERP image
- Channel ERPs
- ERP map series
- Channel time-frequency

- Component activations (scroll)
- Component spectra and maps
- Component maps
- Component properties
- Component ERP image**
- Component ERPs
- Component time-frequency

ERP Image basics



ERP Image basics

Trial 1:



Trial 2:



.

.

.

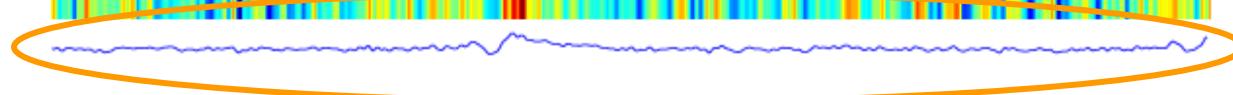
.

.

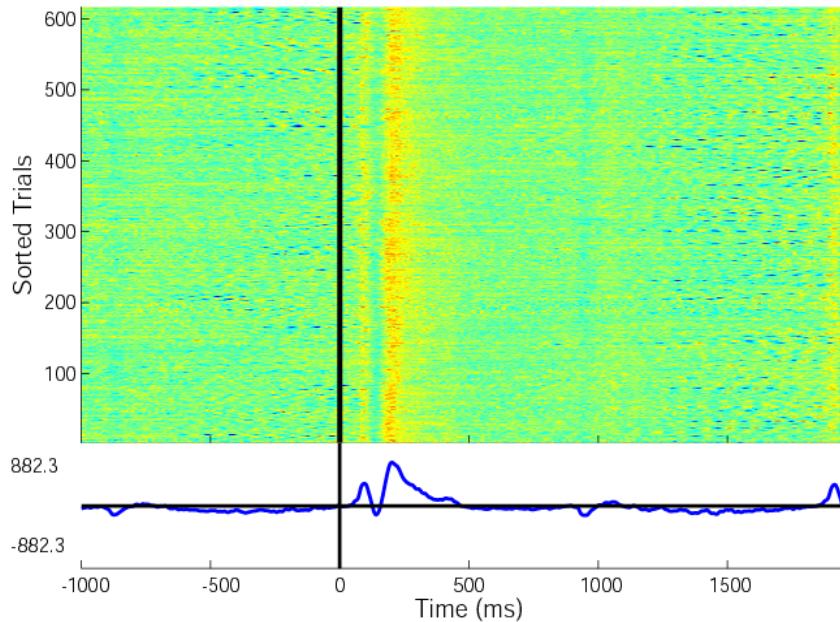
.

.

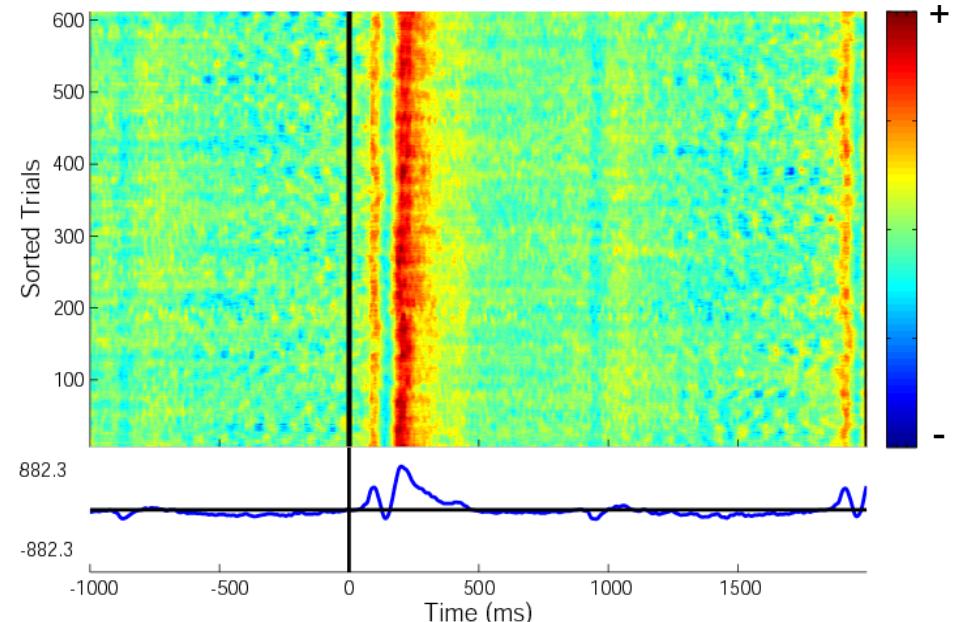
.



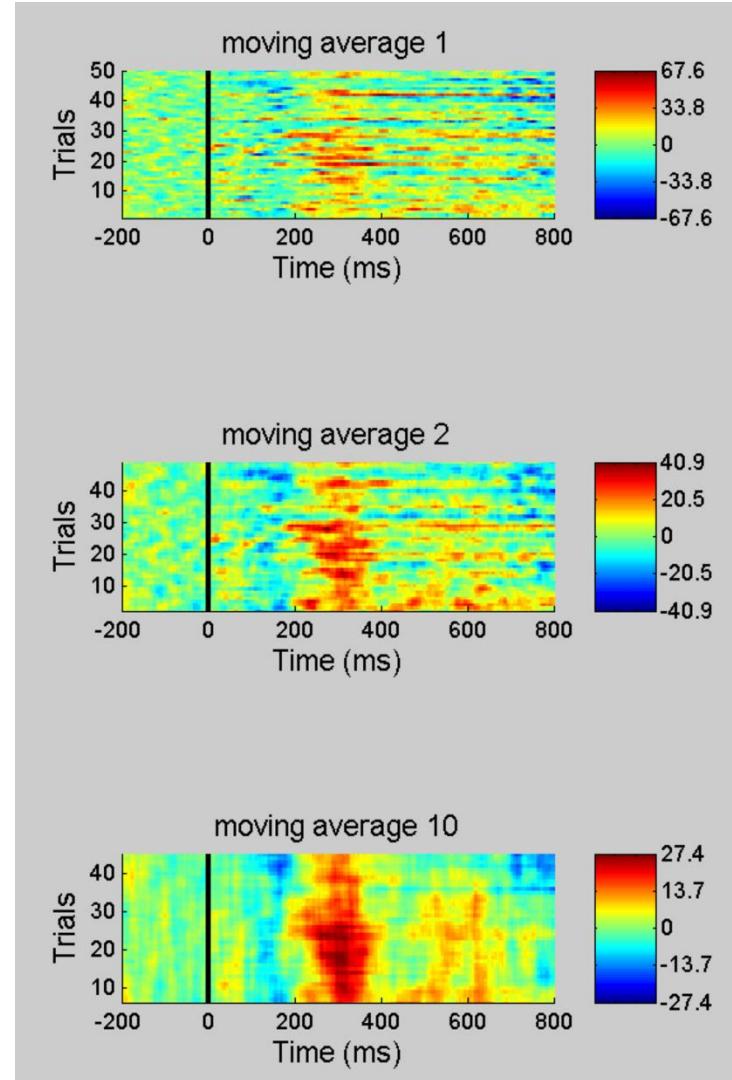
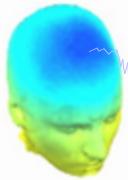
No Smoothing



