# University of Moratuwa

Department of Electronic and Telecommunication Engineering


BM4152

Bio-signal Processing

## Multi-channel EEG: Analyzing using EEGLAB

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# Part 1: Installing EEGLAB and importing data

1. EEGLAB opensource MATLAB toolbox is installed according to the given instructions.

2. Then the *xdf import* plugin is installed and then using that the *trial_2.xdf* file is imported and named as *raw_data.*

   Information of the dataset is as follows.

# Part 2: Data preparation, time and frequency domain analysis

3. Channel labels

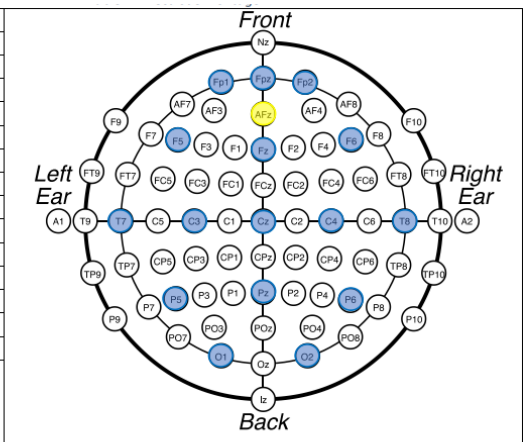
3.1. Channel location information is given using the provided *electrode_locations.locs* file.

3.2. Then it shows in dataset information GUI as follows

| | |
|---|---|
| Channel locations | Yes |

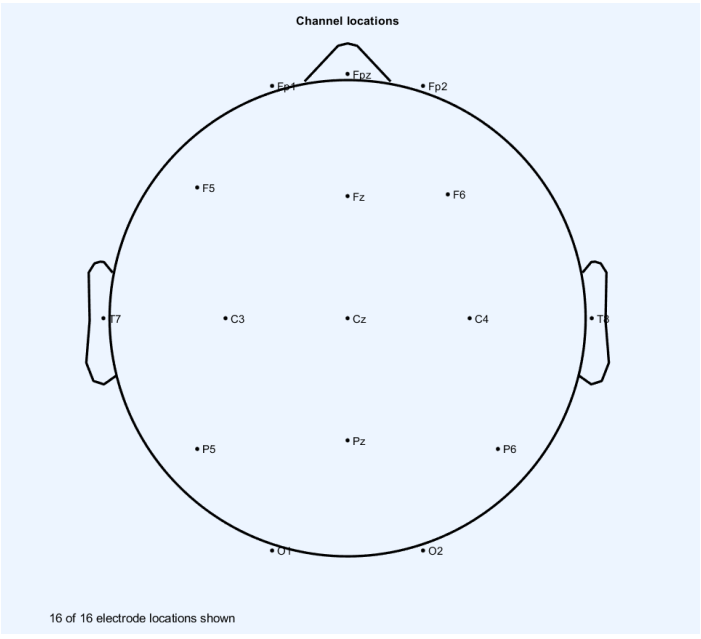
3.3.

Channel locations used during the practical are as follows.

| | | |
|---|---|---|
| 1 | Fp1 |  |
| 2 | Fpz | |
| 3 | Fp2 | |
| 4 | F5 | |
| 5 | Fz | |
| 6 | F6 | |
| 7 | T7 | |
| 8 | C3 | |
| 9 | Cz | |
| 10 | C4 | |
| 11 | T8 | |
| 12 | P5 | |
| 13 | Pz | |
| 14 | P6 | |
| 15 | O1 | |
| 16 | O2 | |
| GND | AFz | Common Ground |
| Z1 | Any location | For impedance measurements |

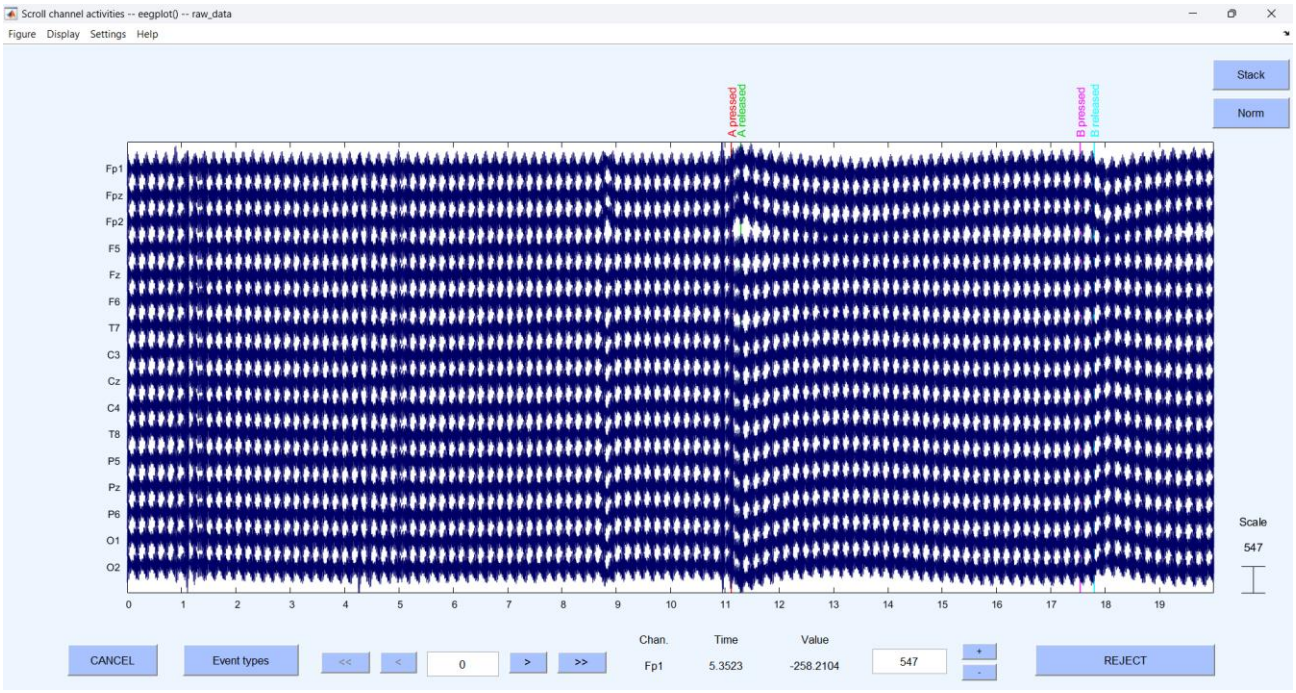


Channel locations in the *electrode_locations.locs* file.



By comparing the electrode positions in both cases, it is clear that the channel locations are correct and well aligned. However, small deviations may have occurred when placing the electrodes on the subject due to the irregular shape of the skull, which is not perfectly spherical. This could cause slight variations in the exact placement.

4. Visualize data in time domain.



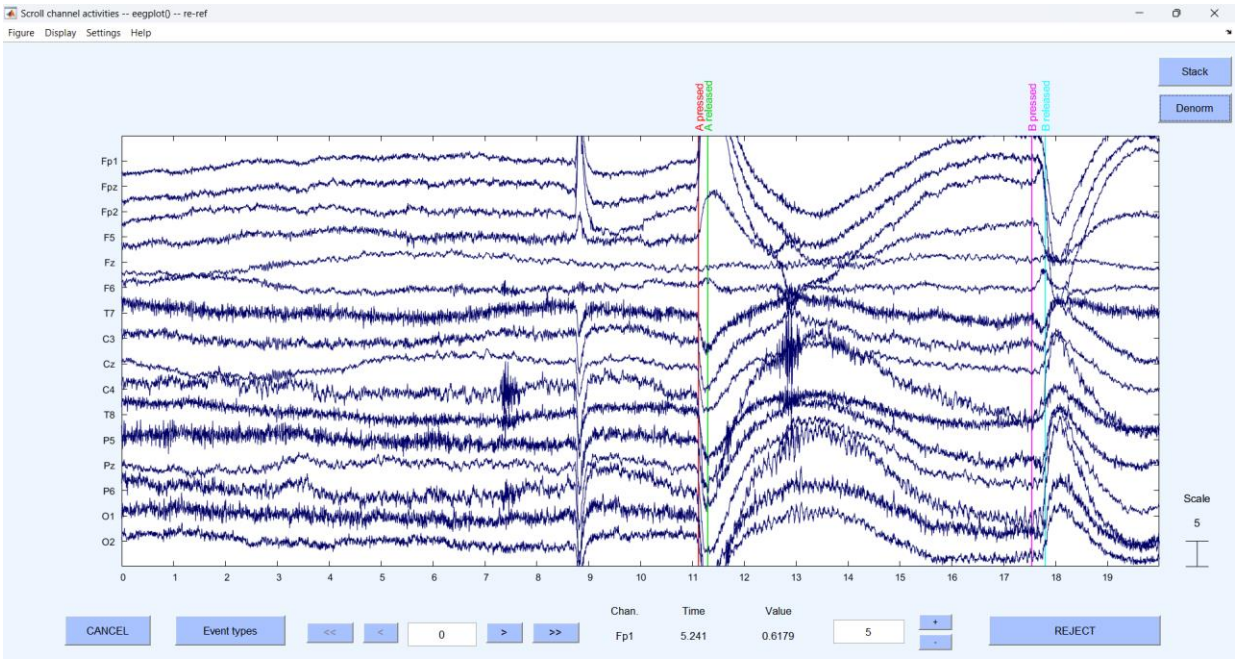

5. Re-referencing

Re-referencing in EEG signal processing refers to the process of selecting a new reference point (or electrode) to improve signal quality and reduce the common mode noise. EEG signals are typically recorded as the difference in voltage between an active electrode and a reference electrode. By re-referencing, the recorded signals are recalculated relative to a different reference electrode or set of electrodes.

Average referencing is one oof the common referencing techniques where the average of all electrodes is used as the new reference.

Here we can clearly observe that the signals have less noise and the some electrical activities are clearly visible.

Referenced and then normalized plot of EEG data is given below.




6. Event renaming

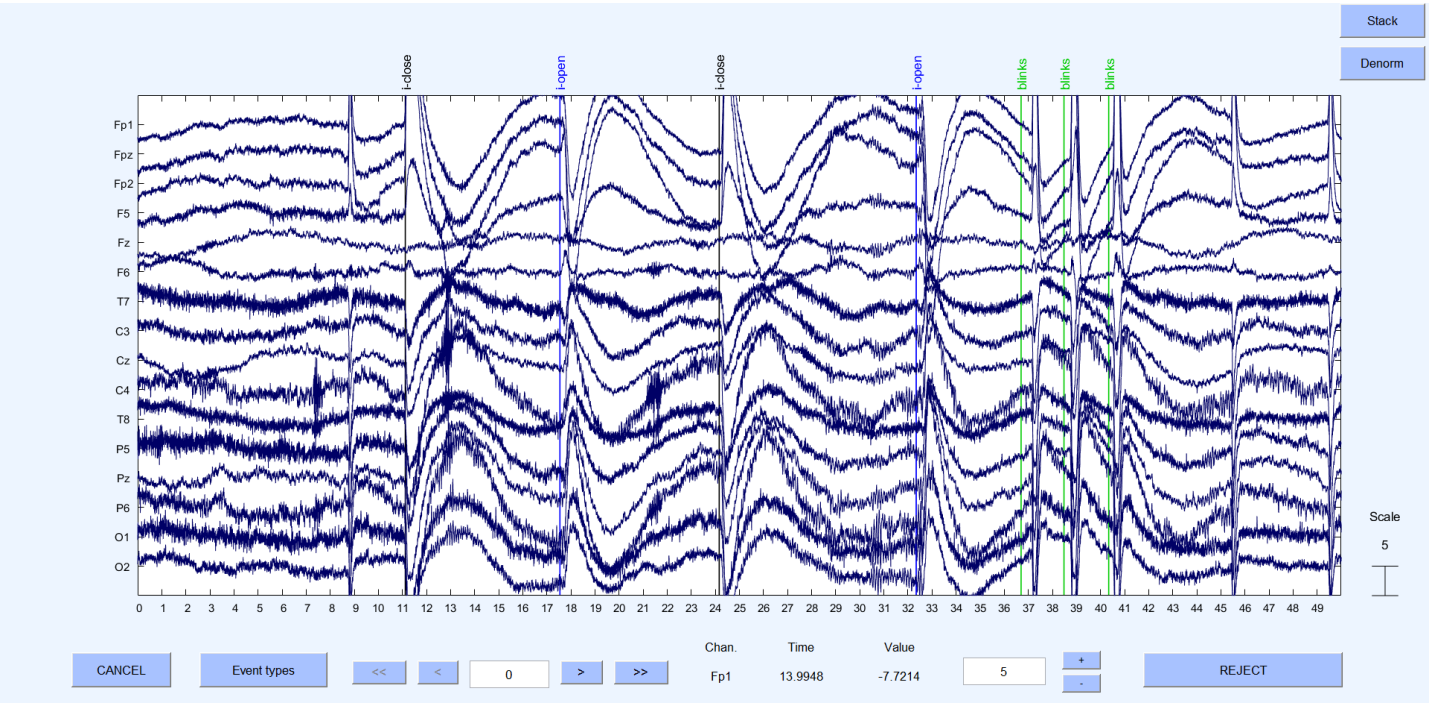
   Events are renamed according to the information in practical guidance.

| Event key | Event description | Event short-name |
|---|---|---|
| A | Eyes closed | i_close |
| B | Eyes open | i_open |
| C | Blink (close and open) | blinks |
| D | Eyeball movement left-right (eyes open) | i_LR |
| E | Eyeball movement up-down (eyes open) | i_UD |
| F | Teeth clenching | teeth |
| G | Head movement (random) | Head |
| H | Noise source ON | noise_ON |
| I | Noise source OFF | noise_OFF |

*Table 3 - Sequence of events*

| Event key | Duration (s) | Description |
|---|---|---|
| - | 10 | Relaxed and eyes open (default) |
| A | 5 | |
| B | 5 | |
| A | 5 | |
| B | 5 | |
| - | 5 | Relaxed and eyes open (default) |
| C | | |
| C | | |
| C | | |
| D | | Center-left-right-center |
| - | 5 | Relaxed and eyes open (default) |
| E | | Center-up-down-center |
| - | 5 | Relaxed and eyes open (default) |
| F | 2 | |
| - | 5 | Relaxed and eyes open (default) |
| F | 2 | |
| - | 5 | Relaxed and eyes open (default) |
| F, C | 5 | Together |
| - | 5 | Relaxed and eyes open (default) |
| G | 5 | |
| - | 10 | Relaxed and eyes open (default) |
| H | 5 | Near the right temporal lobe |
| H, C | 5 | |
| I | 5 | |
| H | 5 | Near the left temporal lobe |
| H, C | 5 | |
| I | 5 | |

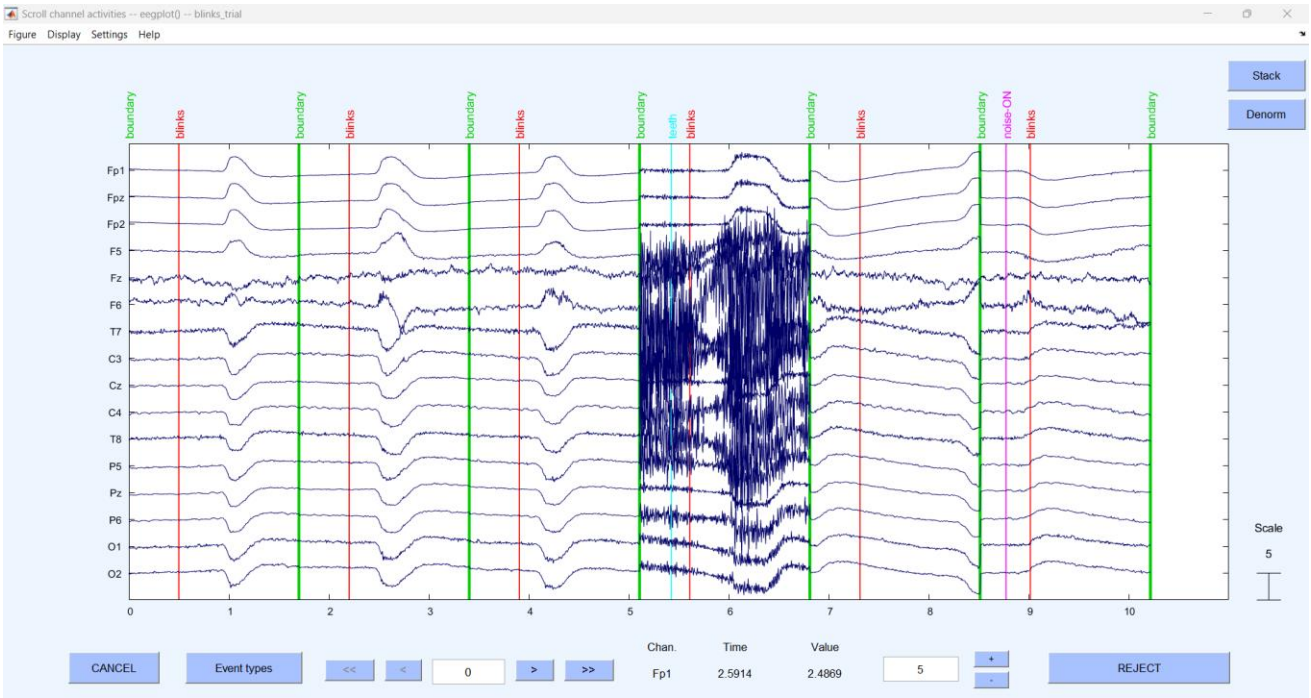
time domain plot with renamed events




7. Segmenting data related to events

Method 1: based on events

Eye blinking events are segmented: Set the start time limit to -0.5 from the event and end time limit to 1.2 from the event.




