Department of Electronic and Telecommunication Engineering

University of Moratuwa

BM4152 - Biosignal Processing

Multi-channel EEG: Analysing using EEGLAB

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Date: October 21, 2024

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1 Part 1 - Installing EEGLAB and importing data

According to the given instruction, the EEGLab MATLAB toolbox was installed. As well as, to import the *".xdf"* files, *"xdfimport"* plugin was installed.

Then *"trial_2.xdf"* dataset imported and the details of the dataset are as follows.

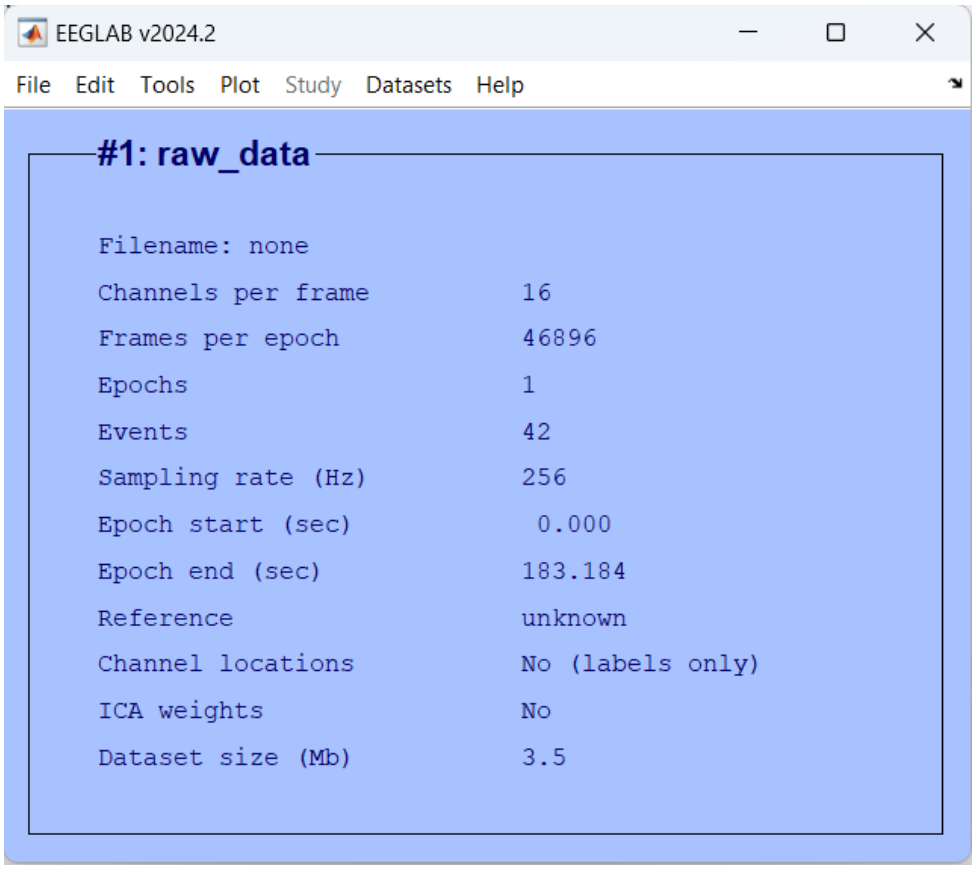


Figure 1: Details of the dataset

2 Part 2 - Data preparation, time and frequency domain analysis

2.1 Channel labels

Table 1 - Electrode montage

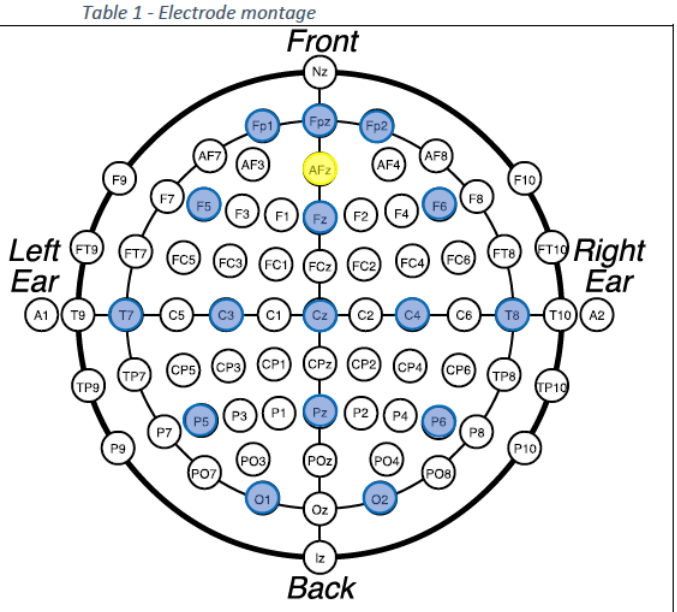
1	Fp1	
2	Fpz	
3	Fp2	
4	F5	
5	Fz	
6	F6	
7	T7	
8	C3	
9	Cz	
10	C4	
11	T8	
12	P5	
13	Pz	
14	P6	
15	O1	
16	O2	
GND	AFz	Common Ground
Z1	Any location	For impedance measurements

Figure 2: Electrode Montage Given in the Practical Sheet

The following figure is the plot of channel locations in the *electrode_locations.loc* file.

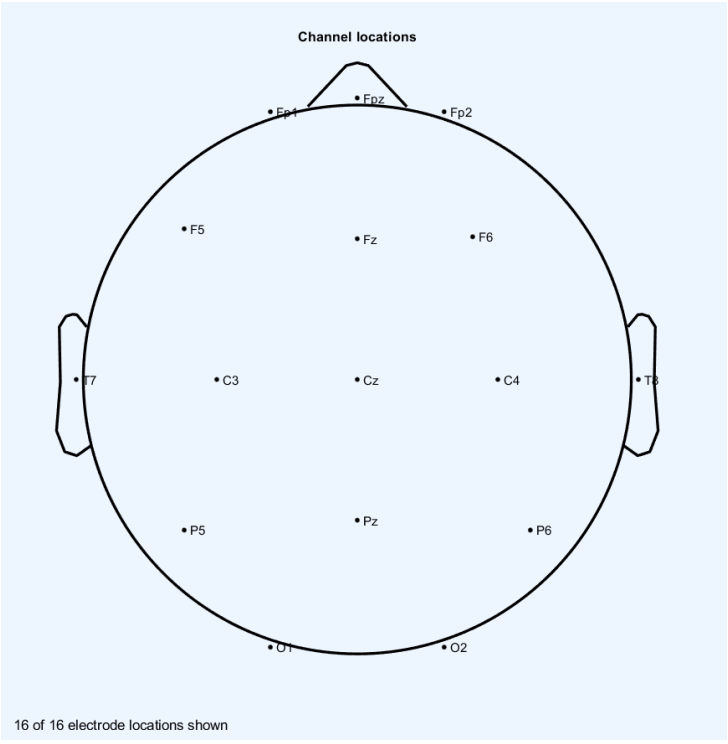


Figure 3: Channel locations from the electrode_location.loc file

When we compare figure 2 and figure 3, we can see that the channel locations that we have used in the practical and the locations in the file are the same.