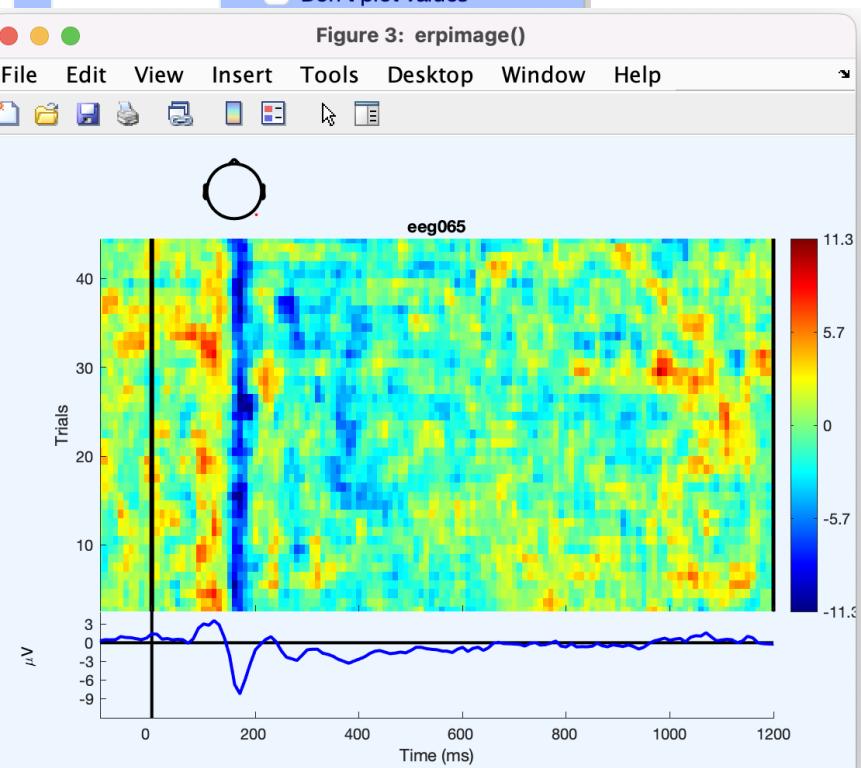
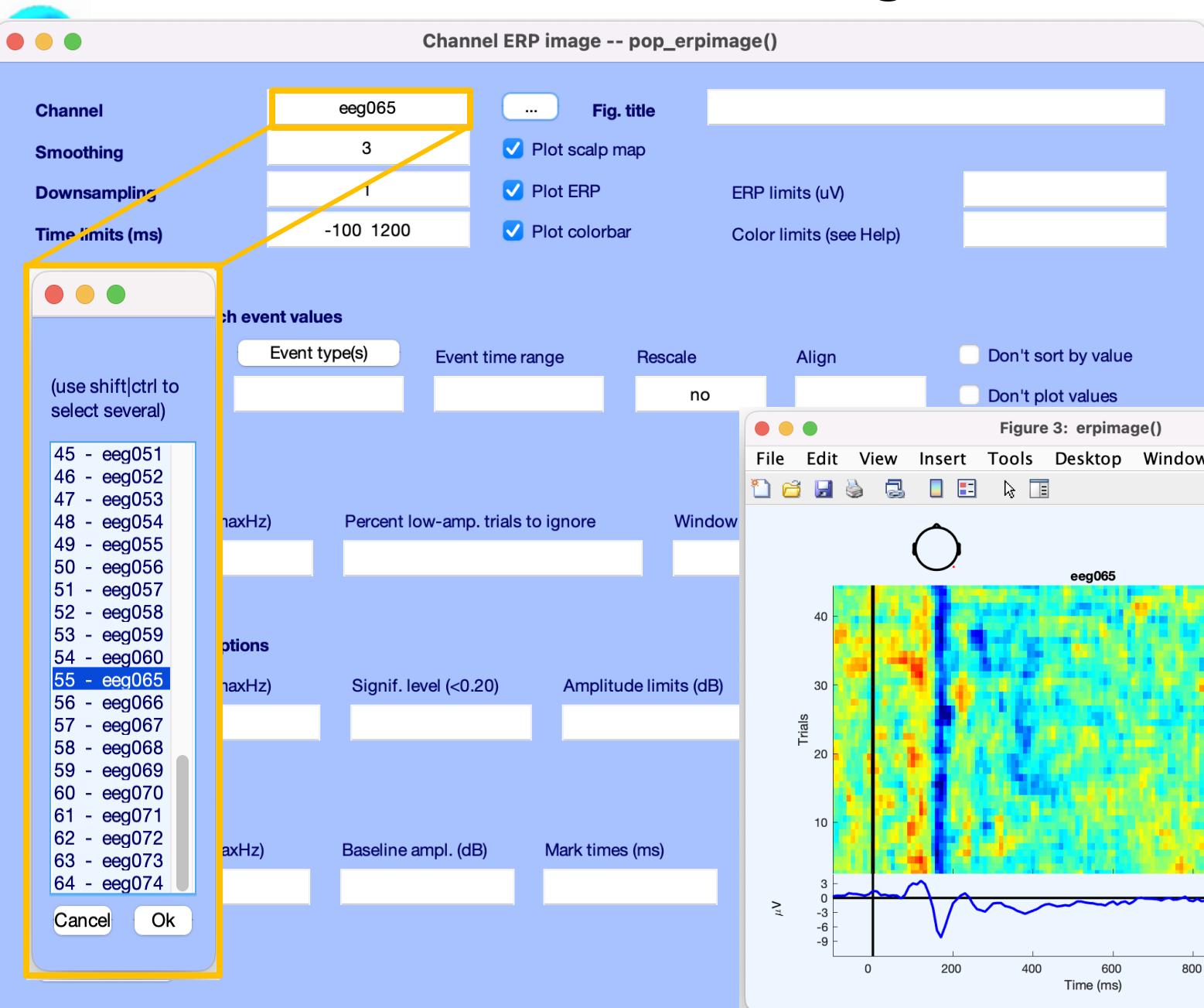
Smoothed across 10 Trials