Segmented dataset is saved as *blinks_trials*.

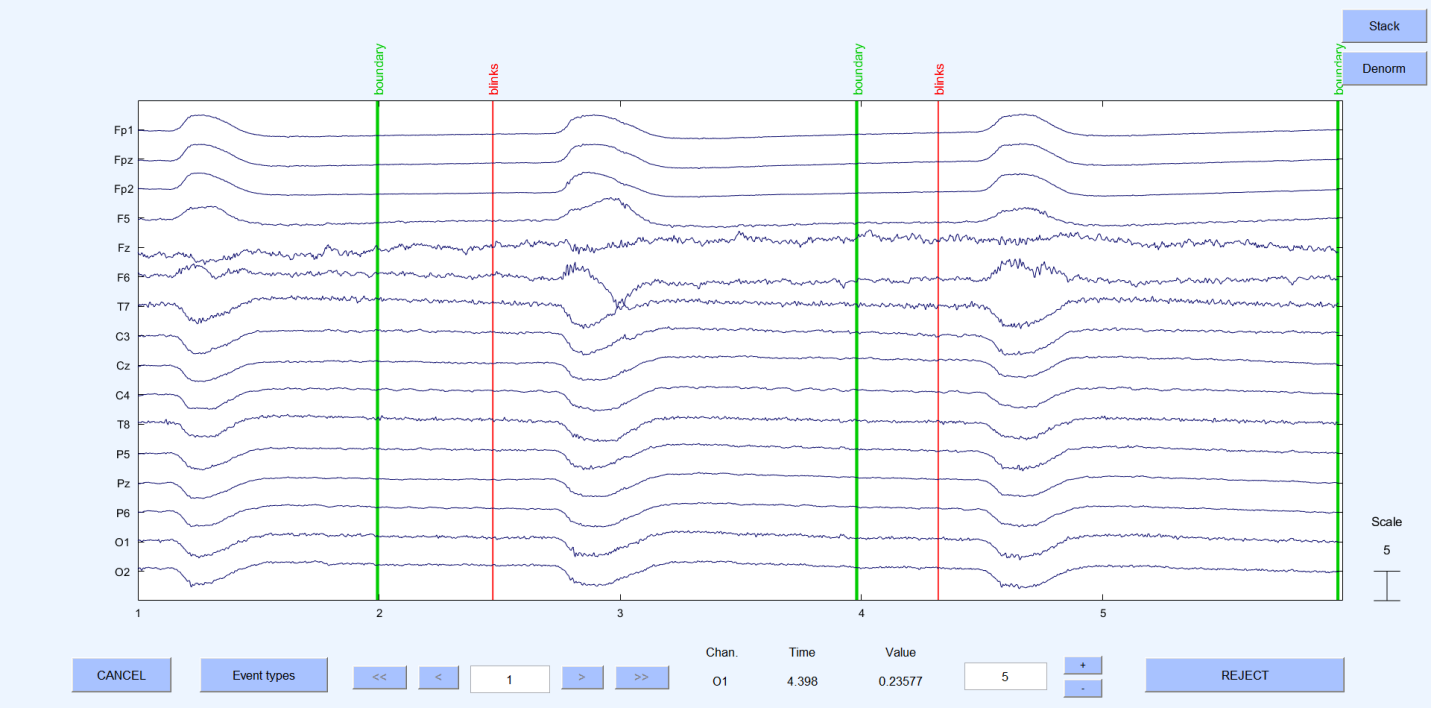
This method has few issues.

- Here we can observe that **some time windows include data from events before or after the target event**.

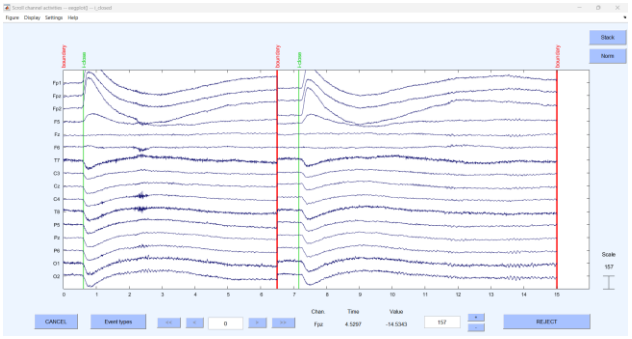
- In event-related data collection, a specific time window is typically chosen to capture data before and after an event. However, the accuracy of these markers is subjective, meaning it can vary based on judgment. This makes it **difficult to find an exact time window that always includes the intended event**. As a result, while the first three trials capture the blink, the last two miss it.

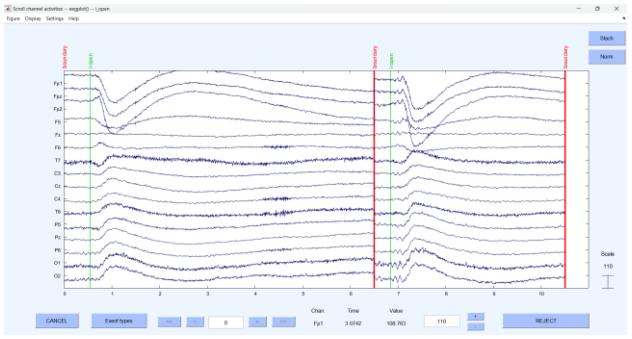
Method 2: based on time

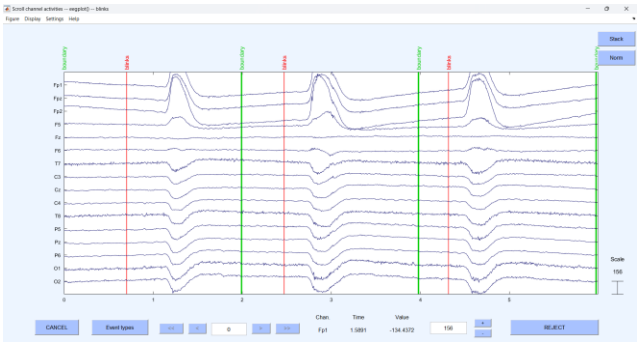
In this method since we manually select the time stamps looking at the recorded data we can isolate the desired events.

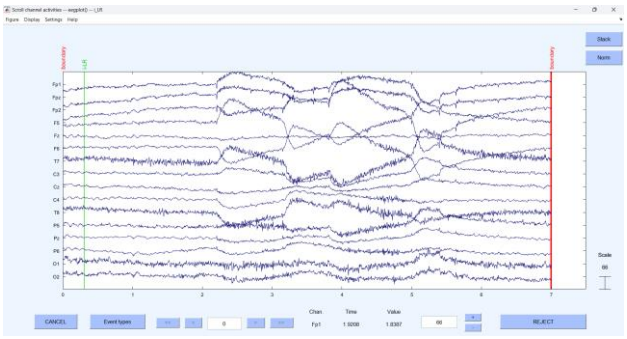


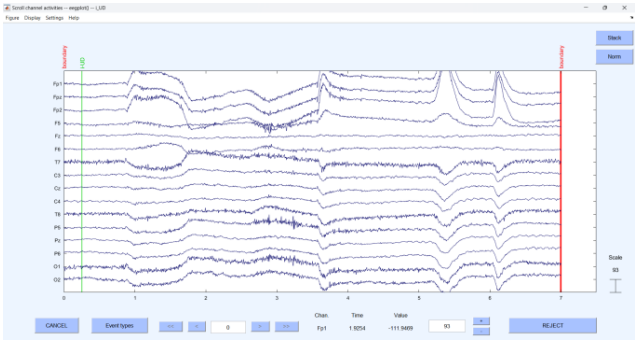

| Events | Time Stamps | Dataset name |
|---|---|---|
| i-close | [10.5 17; 23.5 32] | i_closed |
| i-open | [17 23.5; 32 36] | i_open |
| blinks | [36 38; 38 40; 40 42] | blinks |
| i-LR | [50.5 57.5] | i_LR |
| i-UD | [66 73] | i_UD |
| teeth | [80.5 83.5; 88.5 93.5] | teeth |
| teeth + blinks | [96 100.5] | teeth_blink |
| head | [109 118] | head |
| noise-OFF | [152.5 159; 180 183] | noise_OFF |
| noise-ON + blinks | [145 149; 173 176] | noise_ON_blink |

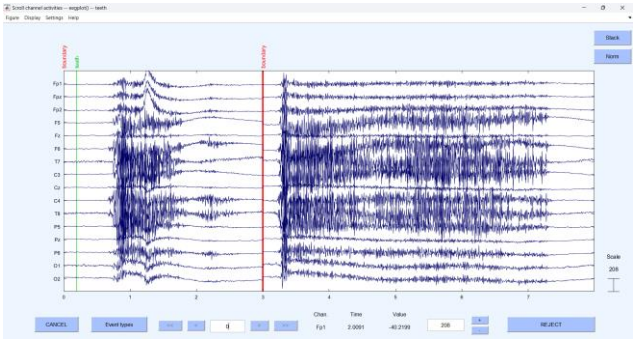


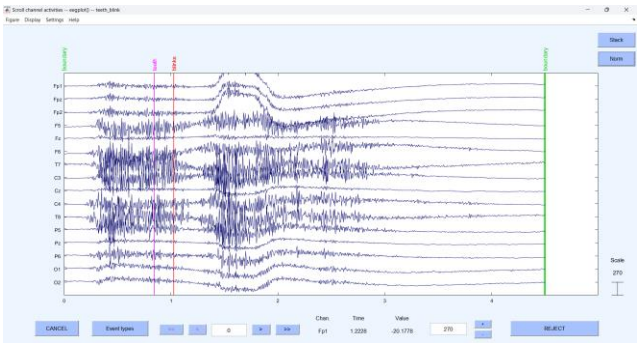


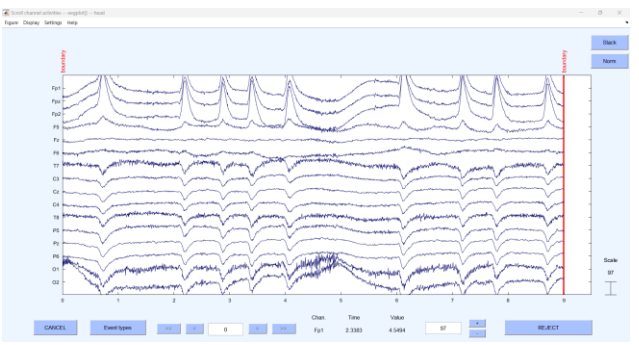


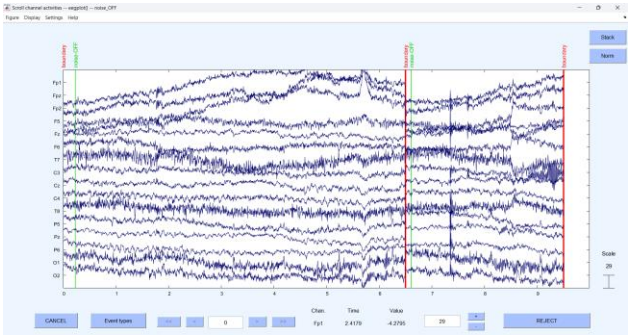


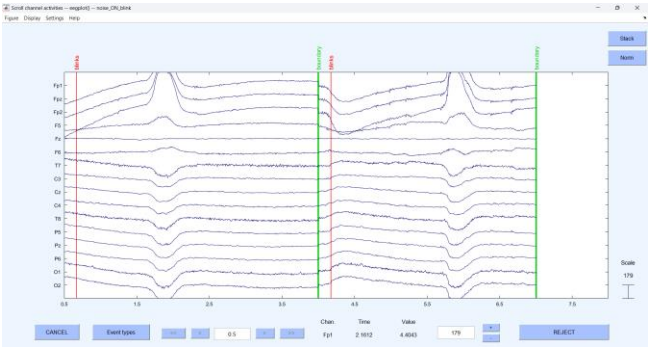








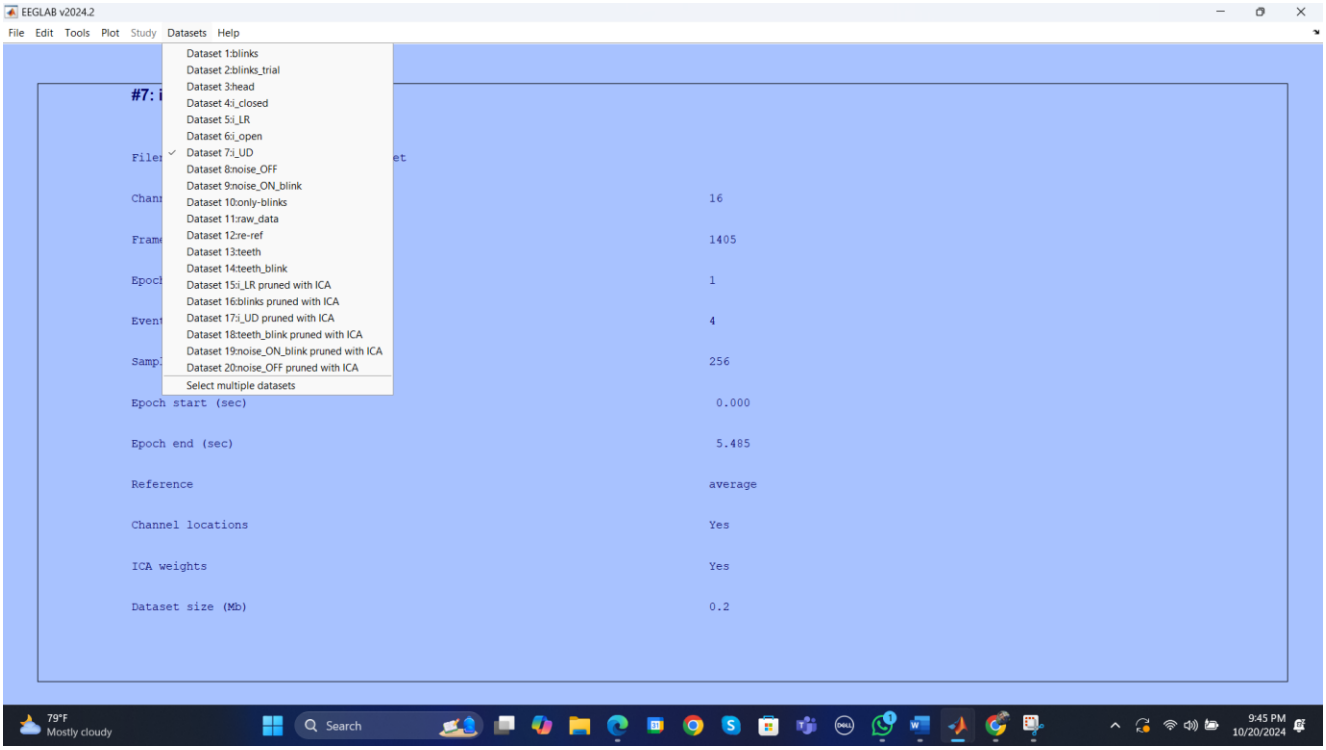




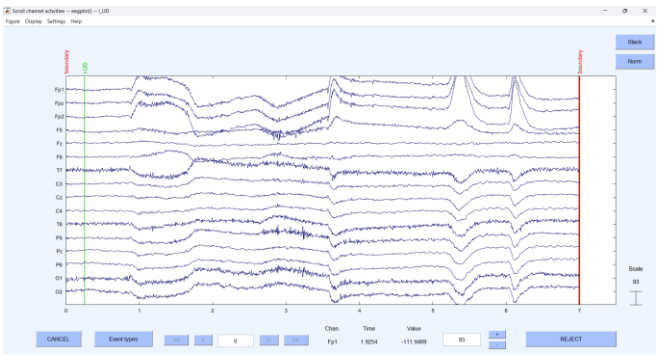
8.

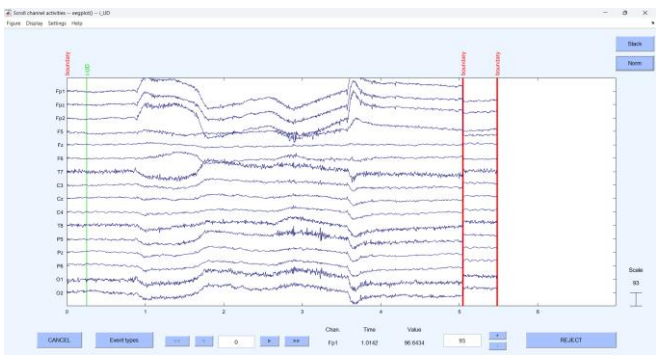
All the datasets after completing the lab.