2.2 Visualise data in time domain

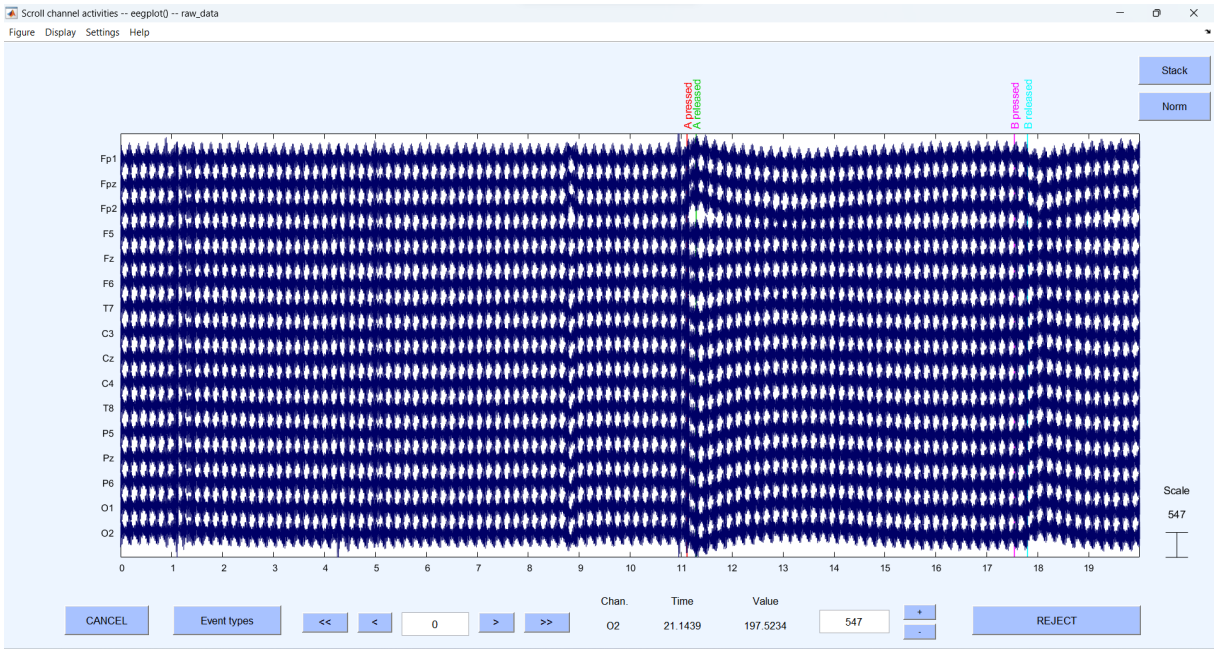


Figure 4: Time domain plot of raw data

2.3 Re-referencing

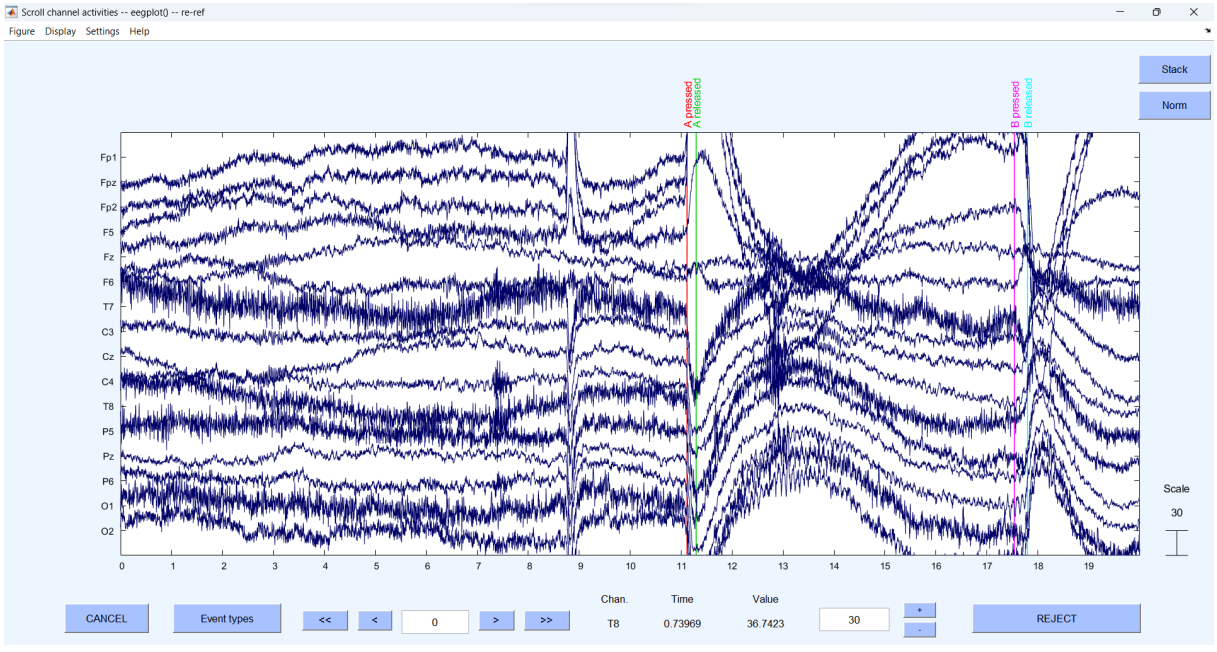


Figure 5: Time Domain Plot of the Re-referenced Data

In an electrically isolated system, the total electrical activity can be considered zero. This idea helps us choose a common reference point for EEG (brain wave) measurements. In our setup, we use the AFz electrode as the reference.
Sometimes, changing the reference point, a process called re-referencing helps remove background noise (common mode noise) shared across all channels. This makes hidden patterns in the EEG data easier to spot.

From the plots, we can notice that the data varies a lot (high variance). To deal with this, it's recommended to normalize the data. Normalization helps bring the data to a standard range, making it easier to analyze. The next plot shows the results after normalization.