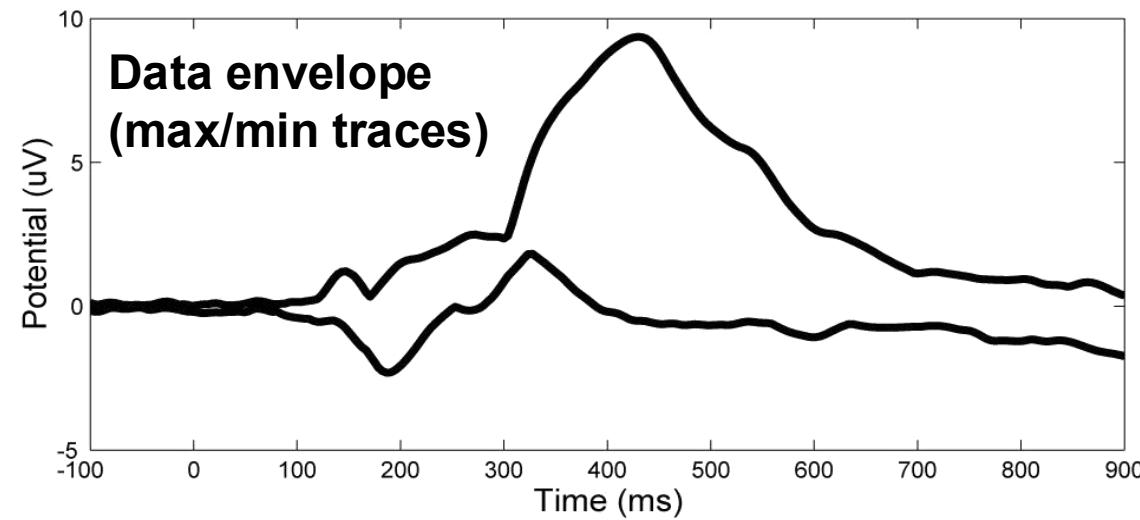
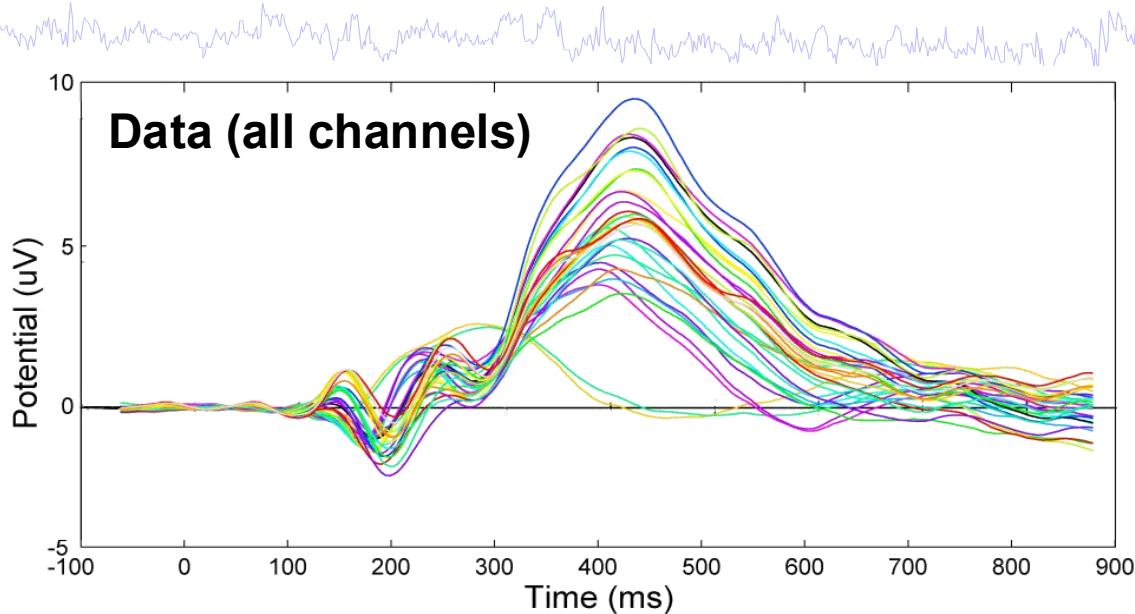
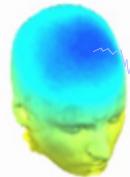
ERP Images: smoothing across trials



Channel ERP Image



Definition: The data envelope



Definition: IC Envelope

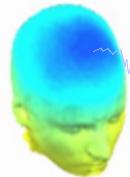
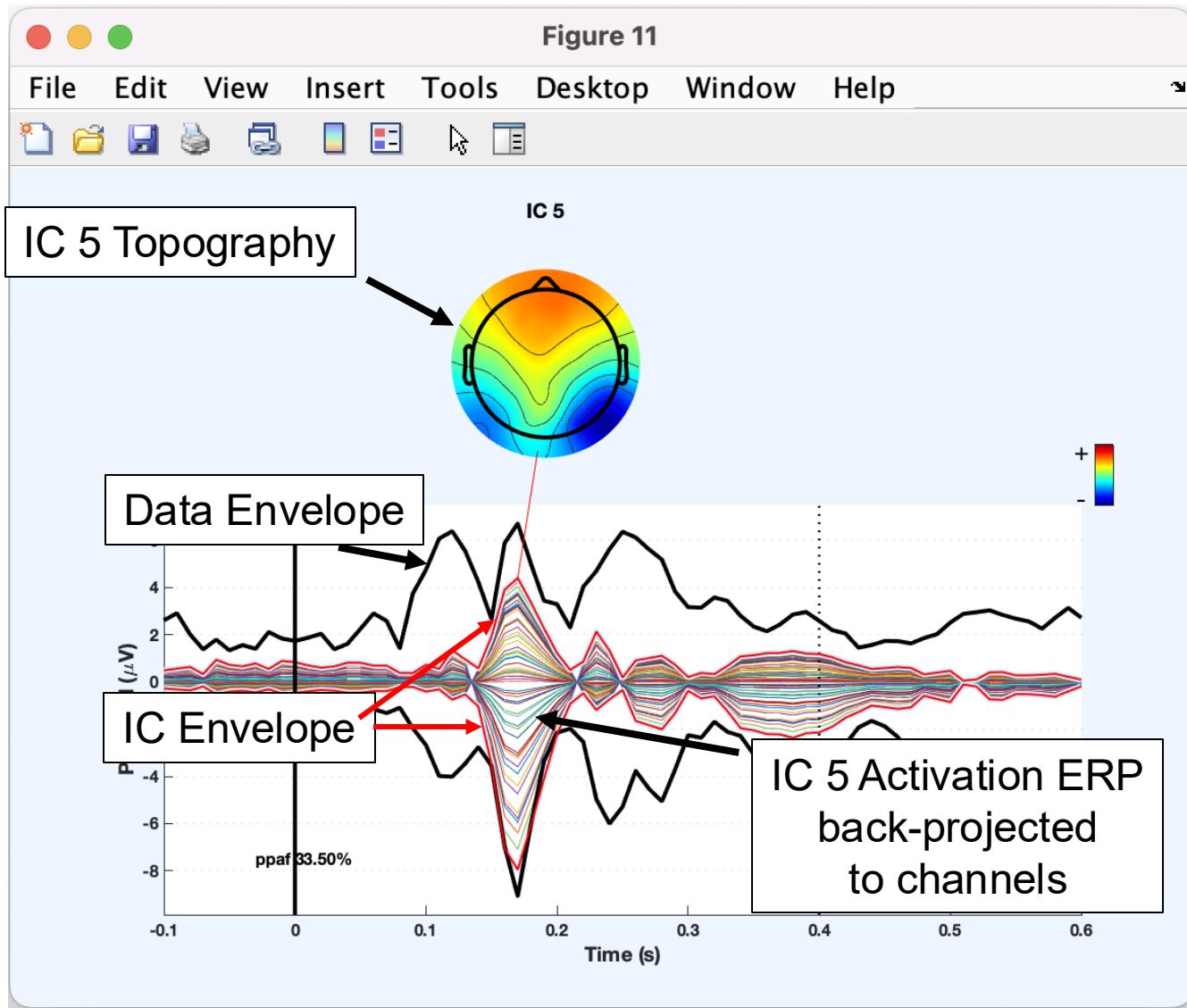
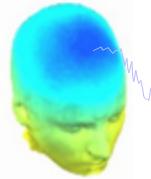
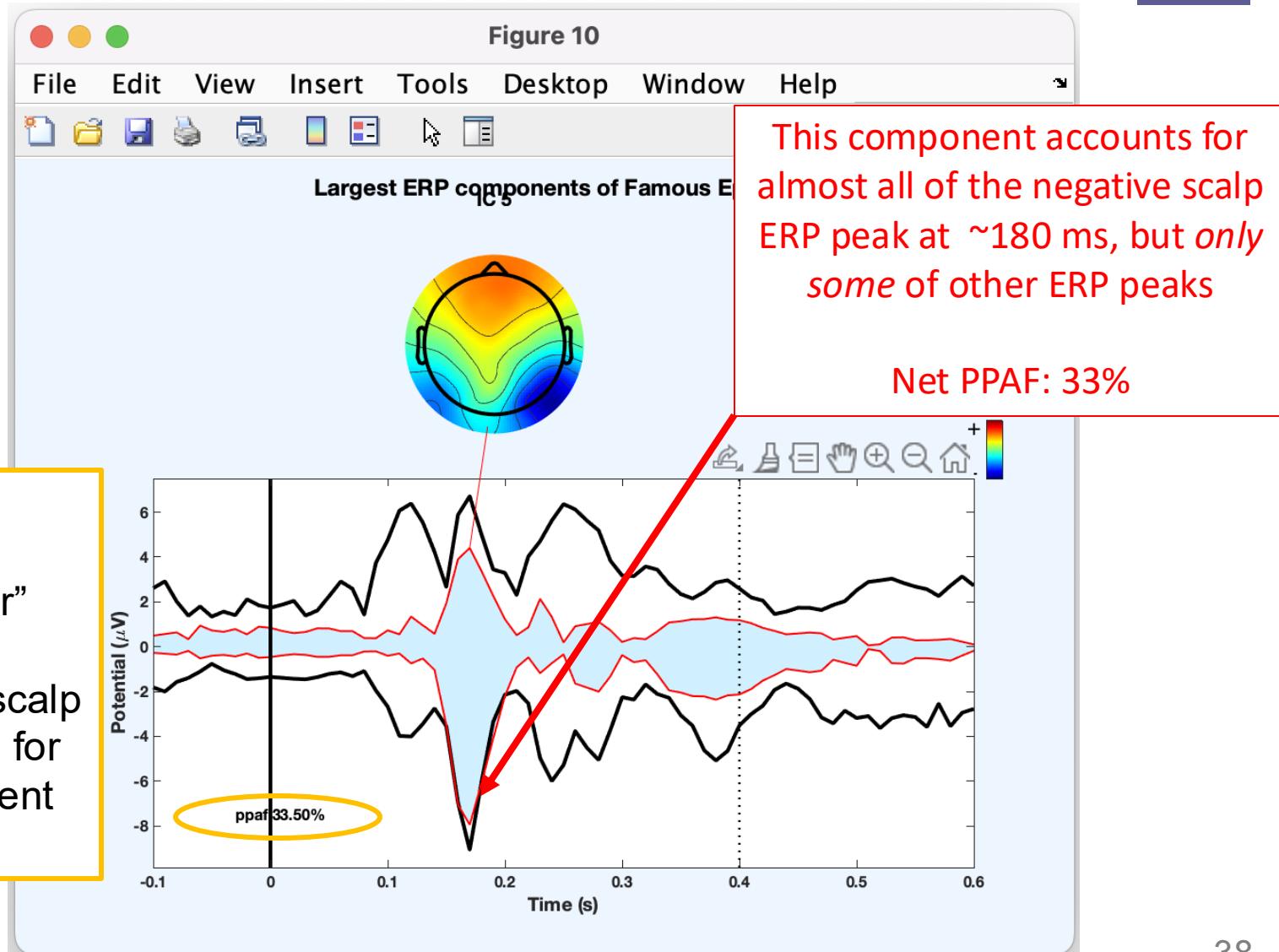