** noise_ON dataset is not prepared as it is not given in the question 7.2.4. but only for the question 10.6 the dataset is temporarily prepared.




9. Manual rejection of artifacts



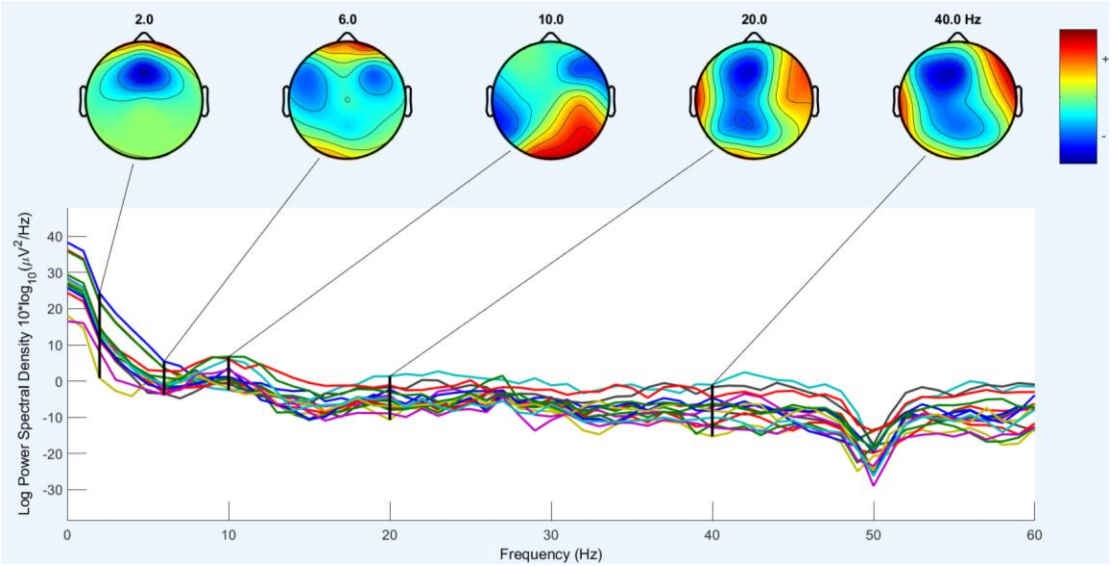


Before

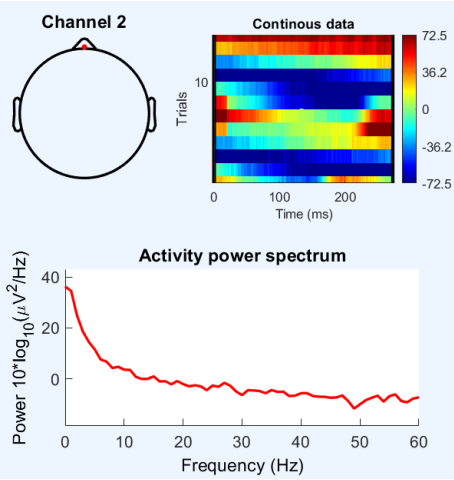
after

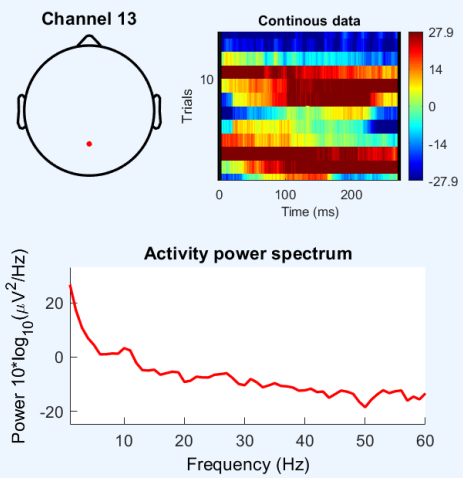
10.

I_closed

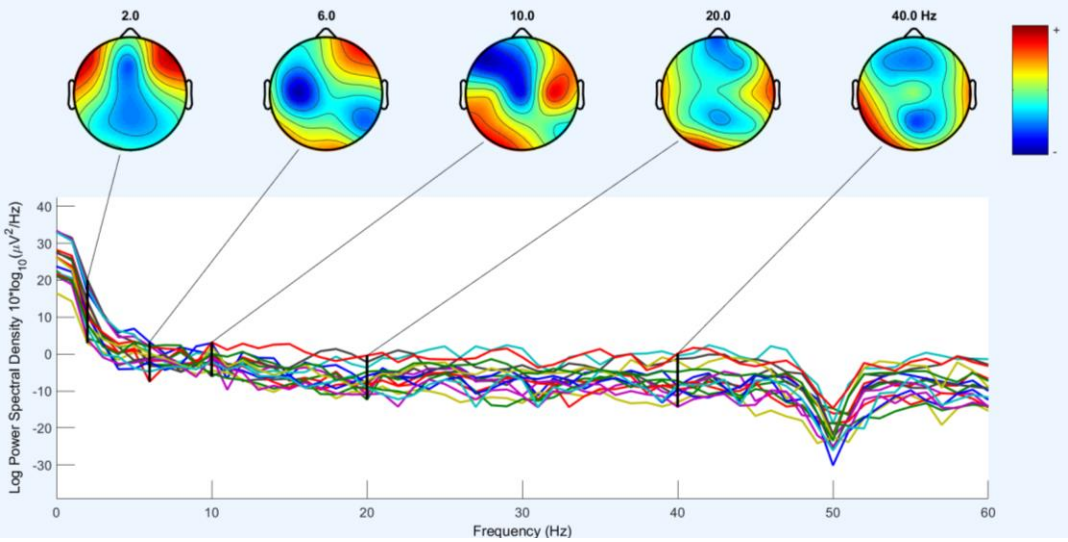


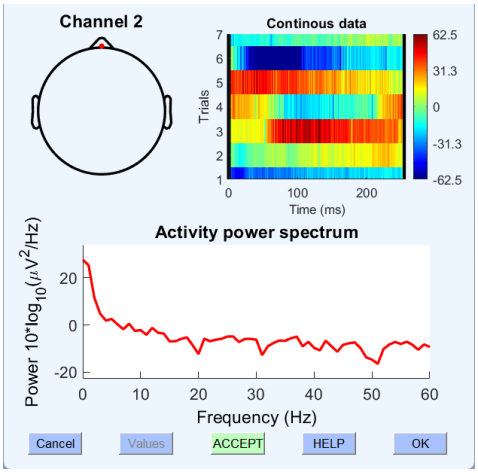

The spectral power shows a clear **alpha peak (8-12 Hz)**, which is characteristic of a relaxed brain state when the eyes are closed. This indicates dominant alpha rhythms, a common feature during rest. The **scalp maps** display concentrated alpha activity in the **occipital lobes** in that frequency band , confirming the brain's visual disengagement and relaxation during the eyes-closed condition.

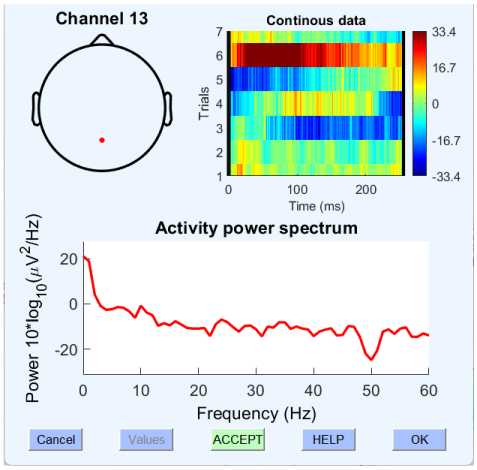


**i_LR**

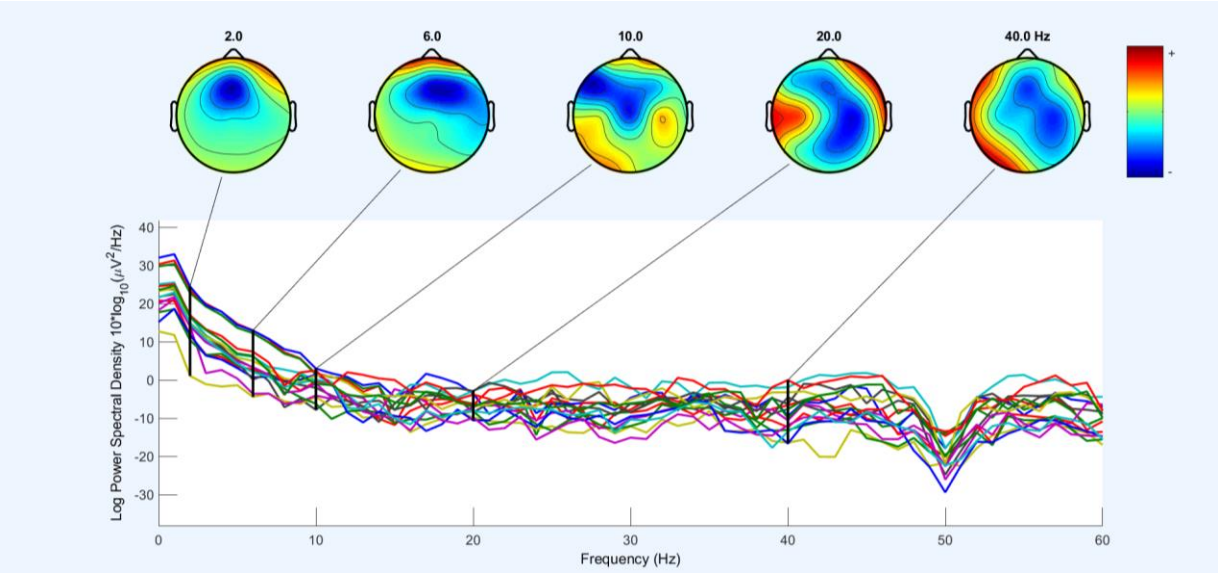


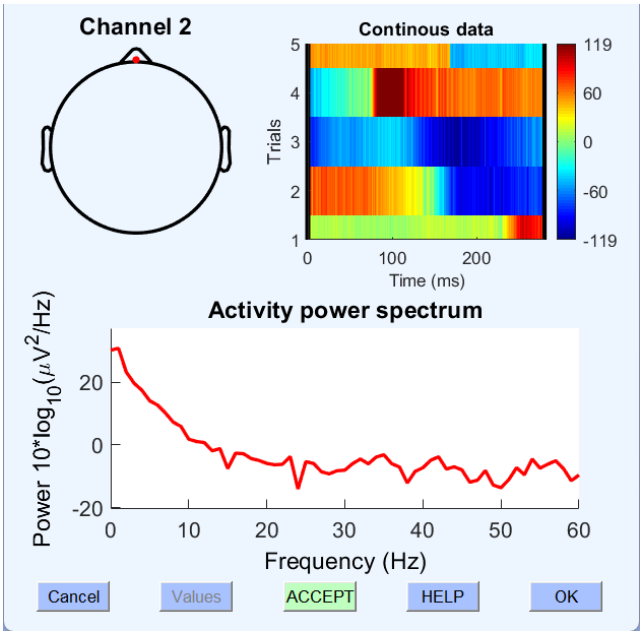



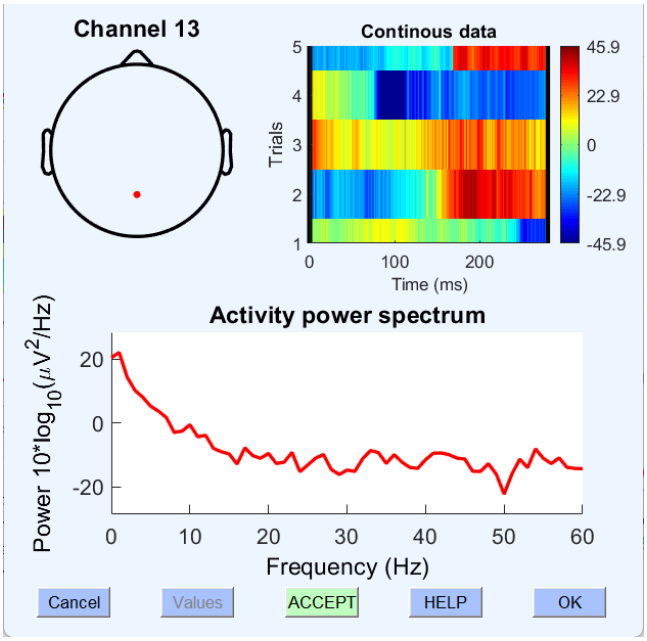




The EEG powers spectrum density plot shows low-frequency activity below 5Hz in the frontal region, which is a clear sign of eye movements. This is supported by the presence of horizontal equivalent current dipoles (ECDs) in scalp topography at 10Hz, indicating horizontal eye movements. The peak at around 10 Hz in channel 13 shows the activity in the occipital region, which suggests that the visual cortex is being stimulated.

**I_UD**

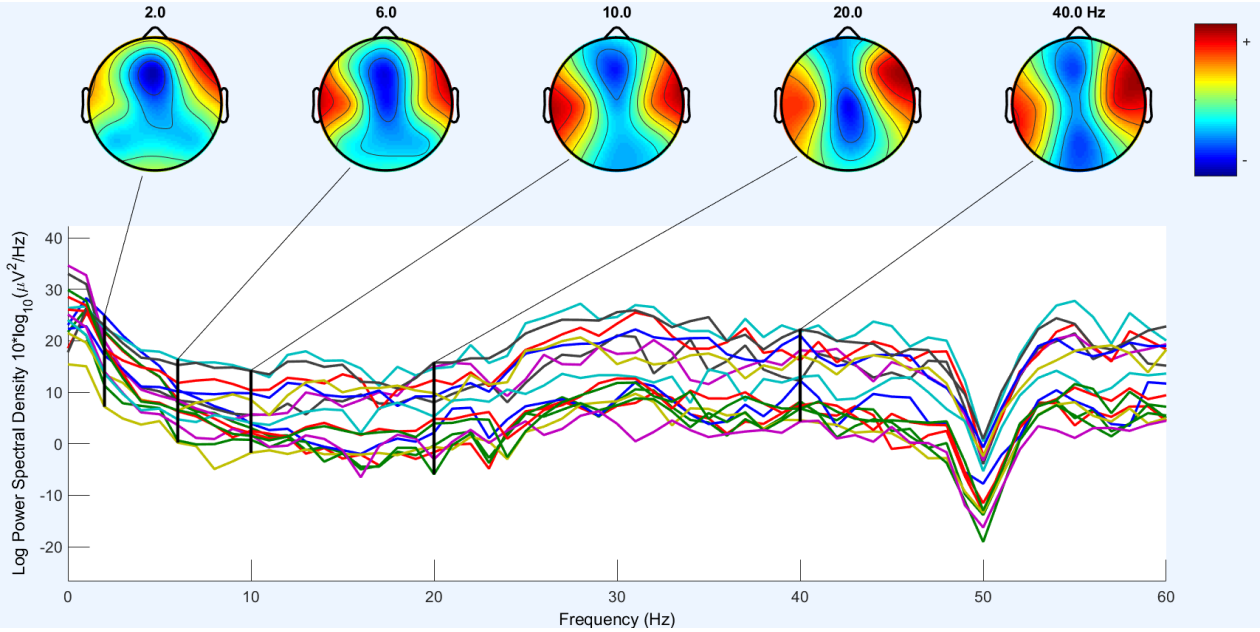


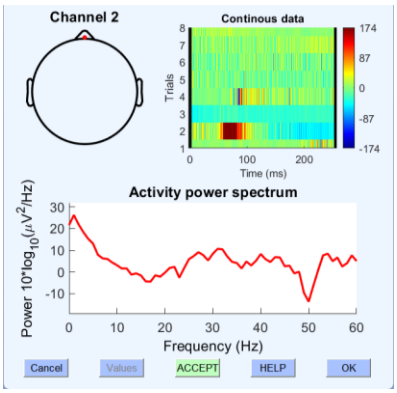



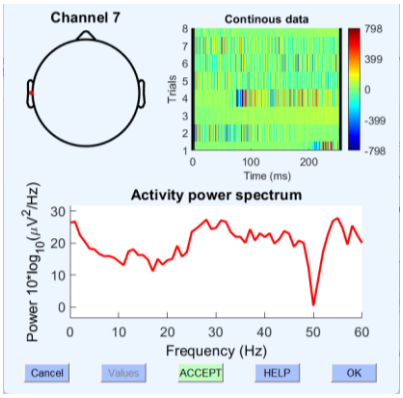



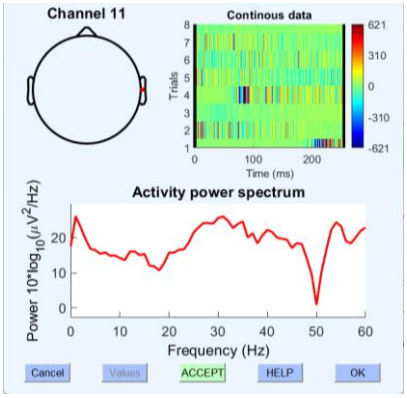

In contrast to i_LR here we can observe vertical equivalent current dipoles (ECDs) in scalp topography at 6Hz and 10Hz.