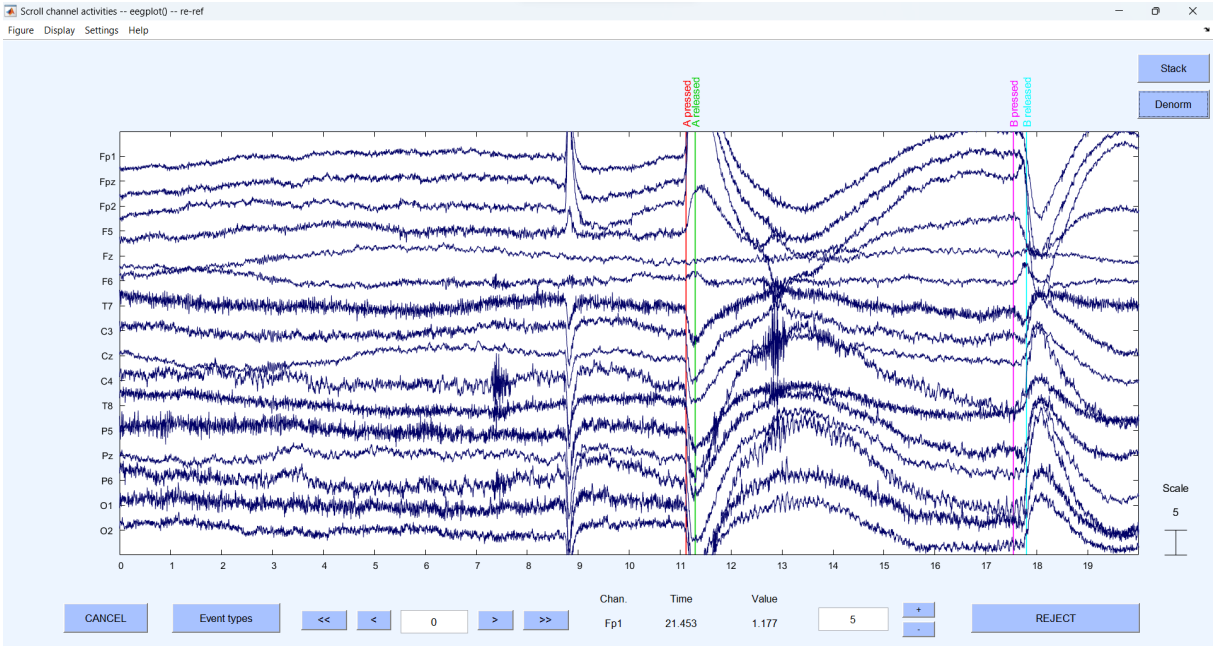


Figure 6: Time Domain Plot of normalized the Re-referenced Data

2.4 Event renaming

Table 1: Renamed Events

Event Key	Event Description	Event Name
A	Eyes closed	i_close
B	Eyes open	i_open
C	Blink (close and open)	blink
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

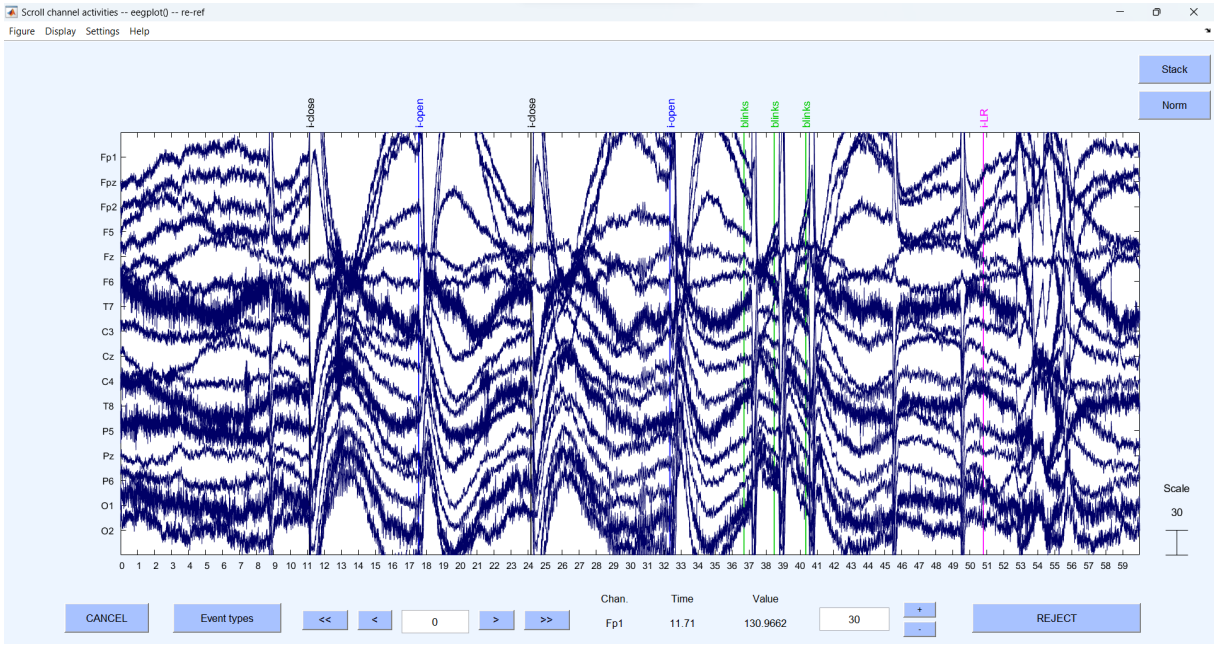


Figure 7: Time Domain Plot indicating Renamed Events

2.5 Segmenting data related to events

2.5.1 Method 1: Based on events

When collecting event-related data, we usually focus on a specific time window before and after the event. However, relying on markers to segment the data has some challenges:

- Subjective accuracy: The precision of where the markers are placed can vary depending on the person doing it.
- High variability: Different trials may have inconsistent markers, making the data less reliable.
- Overlapping events: Sometimes, the selected window can unintentionally include parts of other events, like blinks, which can interfere with the analysis.

The plot below shows an example where blink data overlaps with other event markers, illustrating this issue.