Figure 11

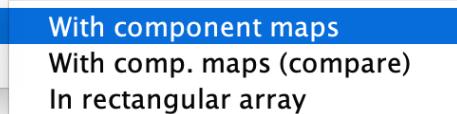
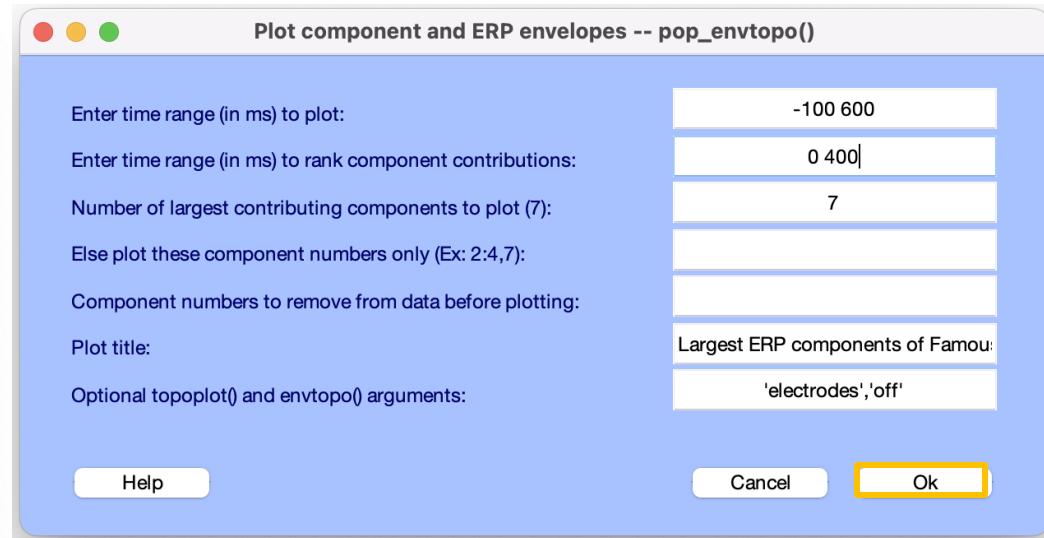
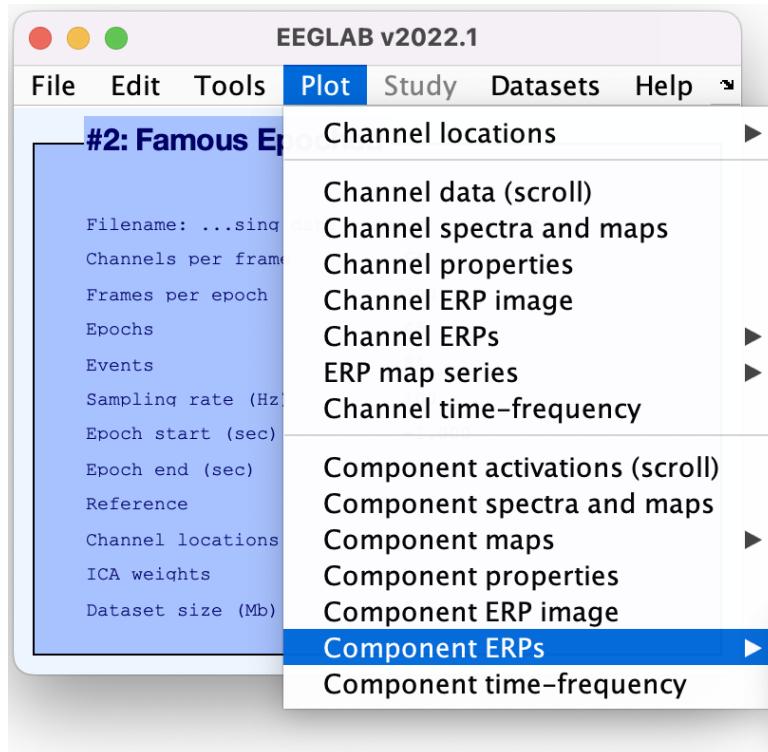
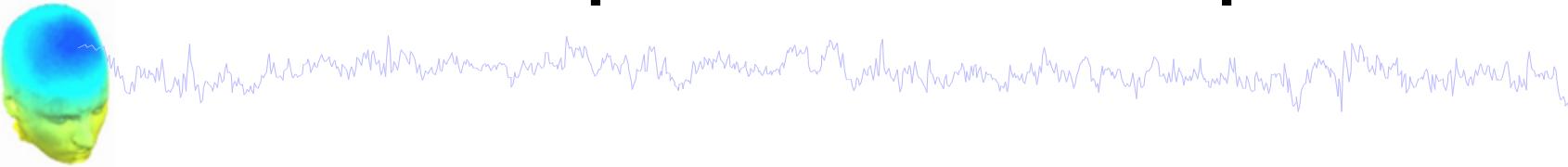