## Teeth



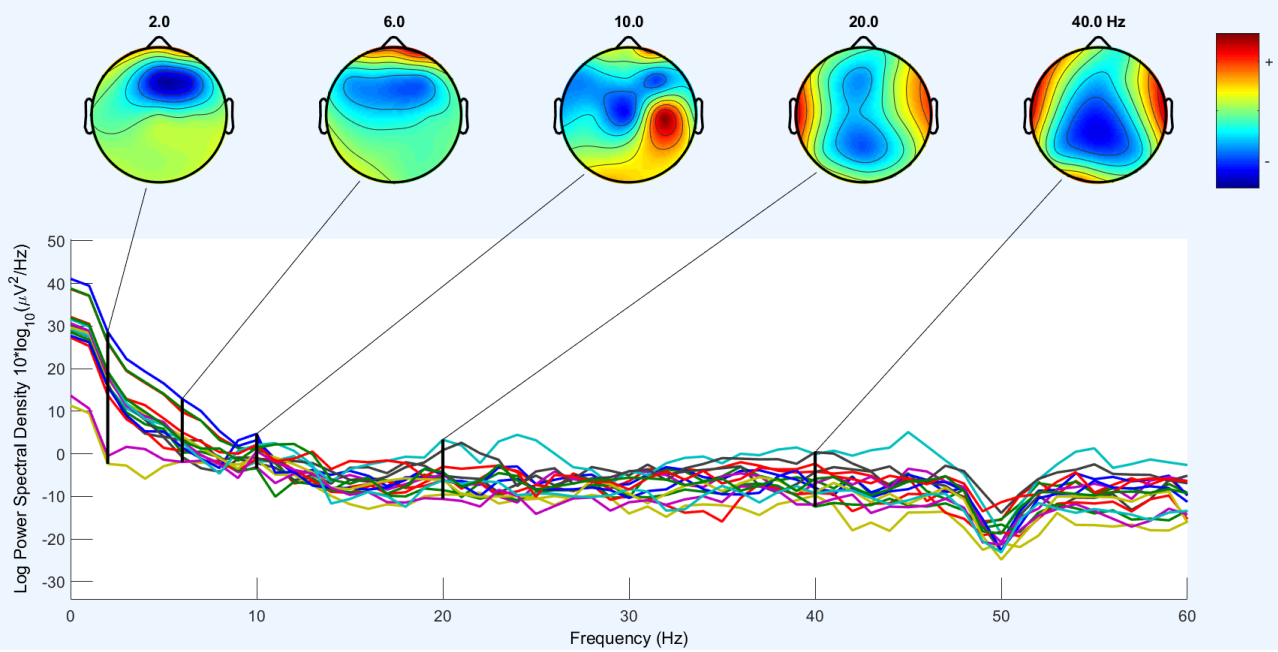




The plots show a significant increase in spectral power, particularly in the higher frequency range (above 20 Hz). This spike in high-frequency activity is a clear indication of muscle movements, specifically from jaw clenching. Such muscle activity dominates the EEG recordings and overshadows the brain's typical electrical activity. The scalp maps confirm that the strong electrical signals are not due to brain activity but rather to muscle contraction, which creates noise in the EEG readings.

**noise_ON**



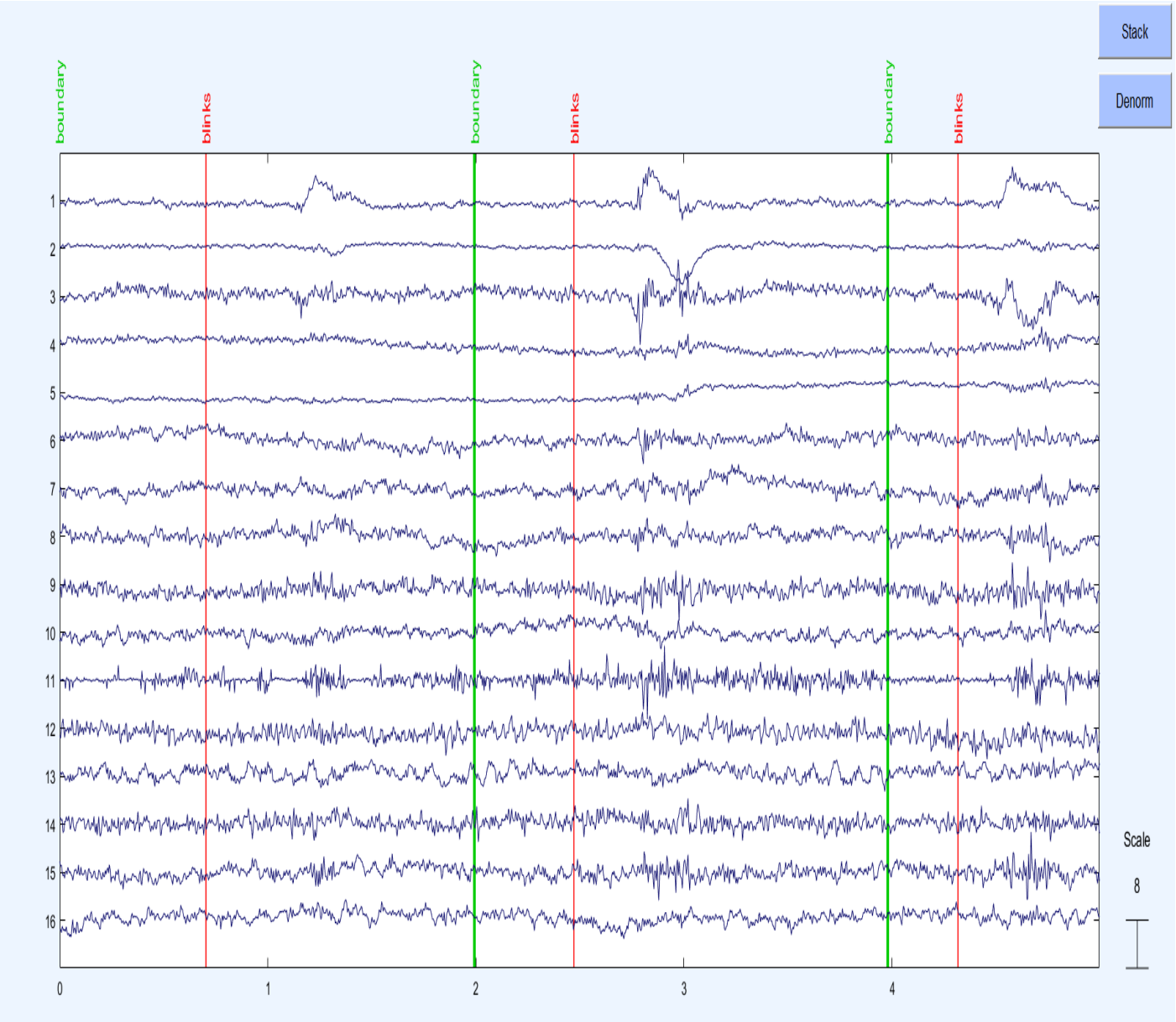

The spectral plots show a steep drop in power at lower frequencies, followed by a relatively flat curve with some small fluctuations. Typically, we would see peaks in the 5-30 Hz range, which are linked to brain rhythms. However, here the noise has overpowered these expected peaks

# Part 3: Using independent component analysis (ICA) of EEG data

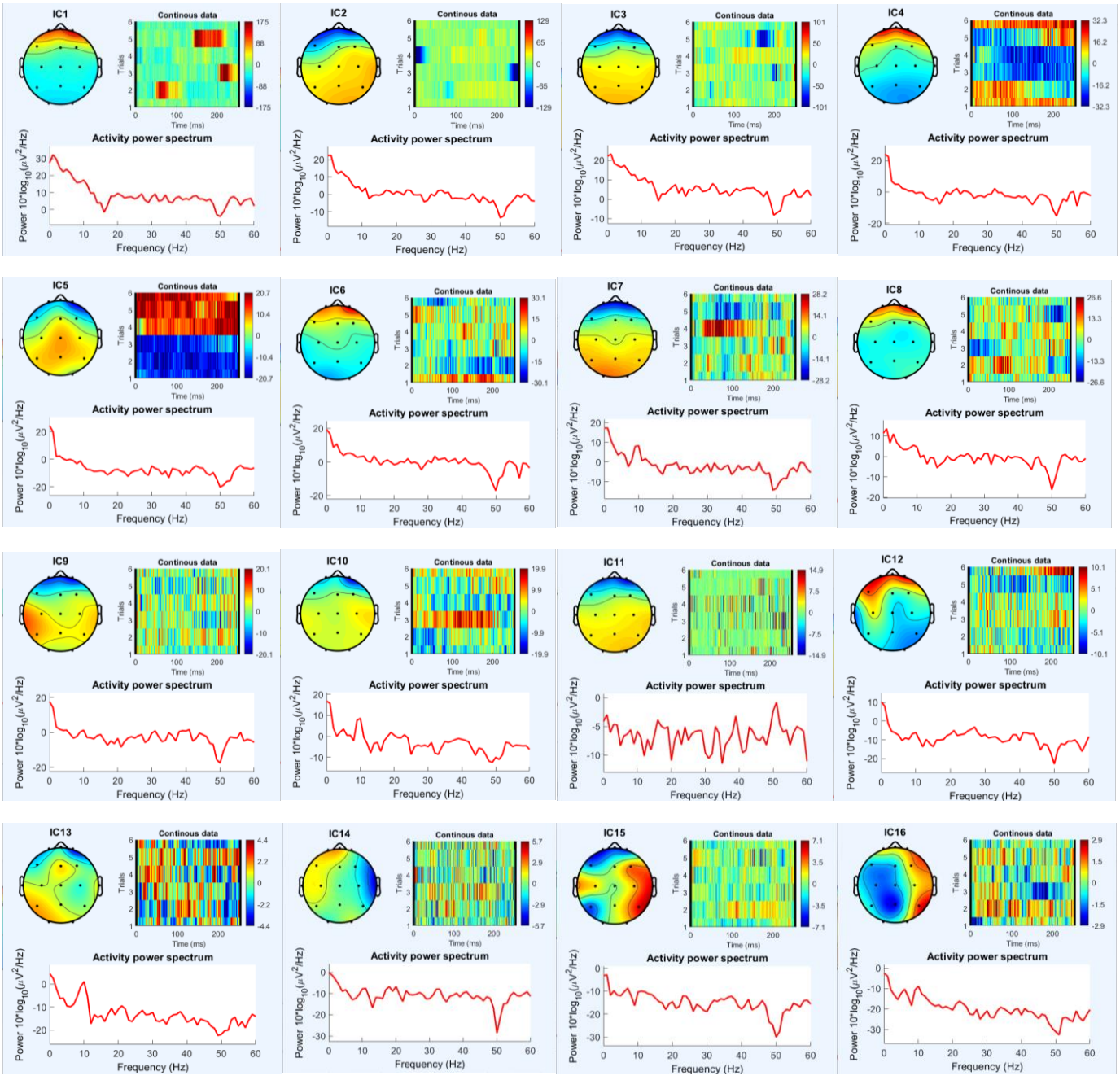
11.

## blinks

Normalized time domain ICA Components of the blinks-dataset



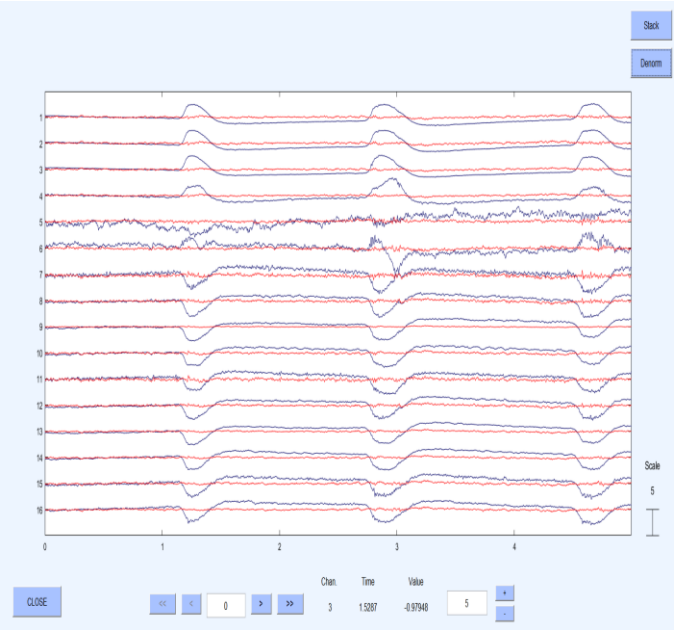
Spectrum and topography of independent components related to blinks

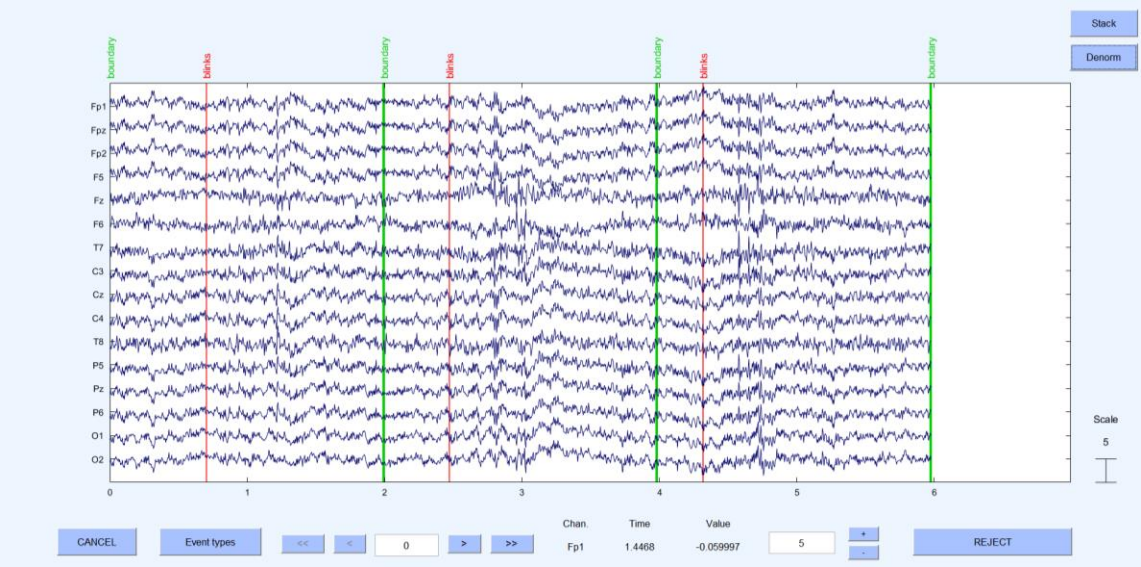


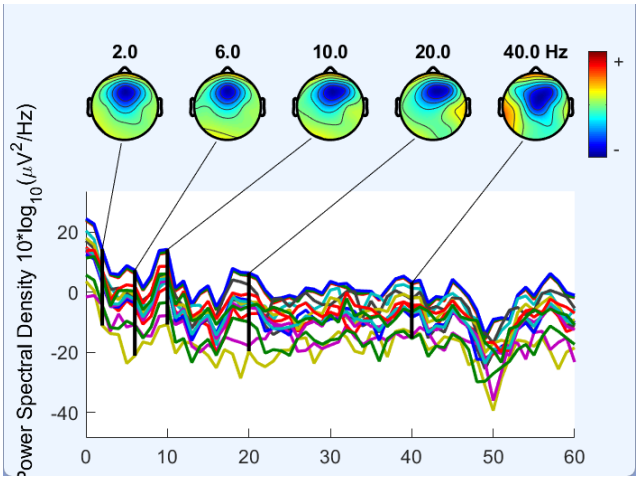
Classification of ICA components

| ICA Component | Category – eye, brain, muscle, power line noise, channel noise, other | Reason |
|---|---|---|
| 1 | Eye | Scalp topographies suggest Equivalent Current Dipoles near eyes, the power concentrated at low frequencies (below 5 Hz) and clearly visible large peaks in the time domain plot. |
| 2 | Eye | Similar to 1 |
| 3 | Eye | Similar to 1 |
| 4 | Eye/ Muscle | Scalp topography suggests Equivalent Current Dipoles near eyes, but some peaks are visible above 20Hz. |
| 5 | Other | Scalp topography suggests Equivalent Current Dipoles but power spectrum and time domain plot don't give a strong evidence . |
| 6 | Eye | Similar to 1 but time domain plot doesn't show large peaks as 1. |
| 7 | Brain | Scalp topography looks dipolar, Power spectrum decreases as frequency increases (1/f) most importantly a peak around 10Hz. |
| 8 | Eye | Similar to 1 but time domain plot doesn't show large peaks as 1. |
| 9 | Muscle | Power concentrated in higher frequencies than lower frequencies and Scalp topography localizes near ears. |
| 10 | Brain | Similar to 7 |
| 11 | Muscle | Power concentrated in higher frequencies than lower frequencies |
| 12 | Muscle | Power concentrated in higher frequencies than lower frequencies, but Scalp topography localizes near eyes – may be due to muscle movements during blinking. |
| 13 | Brain | Similar to 7 |
| 14 | Other | Power spectrum doesn't provide strong conclusion- cannot observe noticeable peaks |
| 15 | Other | Power spectrum doesn't provide strong conclusion- cannot observe noticeable peaks and Non-dipolar scalp maps |
| 16 | Other | Similar to 14 |