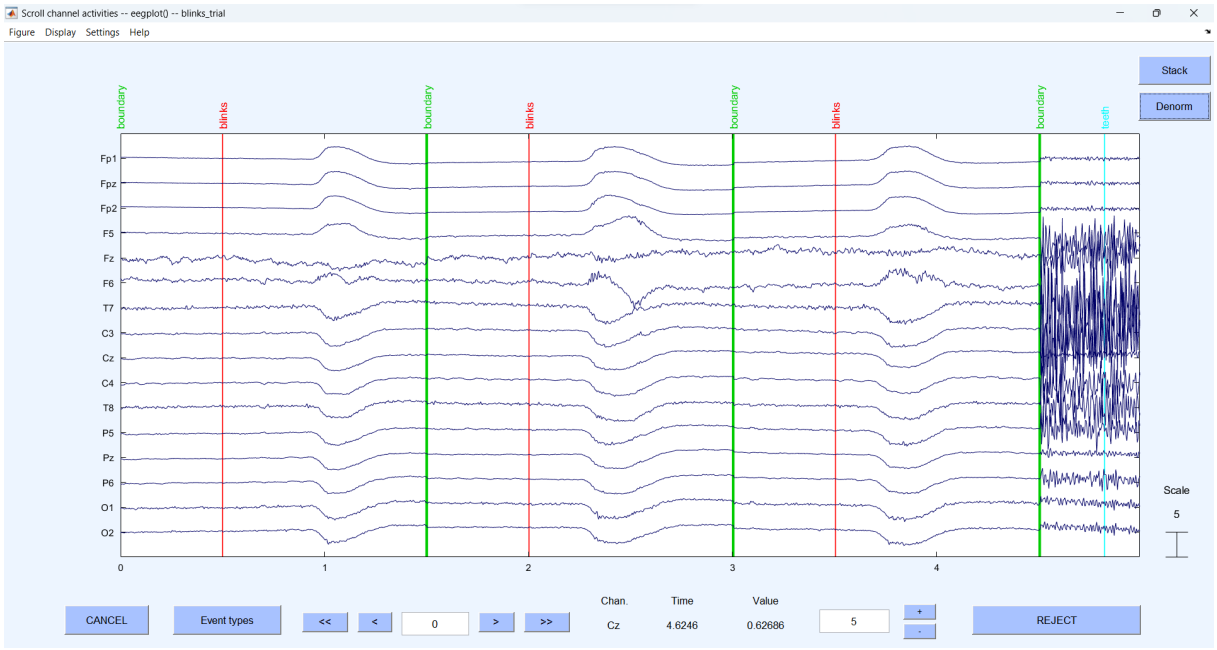
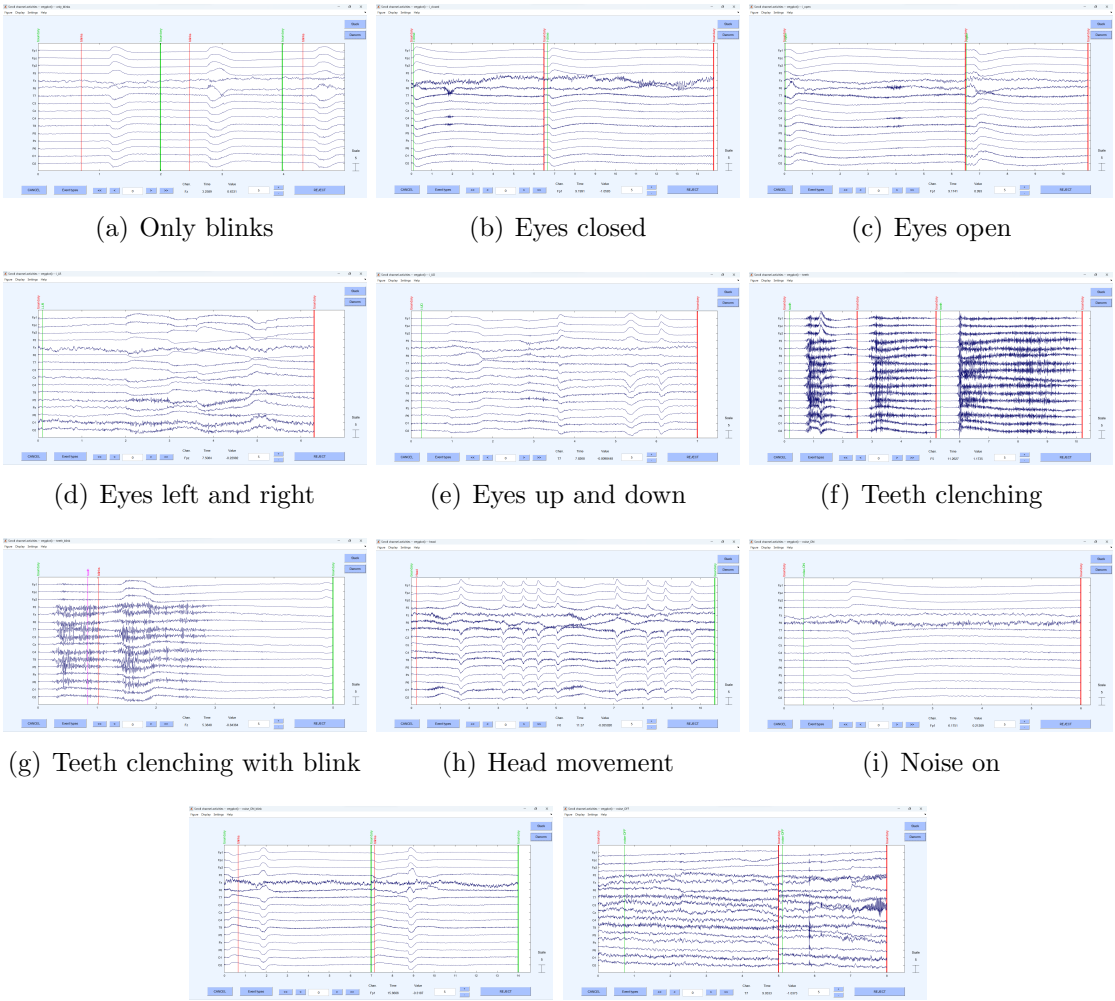


Figure 8: Blink Data close to Other Event Markers

2.5.2 Method 2: Based on time



(a) Only blinks (b) Eyes closed (c) Eyes open

(d) Eyes left and right (e) Eyes up and down (f) Teeth clenching

(g) Teeth clenching with blink (h) Head movement (i) Noise on

(j) Blinking with noise on (k) Noise off

Figure 9: Segmented data related to events based on the time

The following table summarizes the timestamps and durations of the events recorded.

Table 2: Timestamps of the Events

Event Key	Event Name	Time Stamps	Dataset Name
A	i_close	[11 17.5; 24 32.3]	i closed
B	i_open	[17.5 24; 32.3 36.7]	i open
C	blinks	[36 38; 38 40; 40 42]	only blinks
D	i_LR	[50.7 57]	i_LR
E	i_UD	[66 73]	i_UD
F	teeth	[80.5 83; 84.3 87; 88 93]	teeth
F + C	teeth + blinks	[96 101]	teeth blink
G	head	[108 118.5]	head
H	noise_ON	[131 137]	noise_ON
I	noise_OFF	[152 157; 180 183]	noise_OFF
H + C	noise_ON + blinks	[145 152; 173 180]	noise ON blink