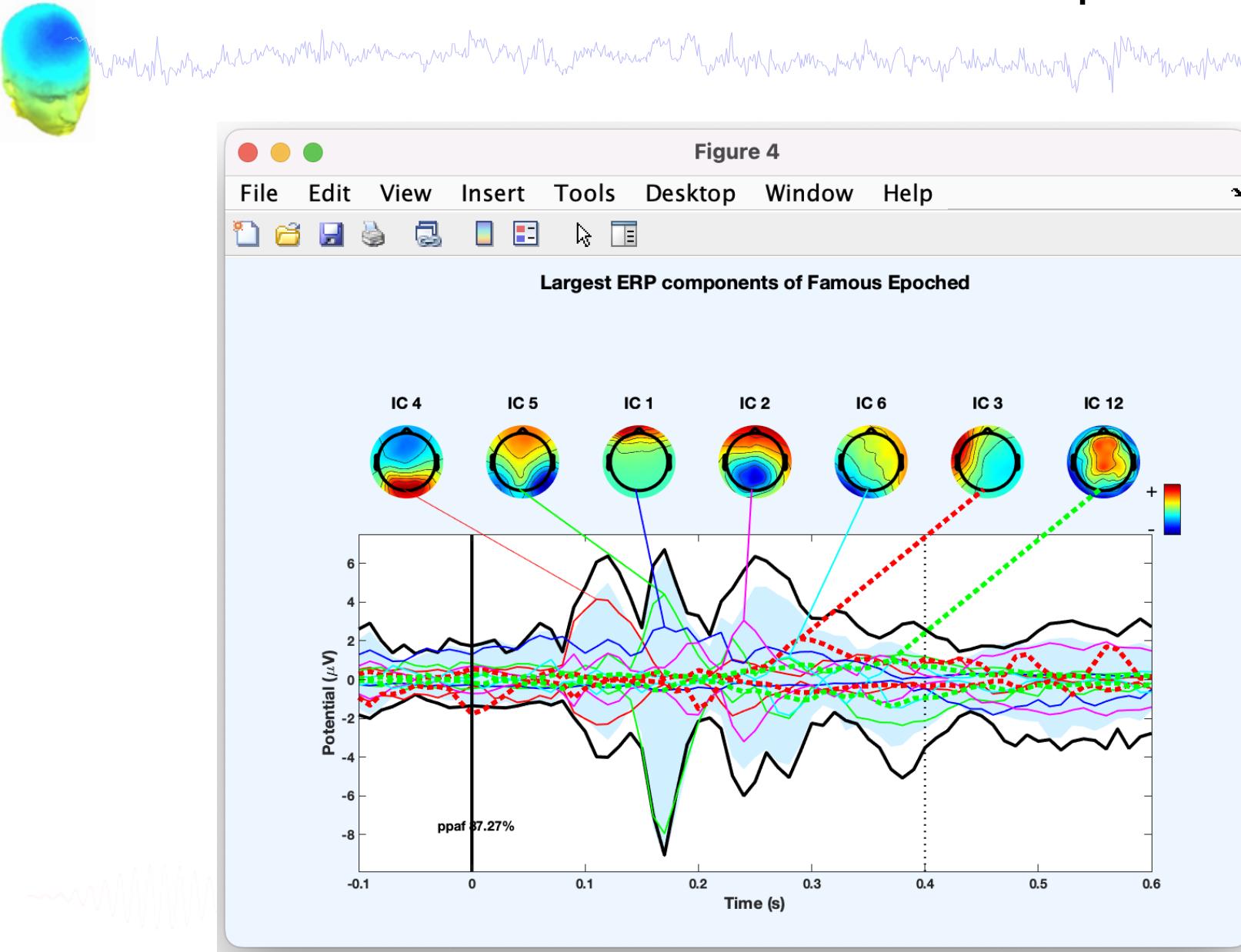
Key: Scalp ERP peaks are often the sum of multiple independent source processes



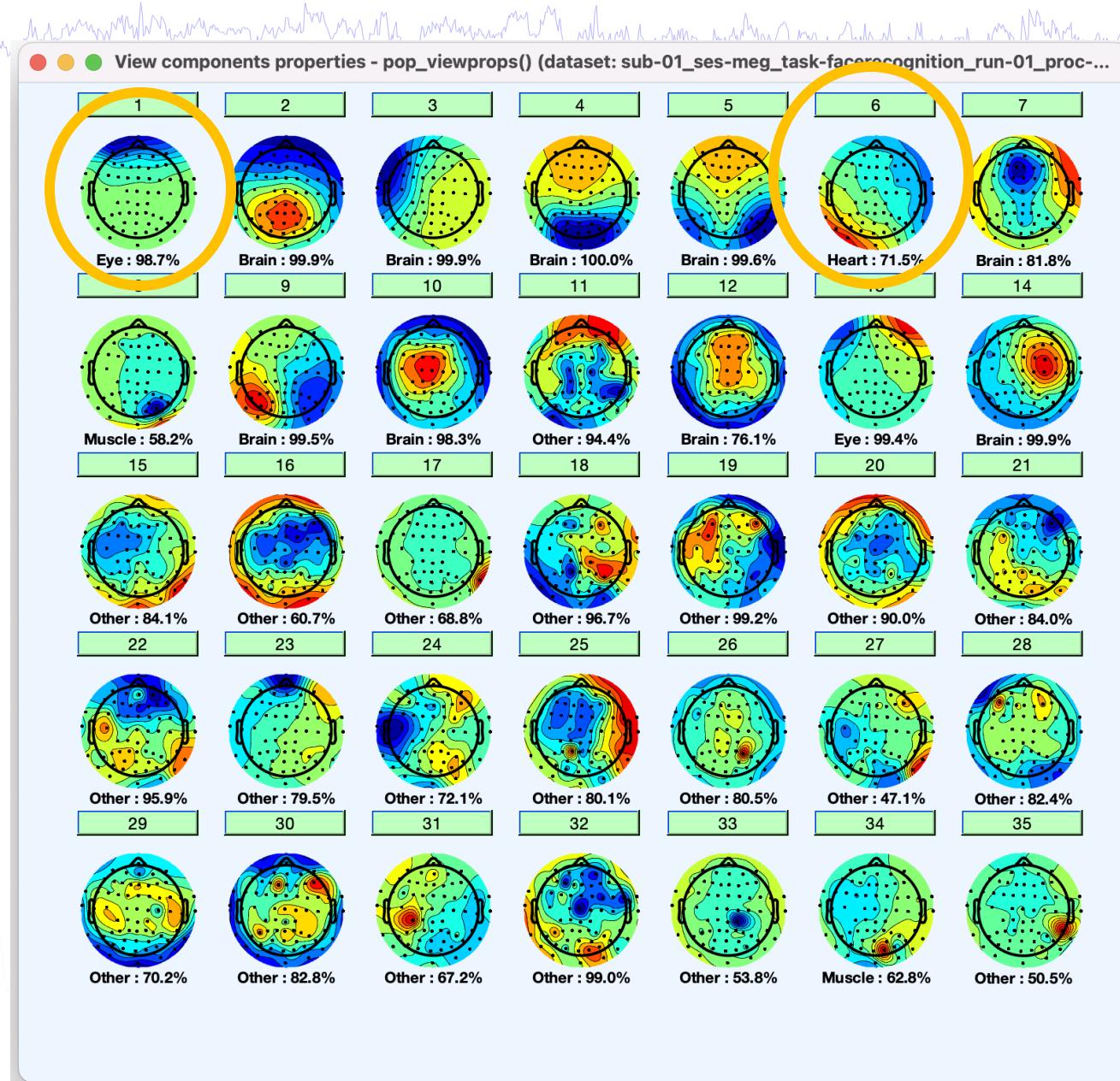
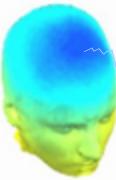
Component ERP envelope