time domain channels the spectra after removing noise components

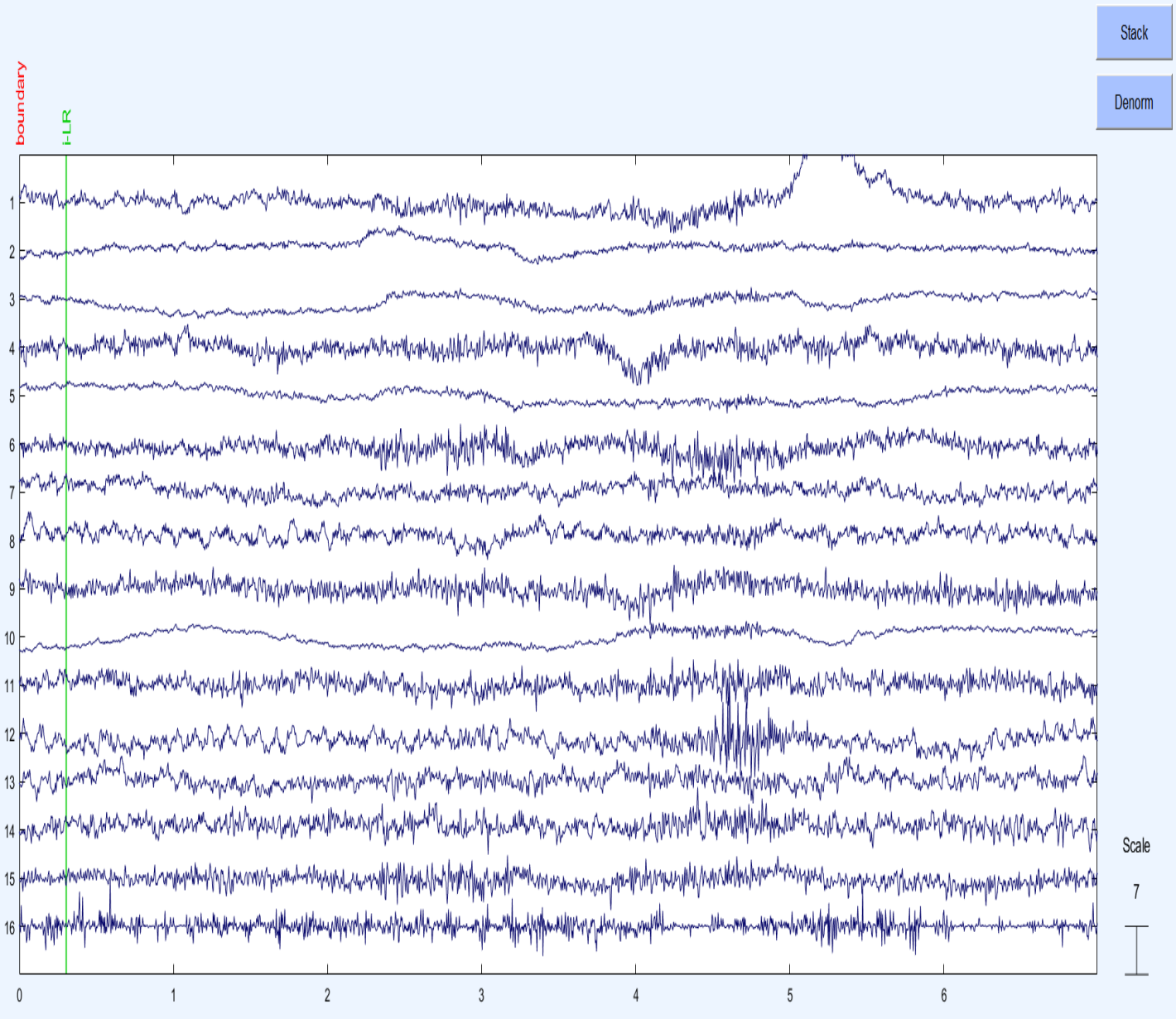


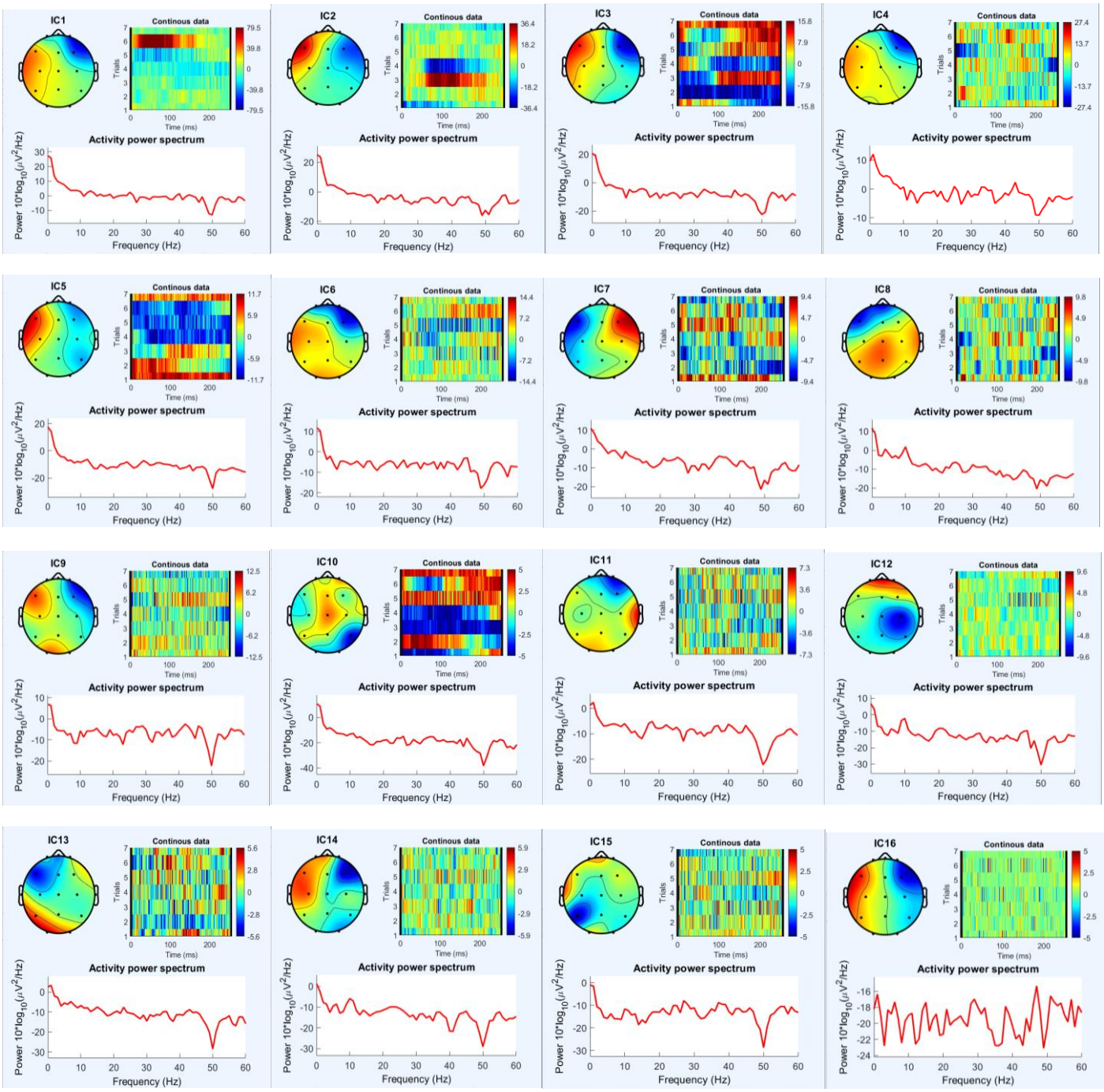



# i_LR

Normalized time domain ICA Components of the i_LR dataset



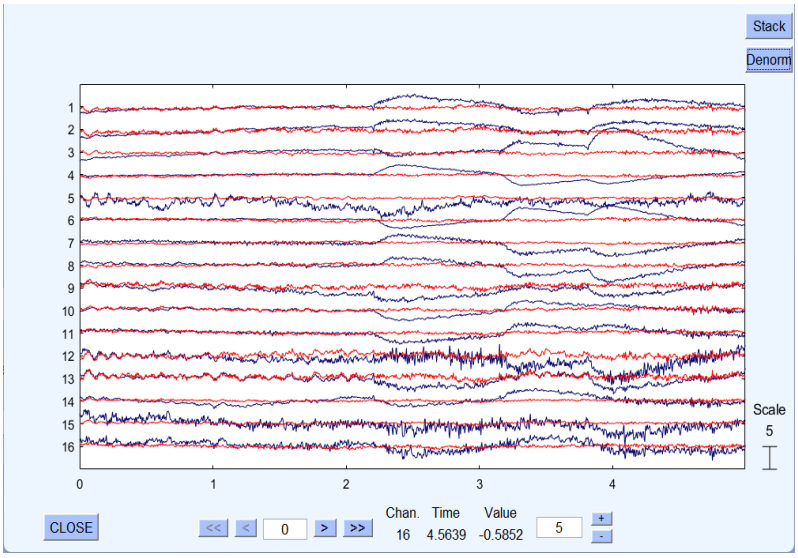
Spectrum and topography of independent components related to i_LR.

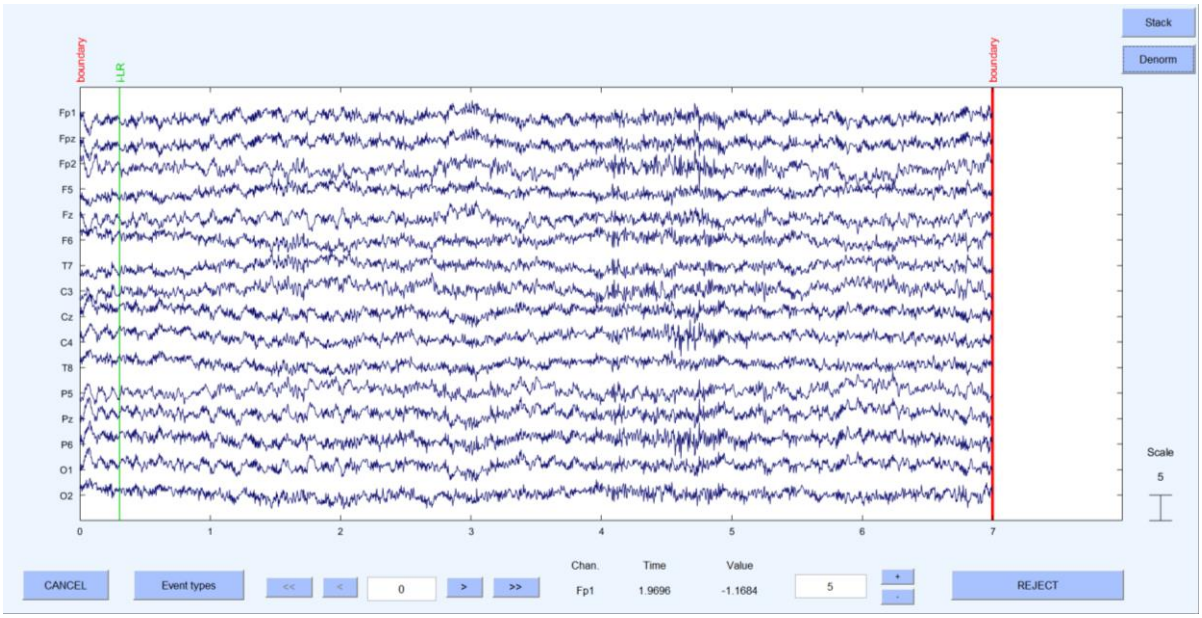


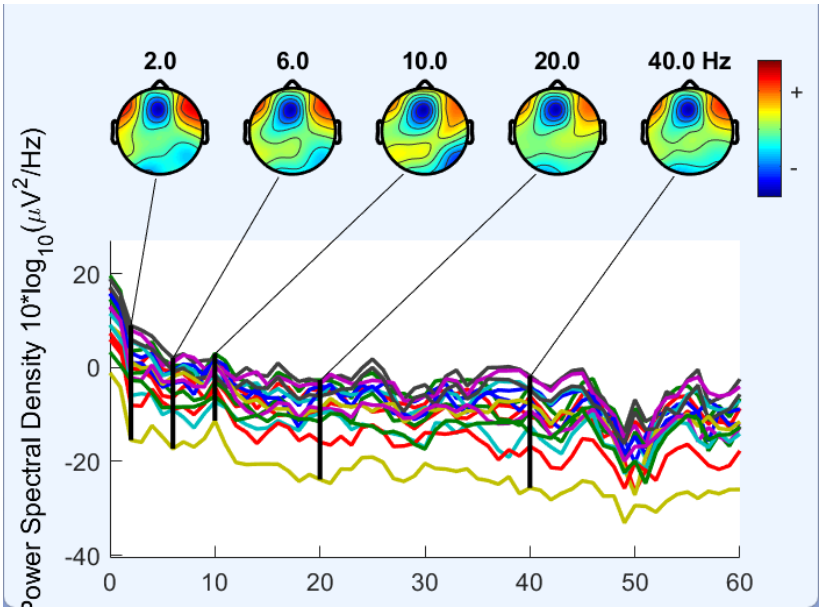
Classification of ICA components

| ICA Component | Category - eye movement, muscle movement, power line noise, channel noise | Reason |
|---|---|---|
| 1 | Eye | Scalp topography strongly suggests this component captures the effects of horizontal eye movement and clearly visible large peaks in the time domain plot. |
| 2 | Eye | Similar to 1 but time domain plot doesn't show large peaks as 1. |
| 3 | Eye | Similar to 2. |
| 4 | Eye | Similar to 1 |
| 5 | Eye | Similar to 2 |
| 6 | Eye/Other | component is well fit by a single dipole located in the brain, |
| 7 | Brain | Scalp topography looks dipolar, Power spectrum decreases as frequency increases (1/f). |
| 8 | Brain | Scalp topography looks dipolar, Power spectrum decreases as frequency increases (1/f) most importantly a peak around 10Hz. |
| 9 | Muscle | Power concentrated in higher frequencies than lower frequencies(>20Hz). |
| 10 | Other | Power spectrum doesn't provide strong conclusion-cannot observe noticeable peaks and Non-dipolar scalp maps |
| 11 | Muscle | Power concentrated in higher frequencies than lower frequencies(>20Hz) and Scalp topography localizes near ears and neck. |
| 12 | Brain | Similar to 8 |
| 13 | Other | Power spectrum doesn't provide strong conclusion-cannot observe noticeable peaks |
| 14 | Brain | Similar to 8 |
| 15 | Other/Muscle | Similar to 13 but power concentrated in higher frequencies than lower frequencies(>20Hz) |
| 16 | Other | Power Spectrum consists rapid peaks, but Scalp topography looks dipolar. |