2.6 Channel spectra and scalp maps

2.6.1 Plots for 'i_closed'

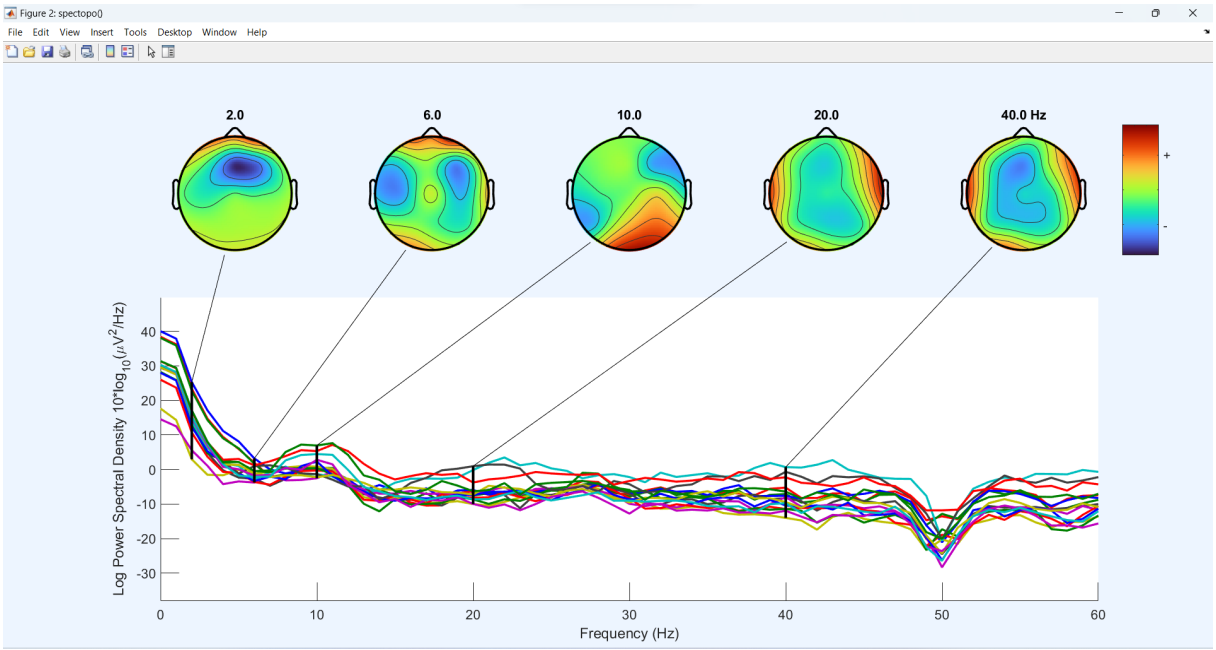


Figure 10: Spectra and Scale Maps - 'i_closed'

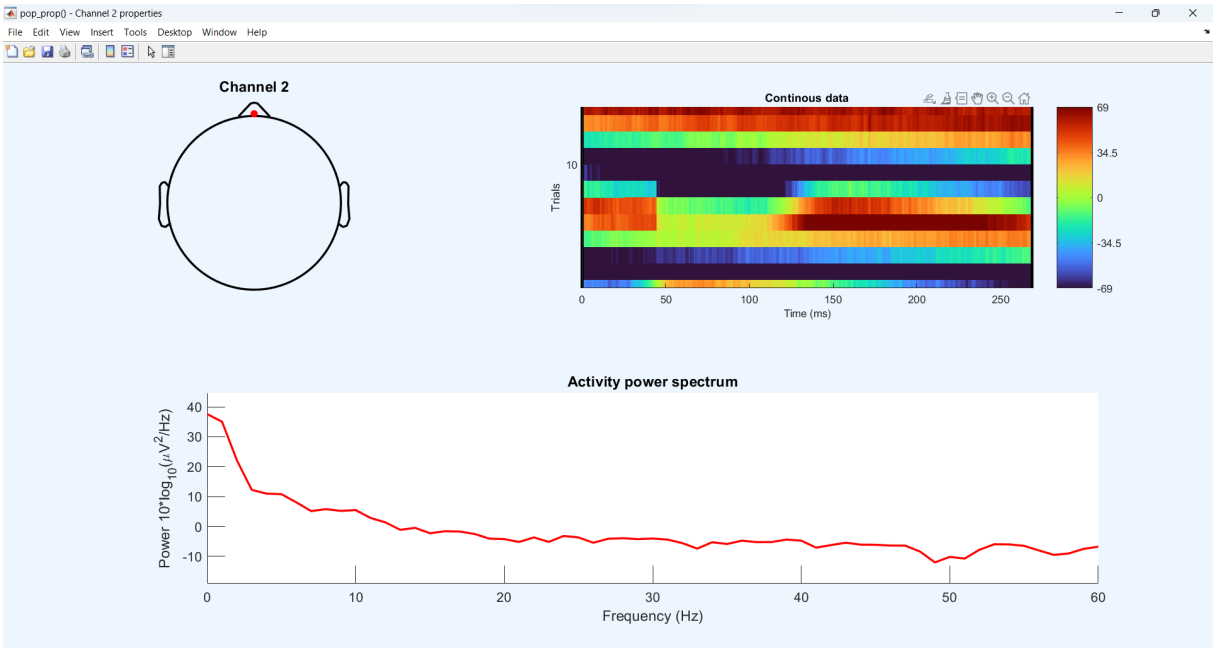


Figure 11: Channel 2 Activity Power Spectrum - 'i_closed'

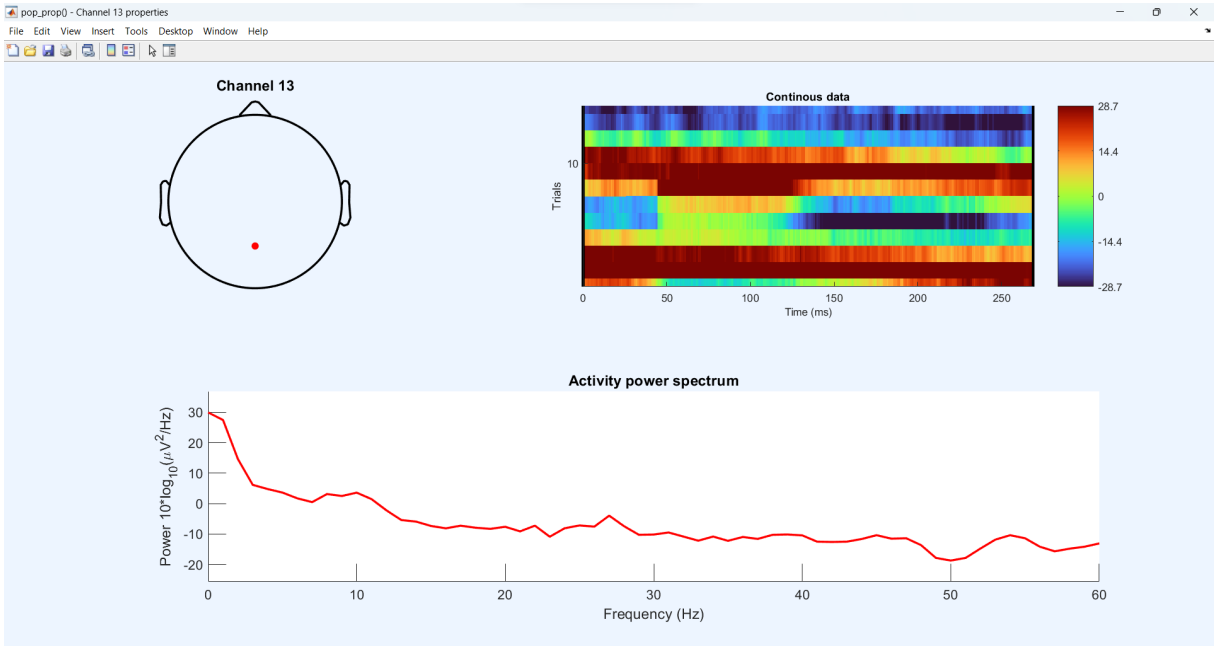


Figure 12: Channel 13 Activity Power Spectrum - 'i_closed'

Interpretation: The results show that the strength of the signal (spectral magnitude) decreases as frequency increases, and vice versa. This means the curve drops as the frequency rises.
The scalp plots display Equivalent Current Dipoles (ECDs), which likely represent brain activity under specific conditions.
We also notice that low-frequency brain activity in the frontal region is minimal, indicating a lack of eye movements. However, as the frequency reaches around 10 Hz, there is a noticeable power peak. This aligns with the fact that when we close our eyes, our brain's neurons tend to fire more synchronously, making alpha waves (in the 8-13 Hz range) more dominant.