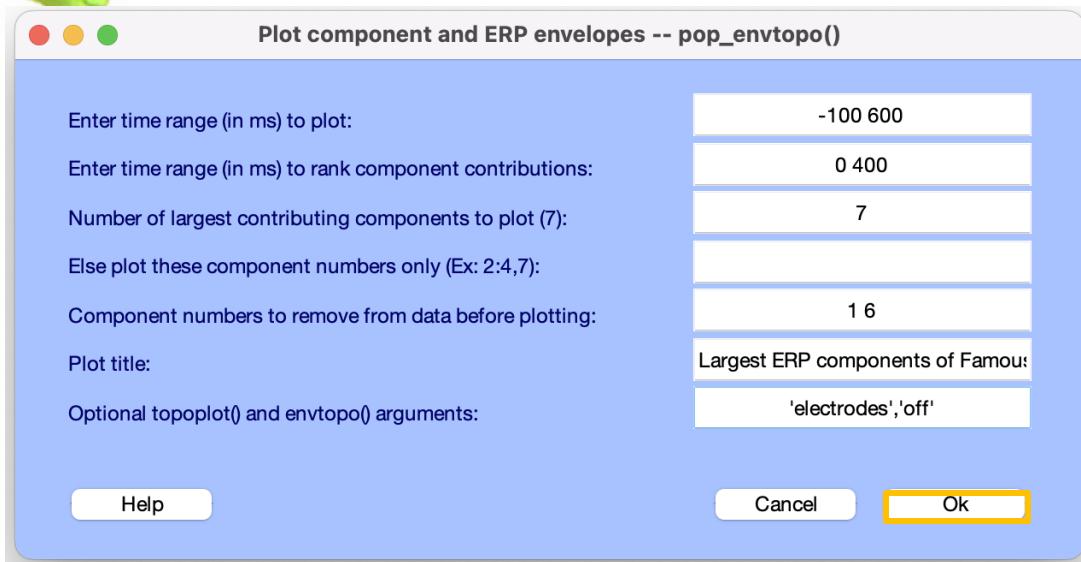
IC contributions to ERP envelope



IC contributions to ERP envelope



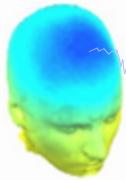
IC contributions to ERP envelope



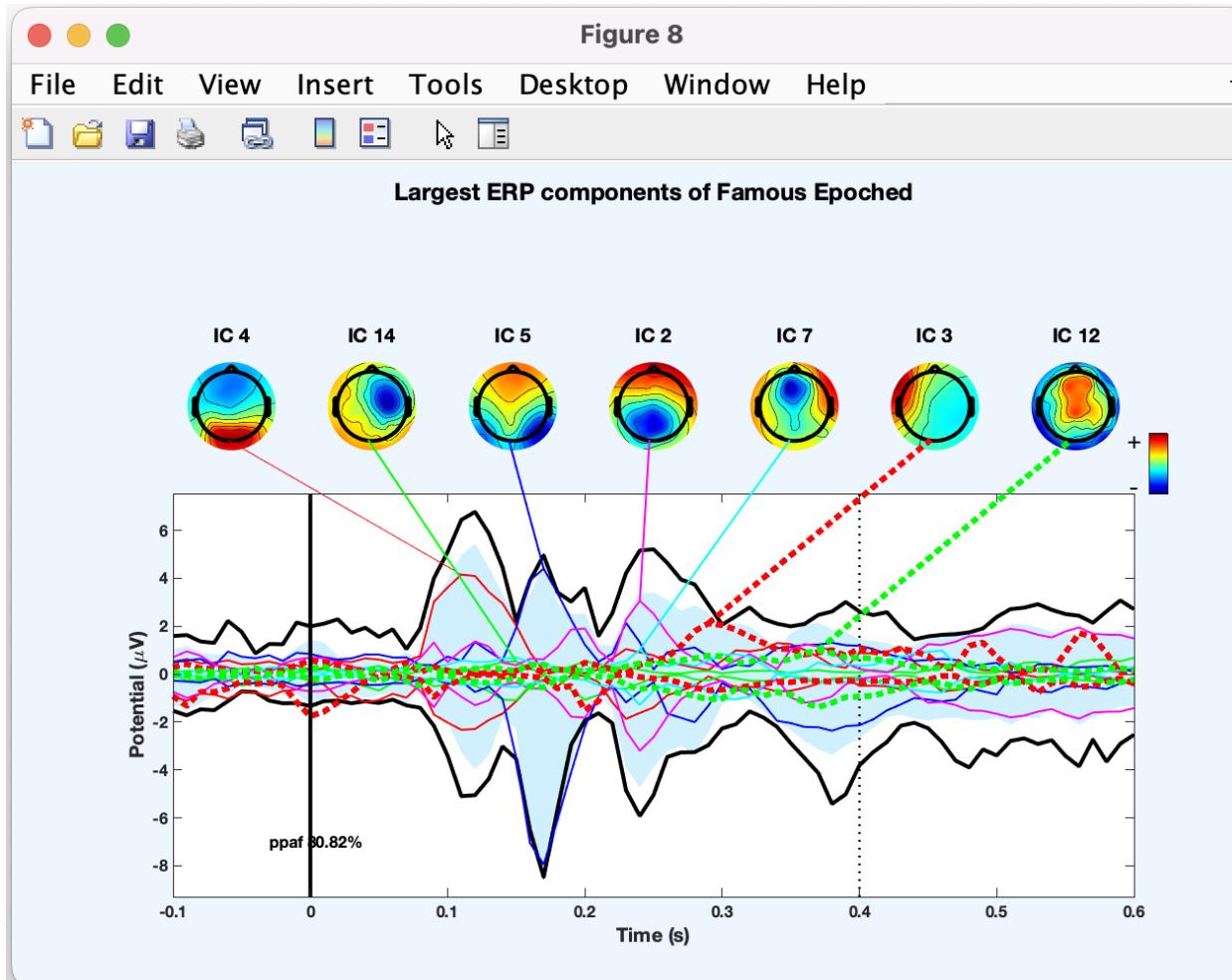
Removing artefact ICs



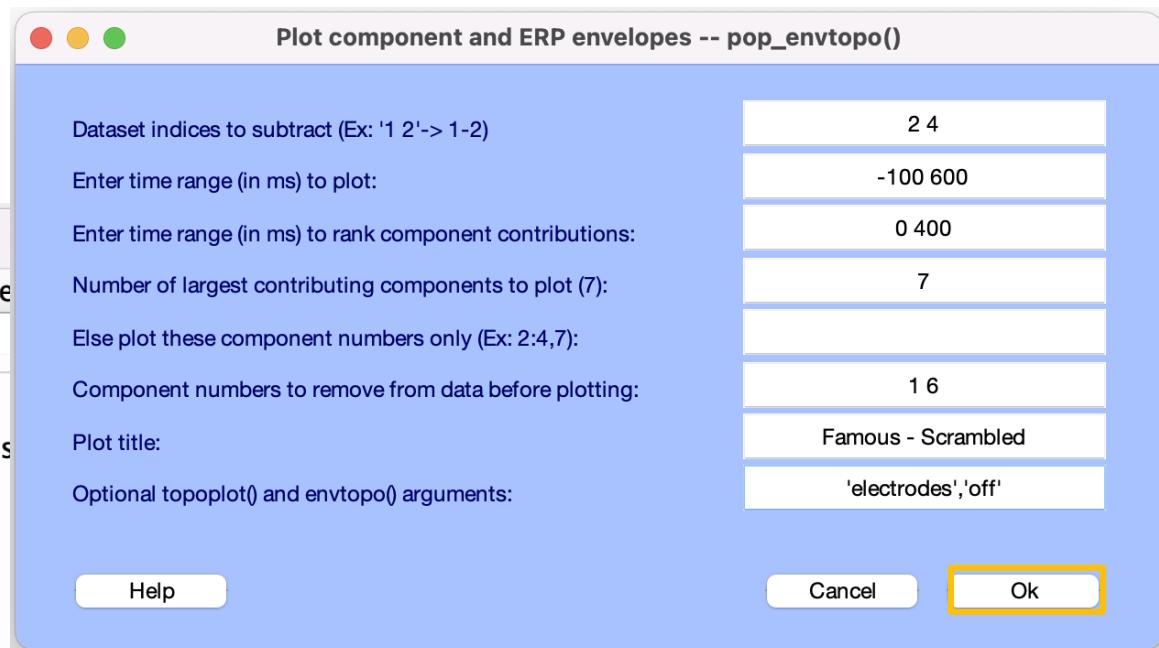
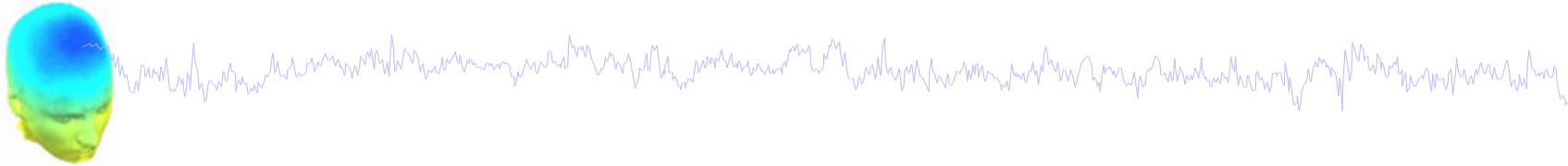
IC contributions to ERP envelope



Removing artefact ICs