time domain channels the spectra after removing noise components

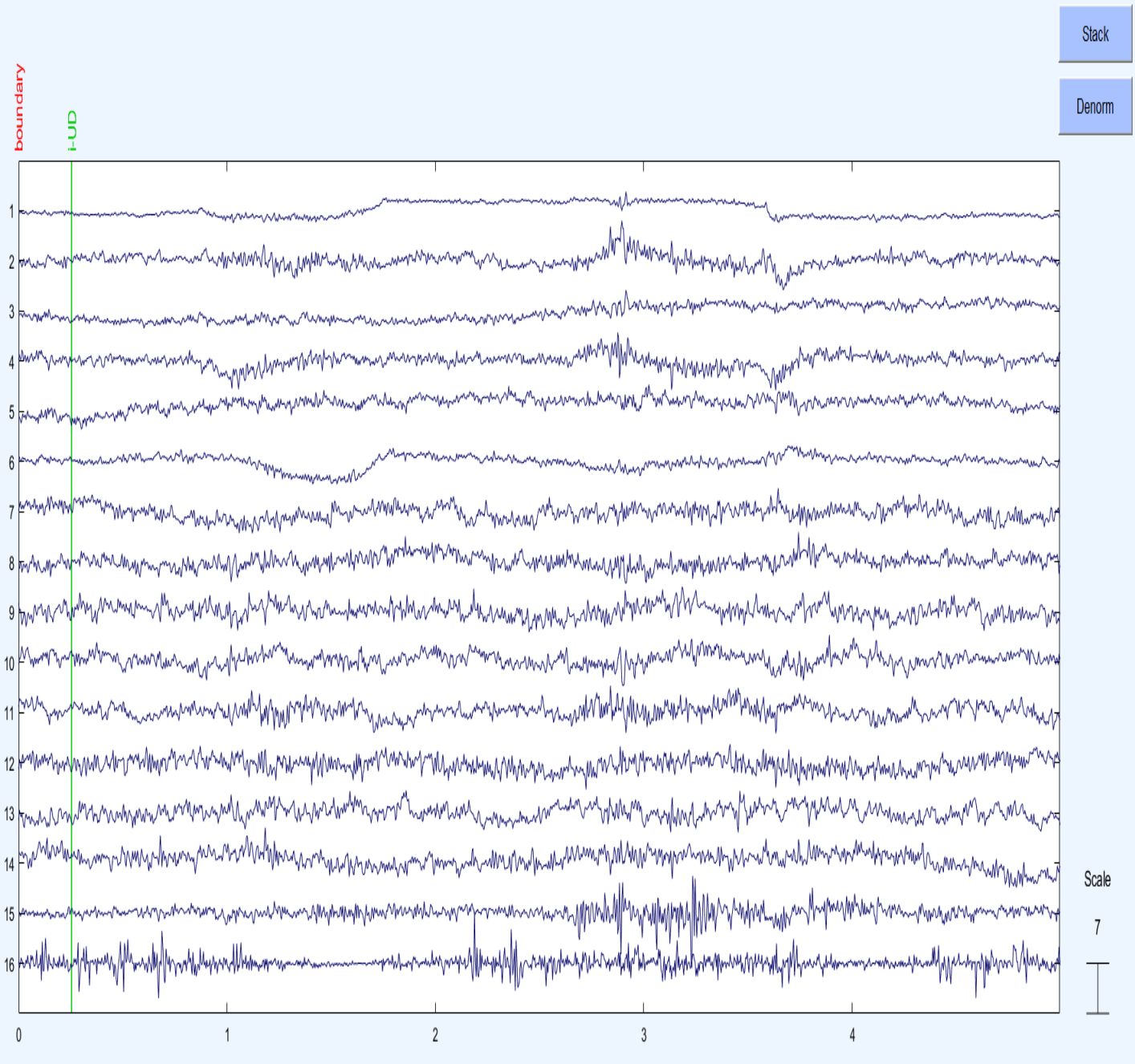


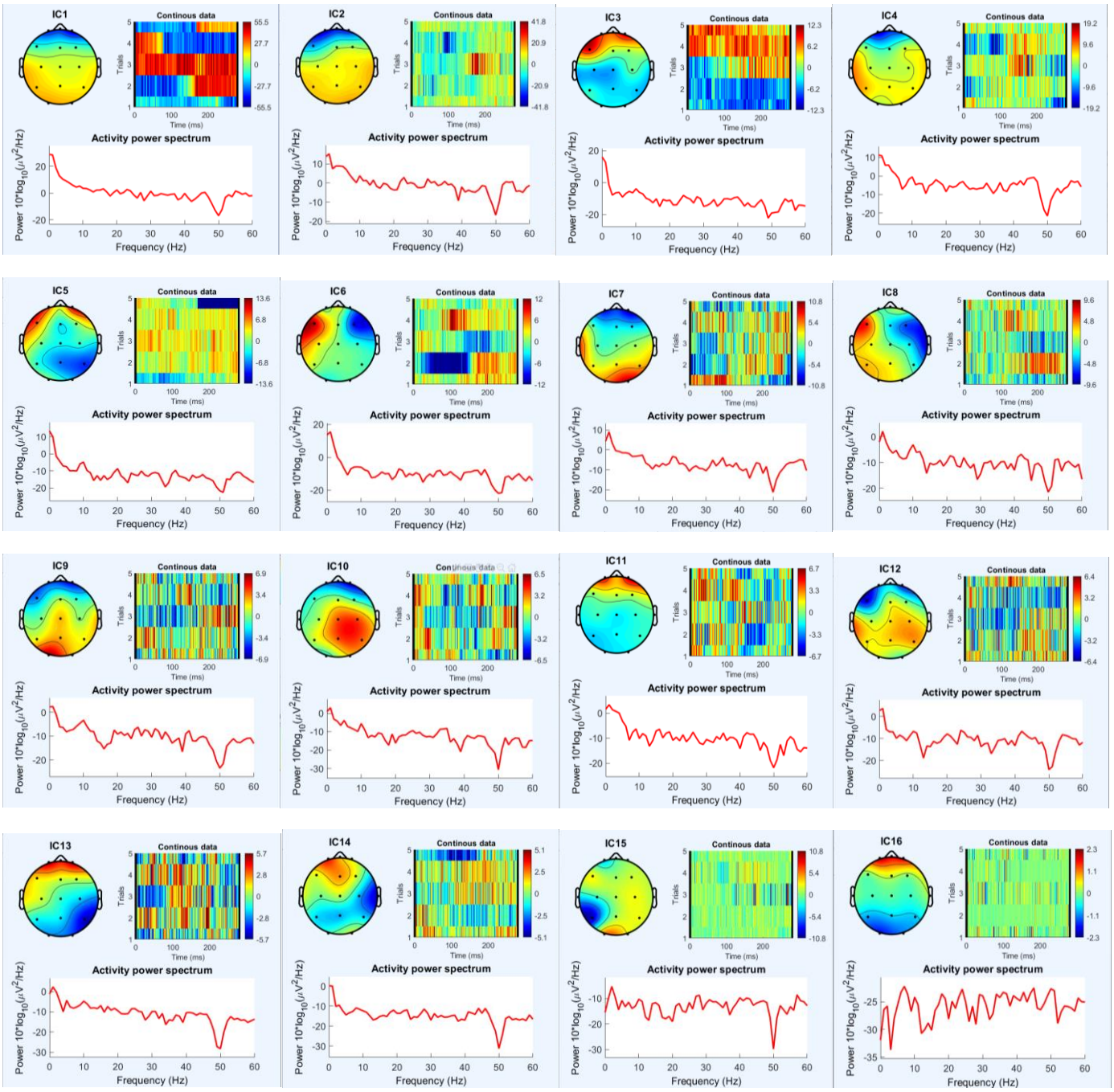



# i_UD

Normalized time domain ICA Components of the i_UD dataset



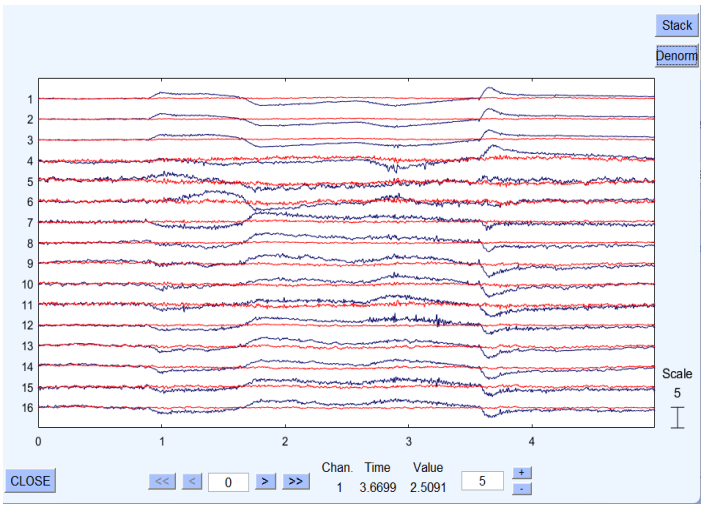

Spectrum and topography of independent components related to i_UD

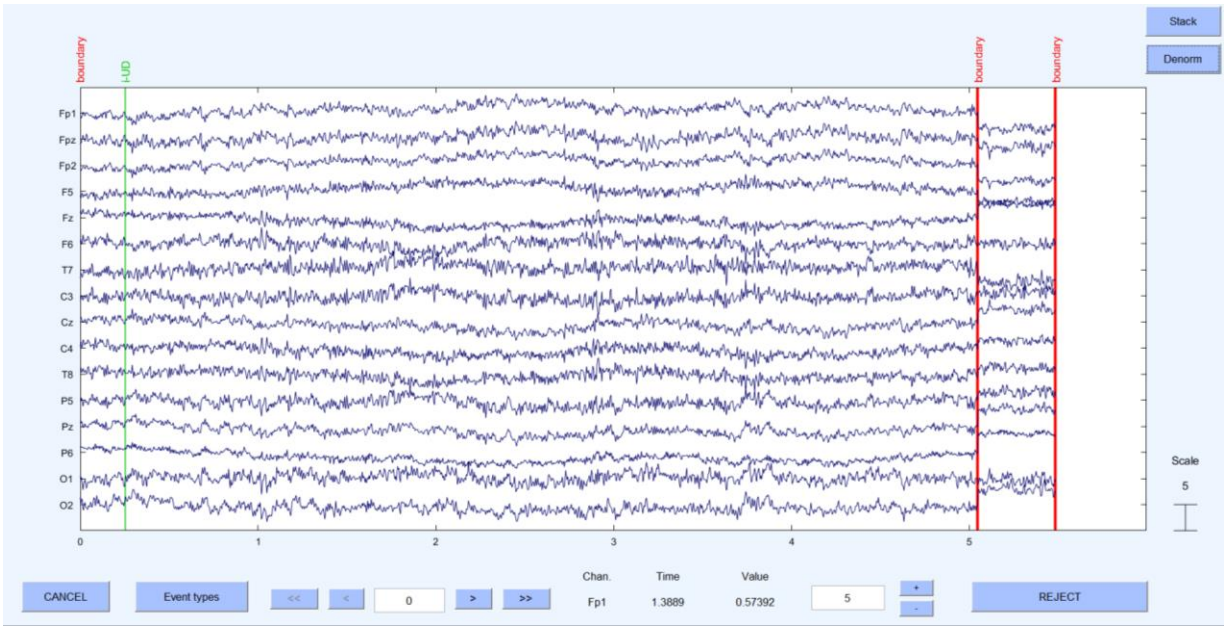


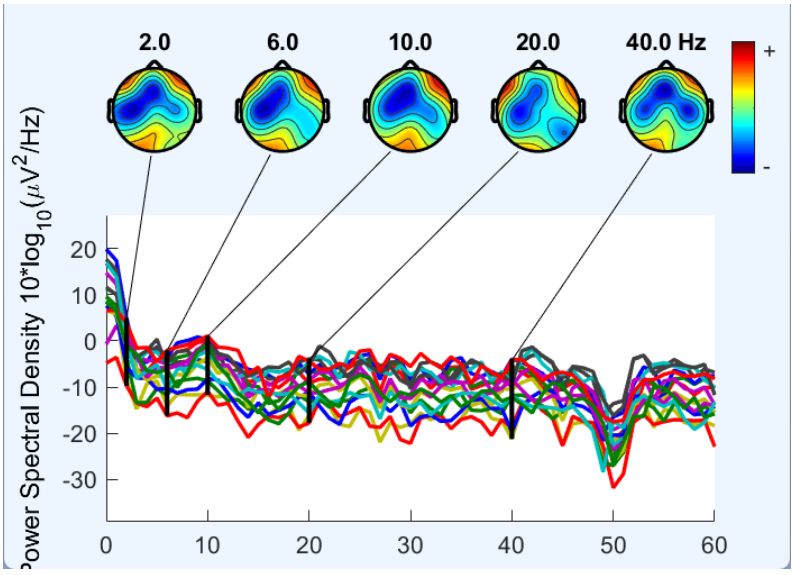

Classification of ICA components

| ICA Component | Category - eye movement, muscle movement, power line noise, channel noise | Reason |
|---|---|---|
| 1 | Eye | Scalp topographies suggest Equivalent Current Dipoles near eyes, the power concentrated at low frequencies (below 5 Hz). |
| 2 | Eye | Similar to 1 |
| 3 | Other | Power spectrum doesn't provide strong conclusion-cannot observe noticeable peaks |
| 4 | Eye | Similar to 1 |
| 5 | Brain | Power spectrum decreases as frequency increases (1/f) most importantly a peak around 10Hz and 20Hz. |
| 6 | Eye | Scalp topography strongly suggests this component captures the effects of horizontal eye movement and clearly visible large peaks in the time domain plot. |
| 7 | Other | Power spectrum doesn't provide strong conclusion-cannot observe noticeable peaks |
| 8 | Brain | Scalp topography looks dipolar, Power spectrum decreases as frequency increases (1/f) most importantly a peak around 10Hz. |
| 9 | Brain | Similar to 8 |
| 10 | Other | Power spectrum doesn't provide strong conclusion-cannot observe noticeable peaks |
| 11 | Eye | Similar to 1 but time domain plot doesn't show large peaks as 1. |
| 12 | Brain | Scalp topography looks dipolar, Power spectrum decreases as frequency increases (1/f) most importantly a peak around 10Hz. |
| 13 | Other | Similar to 10 |
| 14 | Other | Similar to 10 |
| 15 | Other | Similar to 10 |
| 16 | Other | Power Spectrum consists rapid peaks |

time domain channels the spectra after removing noise components

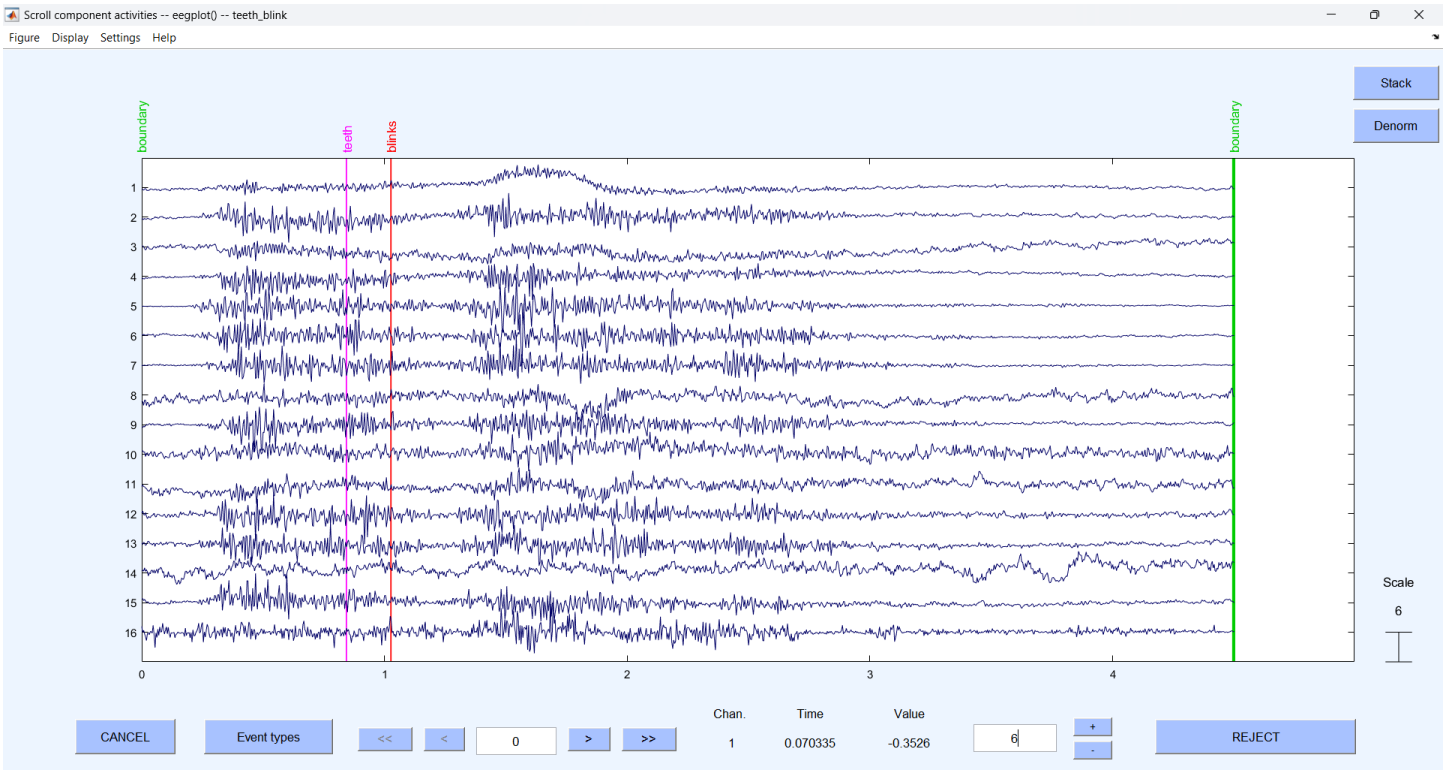

Stack
Denorm
Scale
5
CLOSE
Chan. Time Value
1 3.6699 2.5091


boundary
boundary
boundary
Stack
Denorm
Scale
5
CANCEL
Event types
Chan. Time Value
Fp1 1.3889 0.57392
REJECT