2.6.2 Plots for 'i_LR'

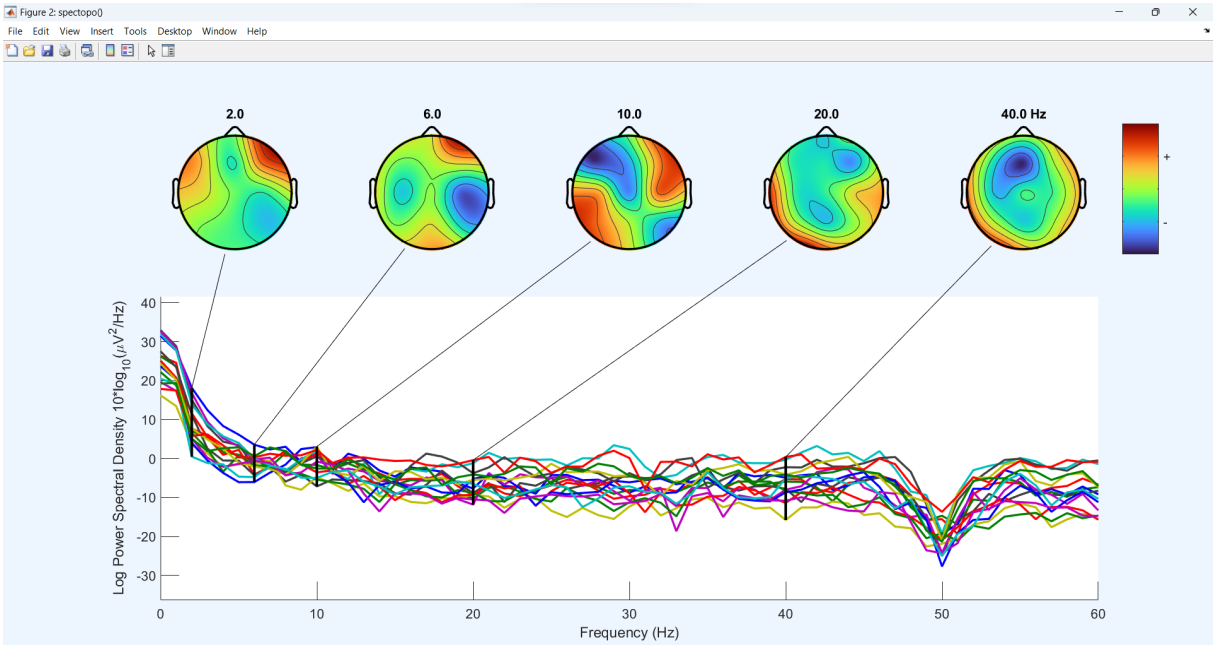


Figure 13: Spectra and Scale Maps - 'i_LR'

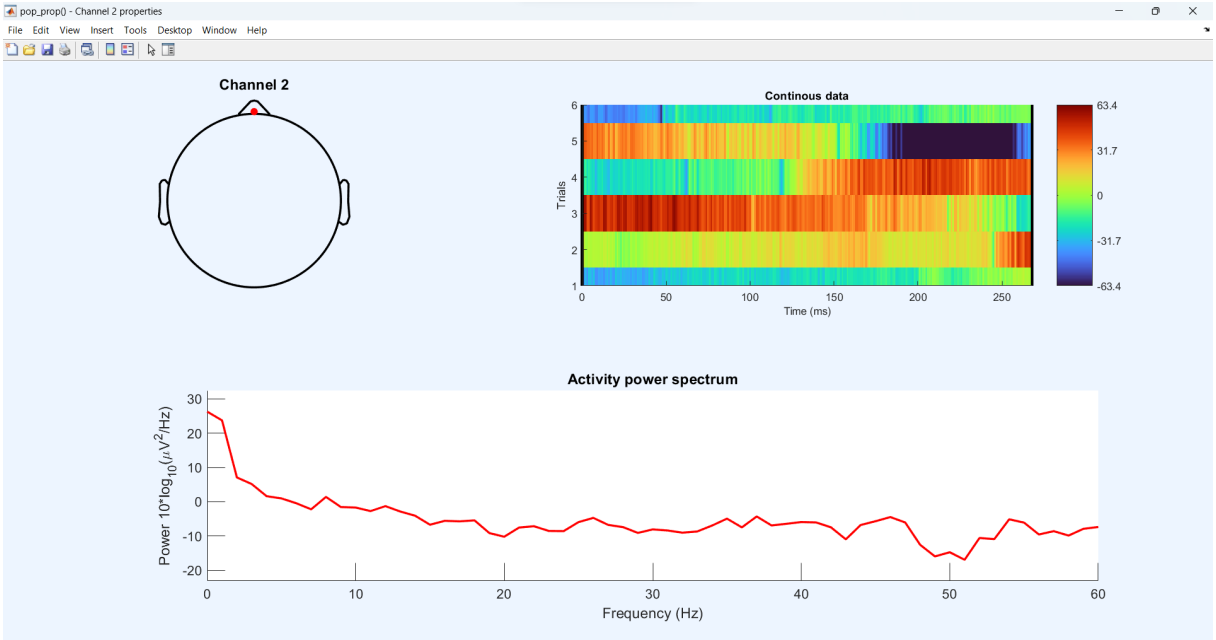


Figure 14: Channel 2 Activity Power Spectrum - 'i_LR'