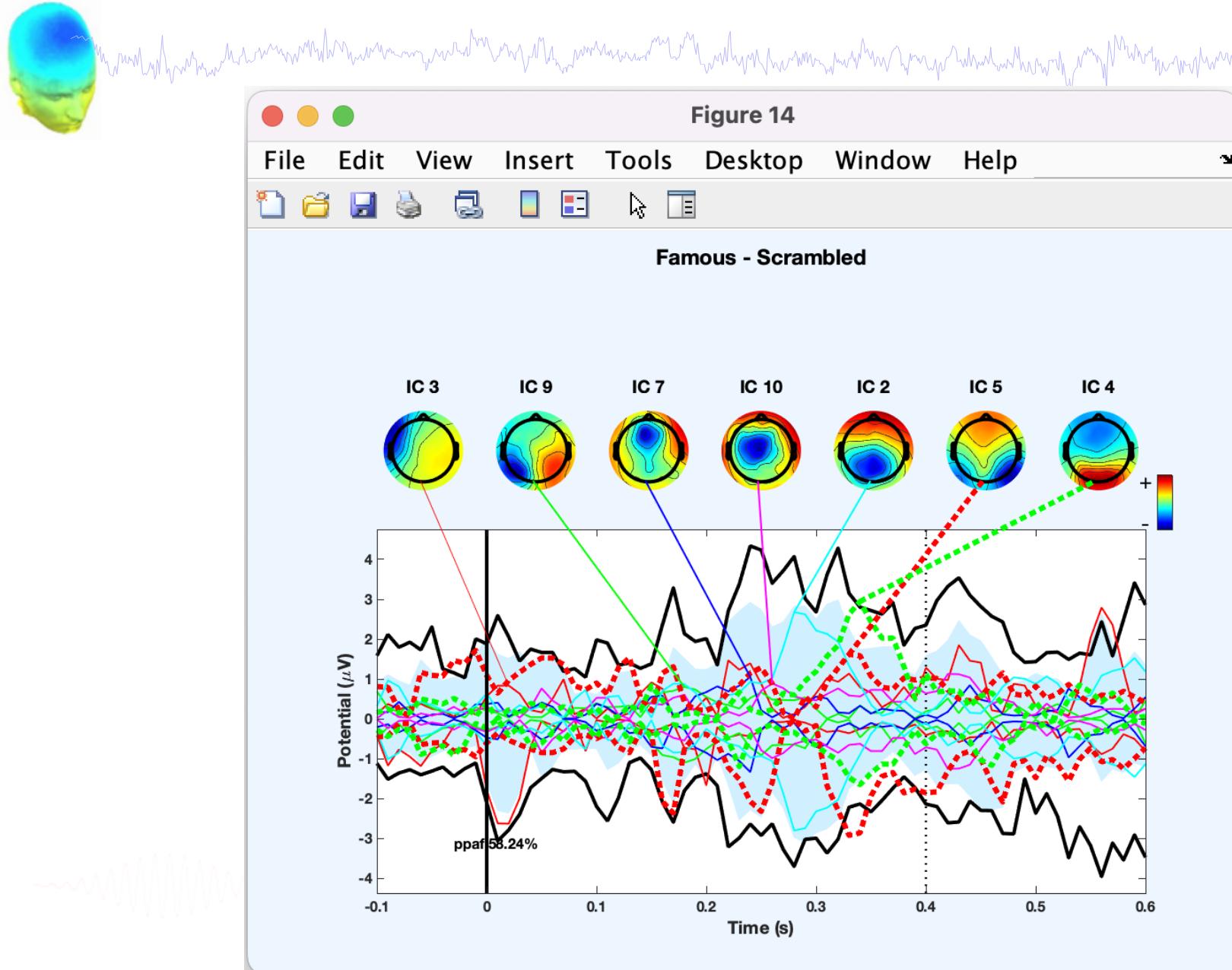


IC ERP difference between two conditions

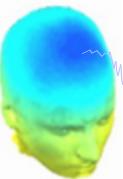


- With component maps
- With comp. maps (compare)
- In rectangular array

IC ERP difference between two conditions



Plot maximum contributing components



EEGLAB v2022.1

File Edit Tools Plot Study Datasets Help

#2: Famous Ep

Channel locations

Channel data (scroll)