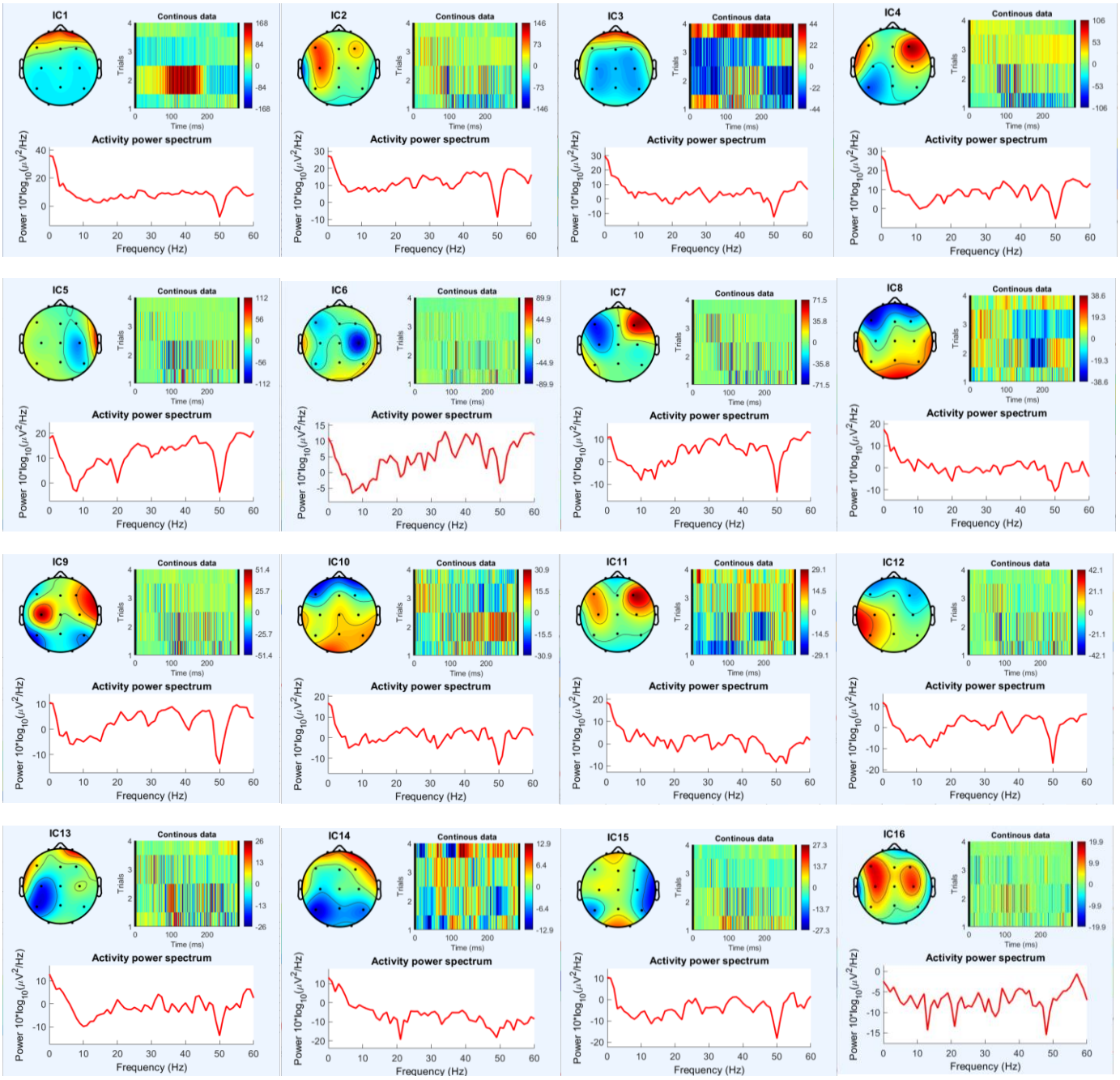

2.0
6.0
10.0
20.0
40.0 Hz
+
-
Power Spectral Density 10*log10(μV2/Hz)

# teeth-blink

Normalized time domain ICA Components of the teeth-blink dataset



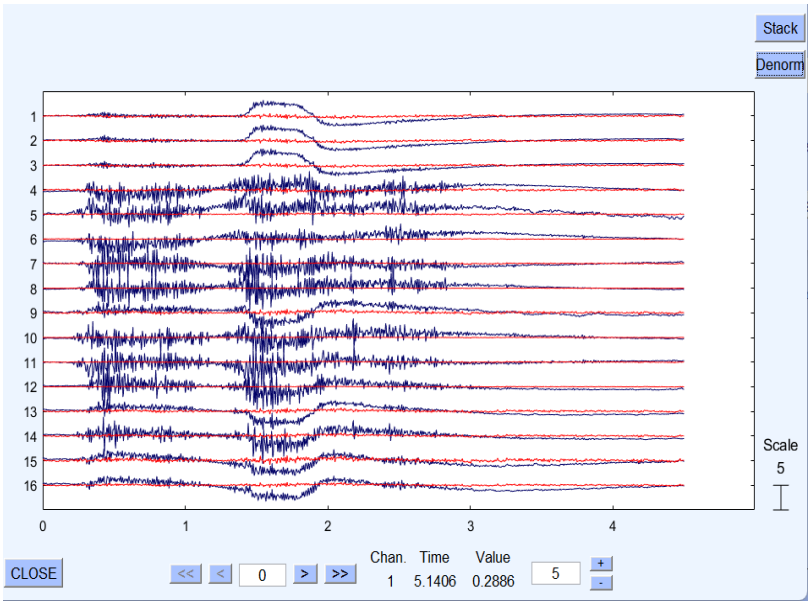
Spectrum and topography of independent components related to teeth-blink

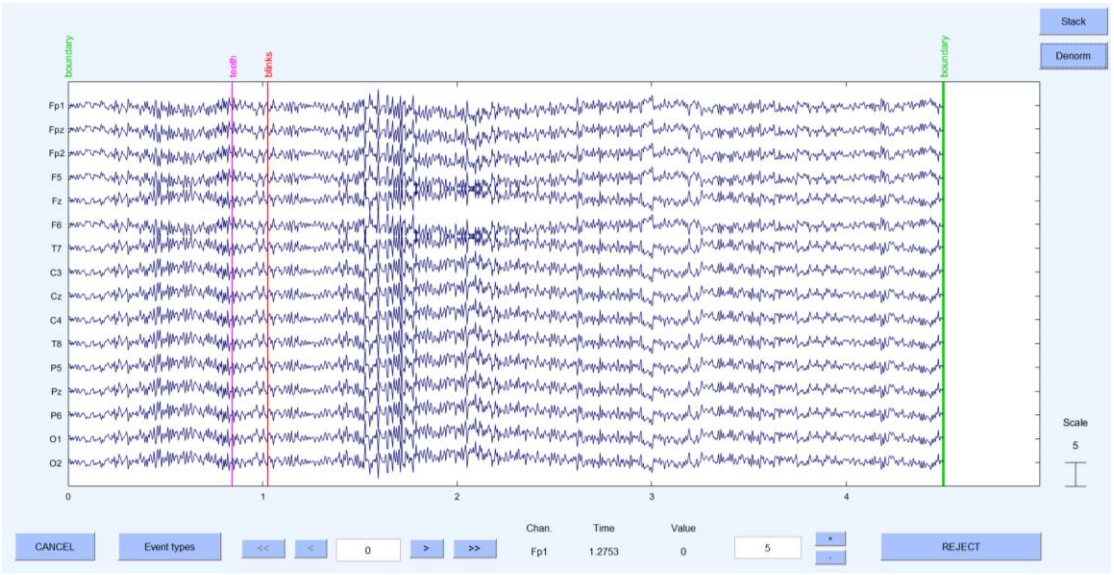


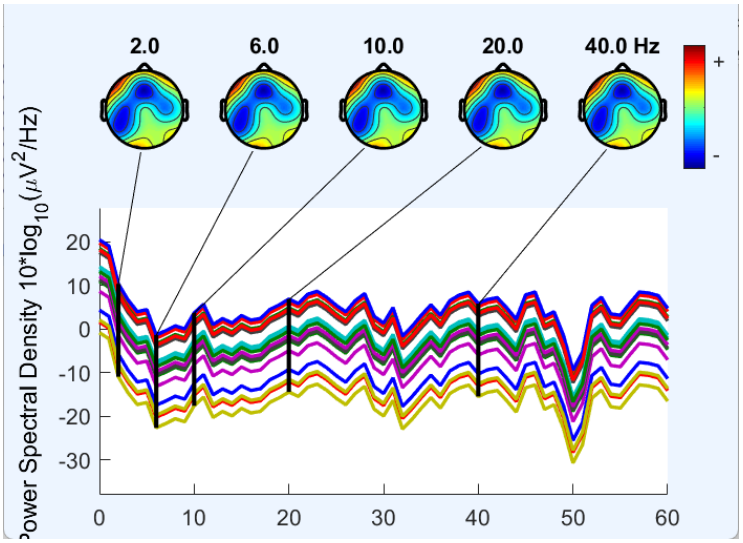
Classification of ICA components

| ICA Component | Category - eye movement, muscle movement, power line noise, channel noise | Reason |
|---|---|---|
| 1 | Eye | Scalp topographies suggest Equivalent Current Dipoles near eyes, the power concentrated at low frequencies (below 5 Hz) and clearly visible large peaks in the time domain plot. |
| 2 | Other | |
| 3 | Eye | Similar to 1 |
| 4 | Muscle | Power concentrated in higher frequencies than lower frequencies(>20Hz) and Scalp topography localizes near ears and neck. |
| 5 | Muscle | Similar to 4 |
| 6 | Muscle | Similar to 4 |
| 7 | Muscle | Similar to 4 |
| 8 | Eye | Similar to 1 |
| 9 | Muscle | Similar to 4 |
| 10 | Brain | Scalp topography looks dipolar, Power spectrum decreases as frequency increases (1/f) most importantly a peak around 10Hz, but also contains frequencies >20Hz. |
| 11 | Muscle | Similar to 4 |
| 12 | Muscle | Similar to 4 |
| 13 | Muscle | Similar to 4 but Scalp topography localizes near eyes. |
| 14 | Eye | Similar to 1 |
| 15 | Muscle/Other | Power concentrated in higher frequencies than lower frequencies(>20Hz) and non-dipole scalp topography. |
| 16 | Other | Power spectrum consists of rapid peaks; doesn't provide strong conclusion. |

time domain channels the spectra after removing noise components

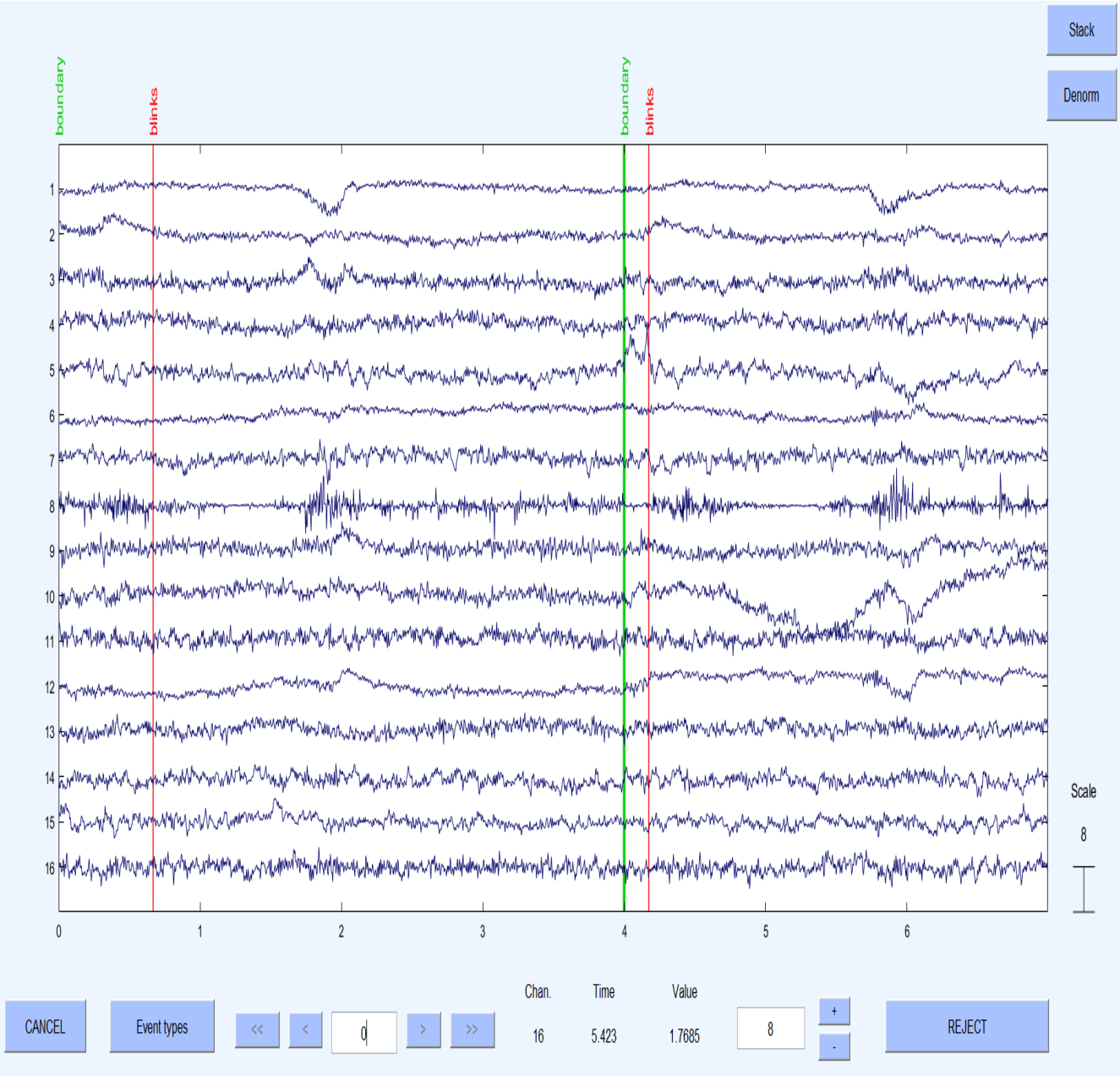


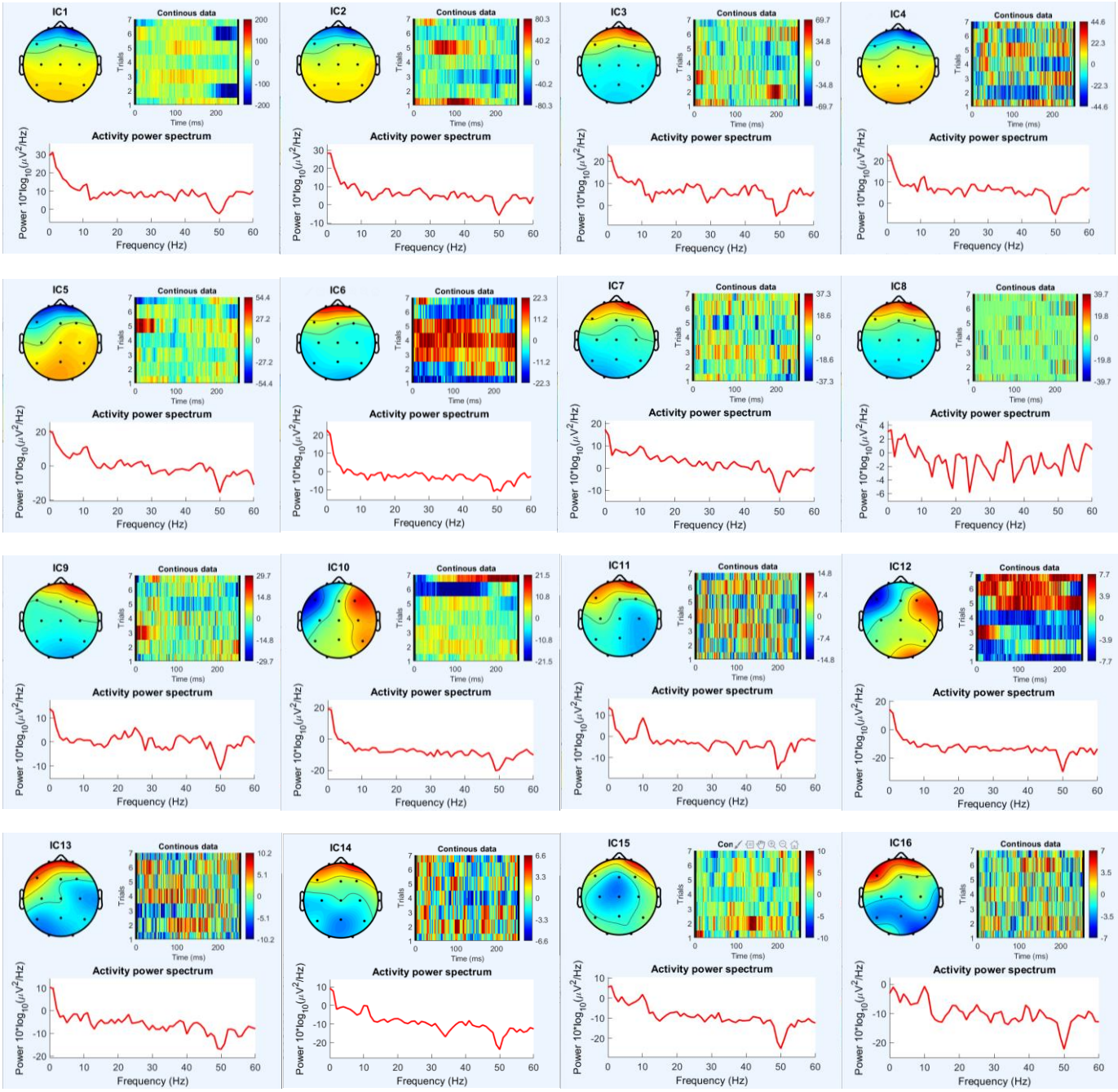



# noise-ON-blink

Normalized time domain ICA Components of the noise_ON_blink dataset



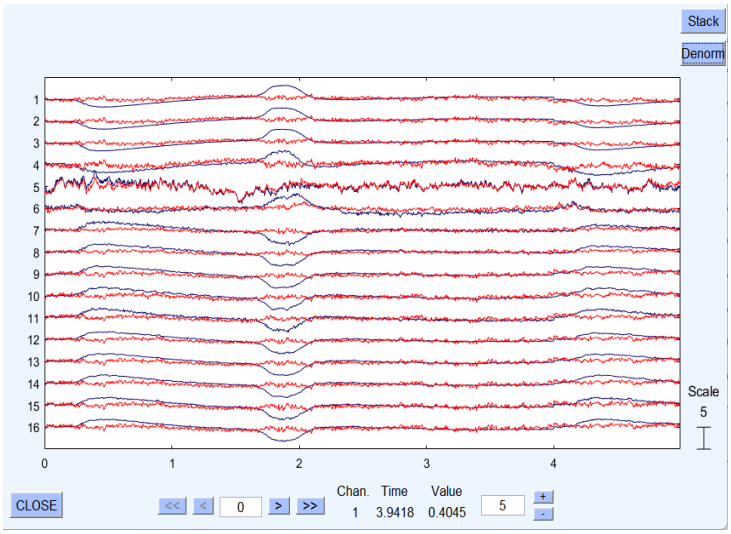
Spectrum and topography of independent components related to noise_ON_blink