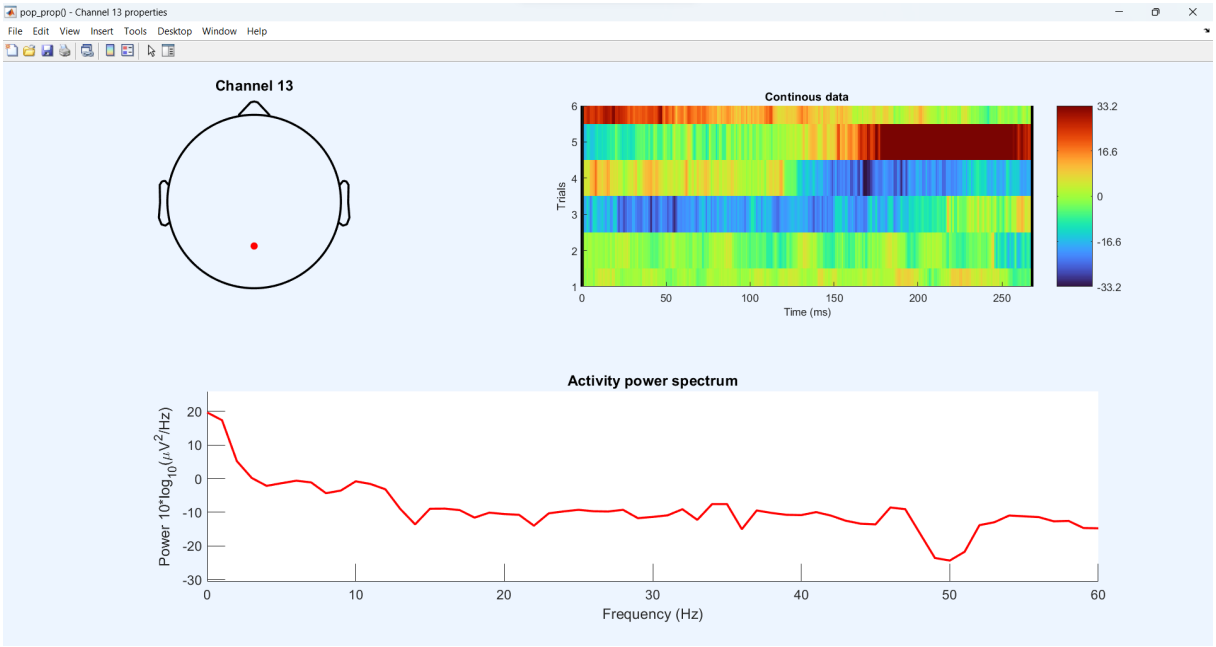


Figure 15: Channel 13 Activity Power Spectrum - 'i_LR'

Interpretation: As with the previous plot, the signal strength (spectral magnitude) decreases as the frequency increases.
We can observe some brain activity in the frontal region at low frequencies, particularly around 2-3 Hz. In the power spectrum for channel 2, there is a noticeable peak near 2 Hz, indicating horizontal eye movement. This is confirmed by horizontal Equivalent Current Dipoles (ECDs).
In the occipital region around 10 Hz, there is significant activity, which suggests that the visual cortex in the occipital region is being stimulated. This is likely due to the left-right (LR) eye movement.

2.6.3 Plots of 'i_UD'

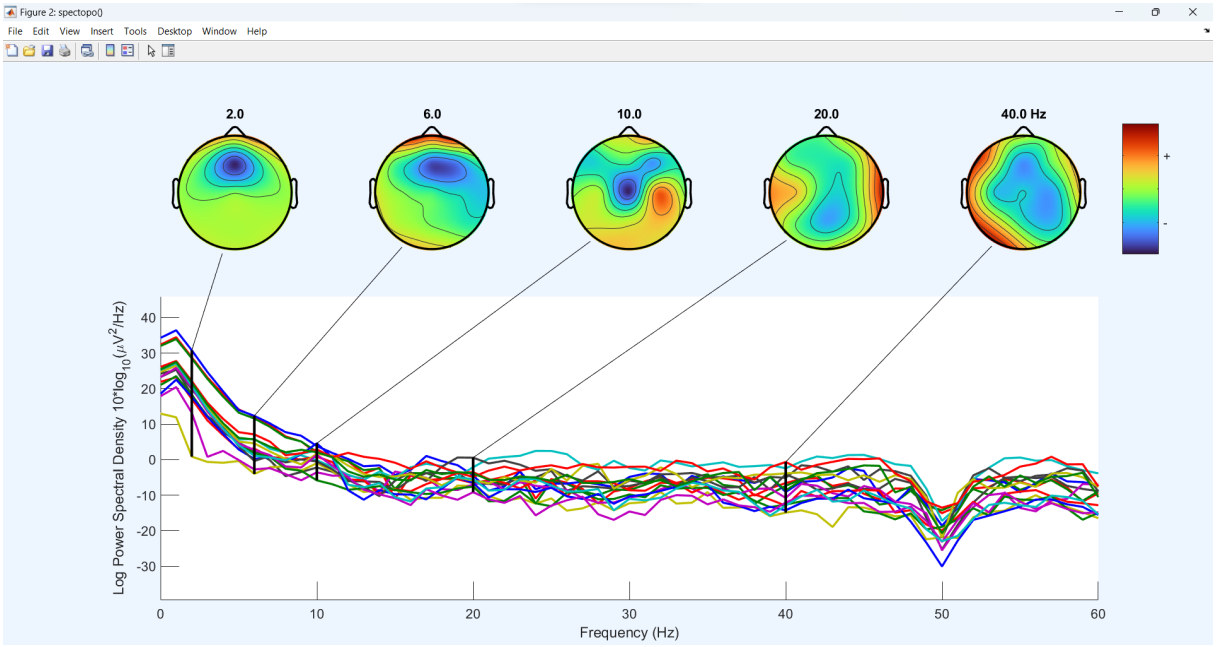


Figure 16: Spectra and Scale Maps - 'i_UD'

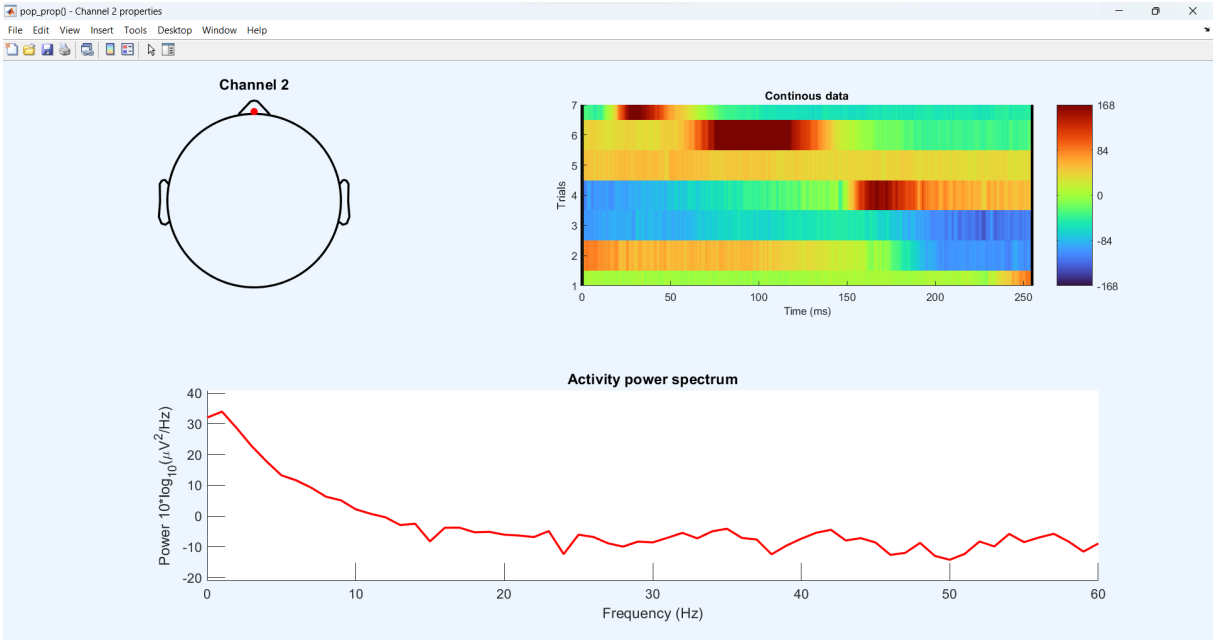


Figure 17: Channel 2 Activity Power Spectrum - 'i_UD'