Channel spectra and maps

Channel properties

Channel ERP image

Channel ERPs

ERP map series

Channel time-frequency

Component activations (scroll)

Component spectra and maps

Component maps

Component properties

Component ERP image

Component ERPs

Component time-frequency

With component maps

With comp. maps (compare)

In rectangular array

Plotting time range (ms): -100 600

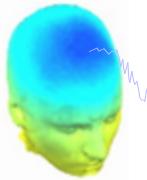
Scalp map latencies (ms, NaN → max-RMS) 120 170 250

Plot title: ERP data and scalp m

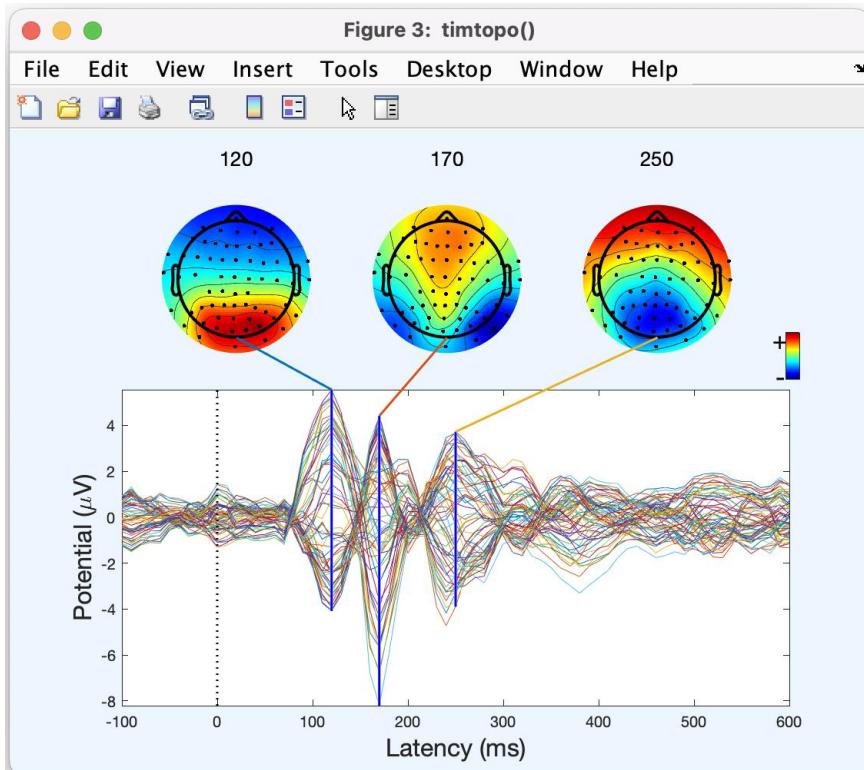
Scalp map options (see >> help topoplot):

Help Cancel Ok

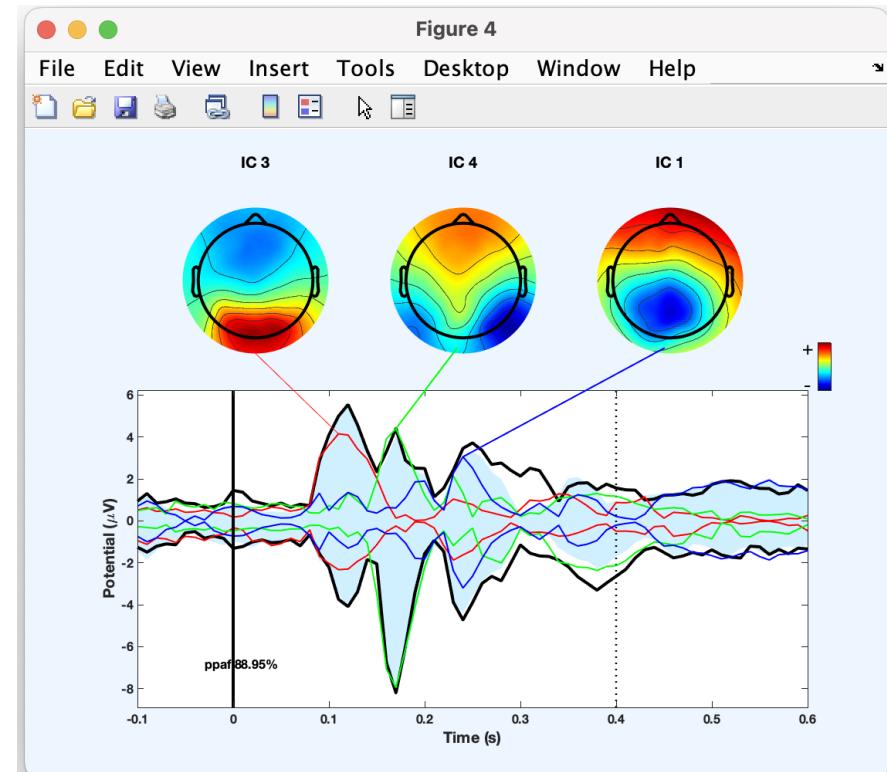
Plot maximum contributing components



Channel scalp distribution



Maximum contributing ICs
from 0 to 400ms



Note the similarity in channel scalp topography at the 3 ERP peaks and IC topography - ICA is able to separate the 3 distinct brain processes reflected in the 3 ERP peaks



Hands On!



Import preprocessed file using menu item **File > load existing dataset**

ds000117_pruned/derivatives/meg_derivatives/sub-01/ses-meg/meg/
wh_S01_run_01_preprocessing_data_session_1_out.set

(run *script_01_import_data.m* and *script_02_preprocess_data.m* to generate this file)

Extract epochs for famous stimuli using menu **Tools > Extract epochs**. Leave all defaults (minus 1 to 2 seconds). Do not remove the baseline.

Plot envelope and look at scalp topography at 170 ms (face-related potential) using menu item **Plot > Plot channel ERPs > With scalp maps**

Plot ERPimage for channel 65 between -100 ms and 500 ms using menu item **Plot > Plot ERPimage**

Plot ICA component contribution to the ERP between 100 ms and 200 ms using menu item **Plot > Plot component ERPs > With component maps**

(run *script_03_epochs_and_erp.m* to generate data epochs files for famous, scrambled and unfamiliar stimuli – these files are used in subsequent lectures)