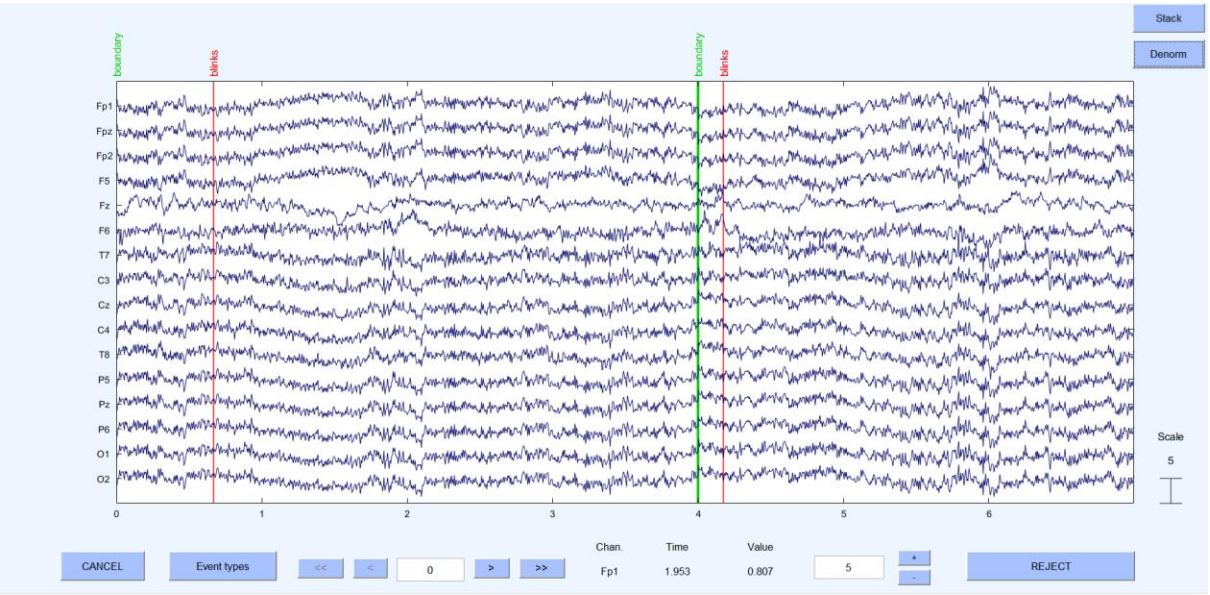


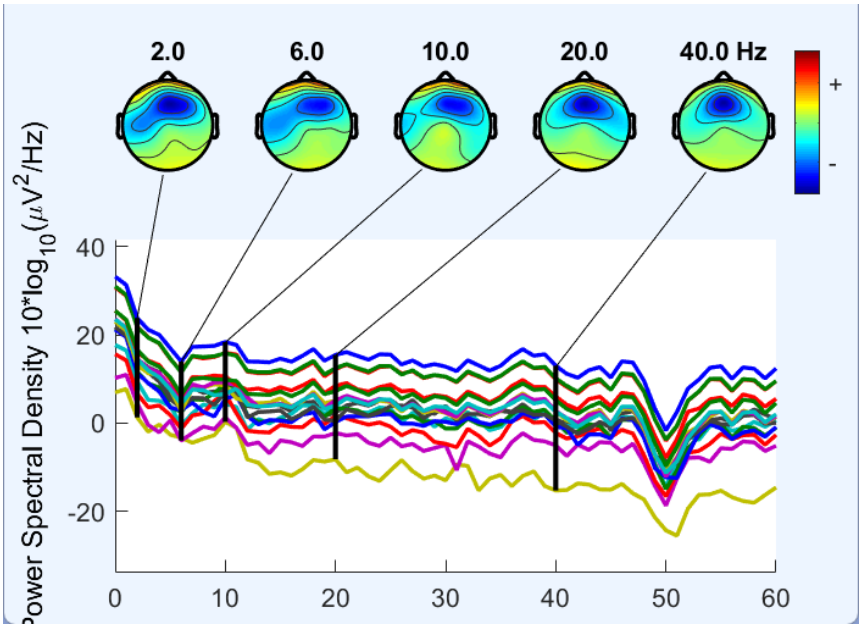
Classification of ICA components

| ICA Component | Category - eye movement, muscle movement, power line noise, channel noise | Reason |
|---|---|---|
| 1 | Eye | Scalp topographies suggest Equivalent Current Dipoles near eyes, the power concentrated at low frequencies (below 5 Hz) and clearly visible large peaks in the time domain plot. |
| 2 | Eye | Similar to 1 but time domain peaks are not visible as much. |
| 3 | Eye | Similar to 1 |
| 4 | Brain | Scalp topography looks dipolar, Power spectrum decreases as frequency increases (1/f) most importantly a peak around 10Hz |
| 5 | Brain | Similar to 4 |
| 6 | Eye | Similar to 1 but time domain peaks are not visible as much. |
| 7 | Brain | Scalp topography looks dipolar, most importantly a peak around 10Hz |
| 8 | Muscle | Power concentrated in higher frequencies than lower frequencies(>20Hz) |
| 9 | Brain | Scalp topography looks dipolar, most importantly a peak around 20Hz |
| 10 | Eye | Scalp topography strongly suggests this component captures the effects of horizontal eye movement and clearly visible large peaks in the time domain plot. |
| 11 | Brain | Similar to 4 |
| 12 | Eye | Similar to 10 |
| 13 | Brain | Similar to 4 |
| 14 | Brain | Similar to 4 |
| 15 | Brain | Similar to 4 |
| 16 | Brain | Similar to 4 |

Time domain channels the spectra after removing noise components

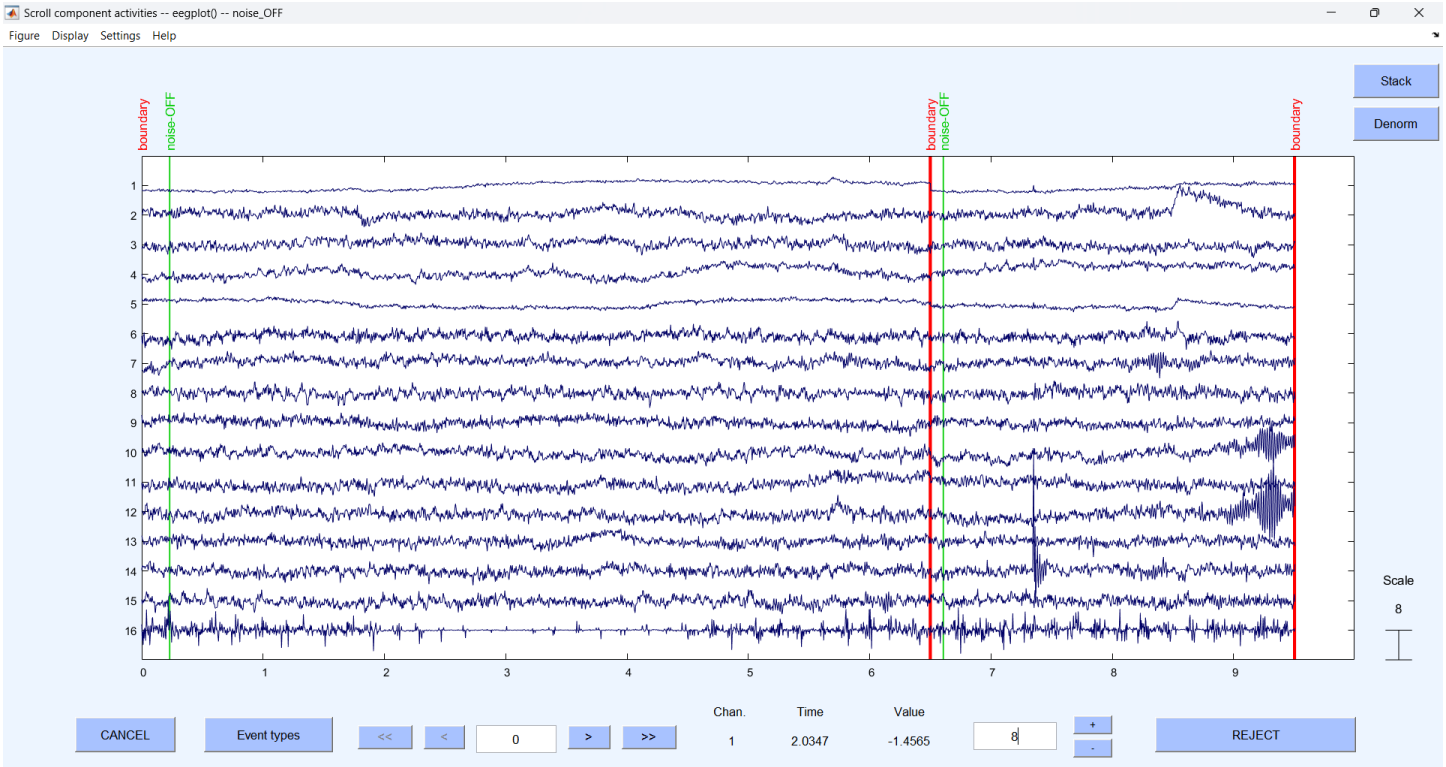


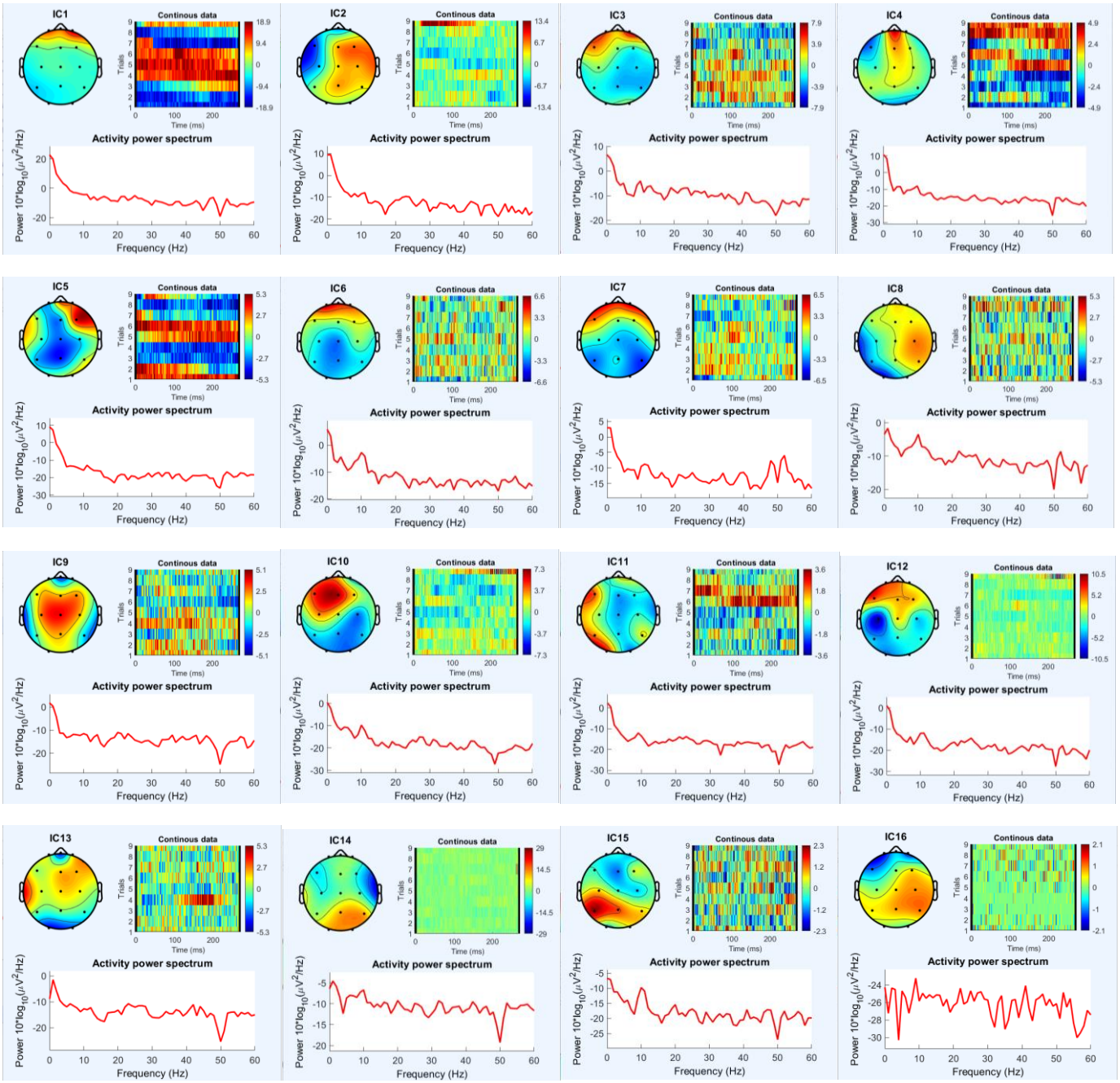



# noise-OFF

Normalized time domain ICA Components of the noise_OFF dataset



Spectrum and topography of independent components related to noise_OFF



Classification of ICA components

| ICA Component | Category - eye movement, muscle movement, power line noise, channel noise | Reason |
|---|---|---|
| 1 | Eye | Scalp topographies suggest Equivalent Current Dipoles near eyes, the power concentrated at low frequencies (below 5 Hz) and clearly visible large peaks in the time domain plot. |
| 2 | Eye | Scalp topography strongly suggests this component captures the effects of horizontal eye movement and clearly visible large peaks in the time domain plot |
| 3 | Eye/ Brain | Similar to 1 but a peak around 10Hz |
| 4 | Other/Channel noise | Very focal scalp topography. |
| 5 | Other | Power spectrum doesn't provide strong conclusion, non-dipole scalp topography. |
| 6 | Brain | Scalp topography looks dipolar, Power spectrum decreases as frequency increases (1/f) most importantly a peak around 10Hz |
| 7 | Brain | Similar to 6 |
| 8 | Brain | Scalp topography looks dipolar most importantly a peak around 10Hz |
| 9 | Other | Similar to 5 |
| 10 | Brain | Similar to 6 |
| 11 | Other | Similar to 5 |
| 12 | Brain | Similar to 6 |
| 13 | Other | Similar to 5 |
| 14 | Other/Brain | Peak around 10 Hz |
| 15 | Brain | Power spectrum decreases as frequency increases (1/f) ,A large peak around 10 Hz |
| 16 | Other | Power spectrum consists of rapid peaks; doesn't provide strong conclusion. |

time domain channels the spectra after removing noise components