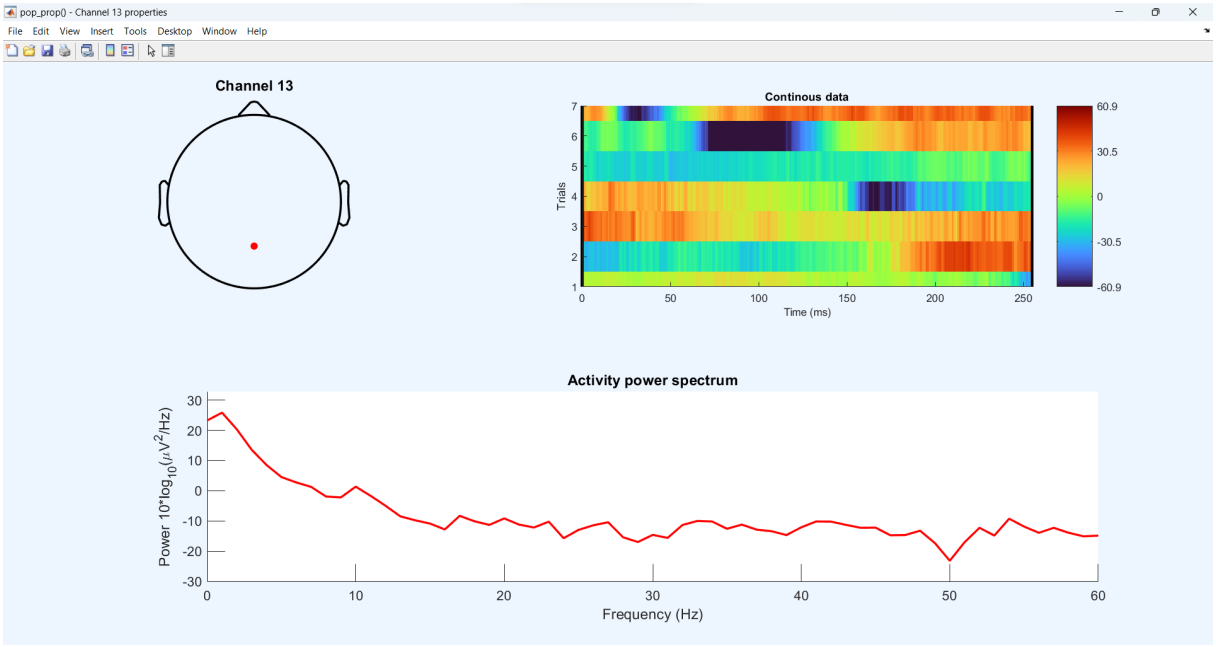


Figure 18: Channel 13 Activity Power Spectrum - 'i_UD'

Interpretation: The plots for left-right (LR) and up-down (UD) eye movements show some similar patterns. For both, we see a peak near 2 Hz. However, in the LR plots, this peak corresponds to horizontal brain activity (horizontal ECDs), while in the UD plots, it corresponds to vertical brain activity (vertical ECDs).

Like before, the signal strength (spectral magnitude) decreases as the frequency increases.

When we focus on the occipital region, we observe significant brain activity around 10 Hz. This suggests that the visual cortex in the occipital region is activated by UD eye movements, just as it is with LR movements. In simpler terms, both types of eye movements stimulate the visual cortex.

2.6.4 Plots of 'teeth'

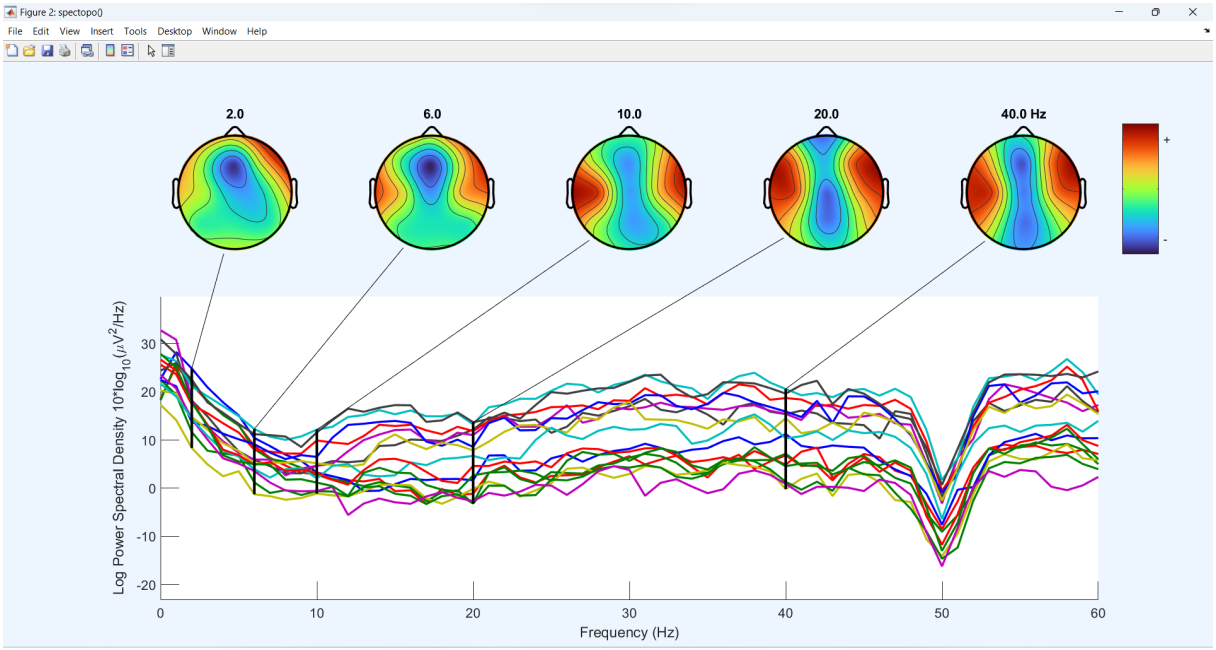


Figure 19: Spectra and Scale Maps - 'Teeth'

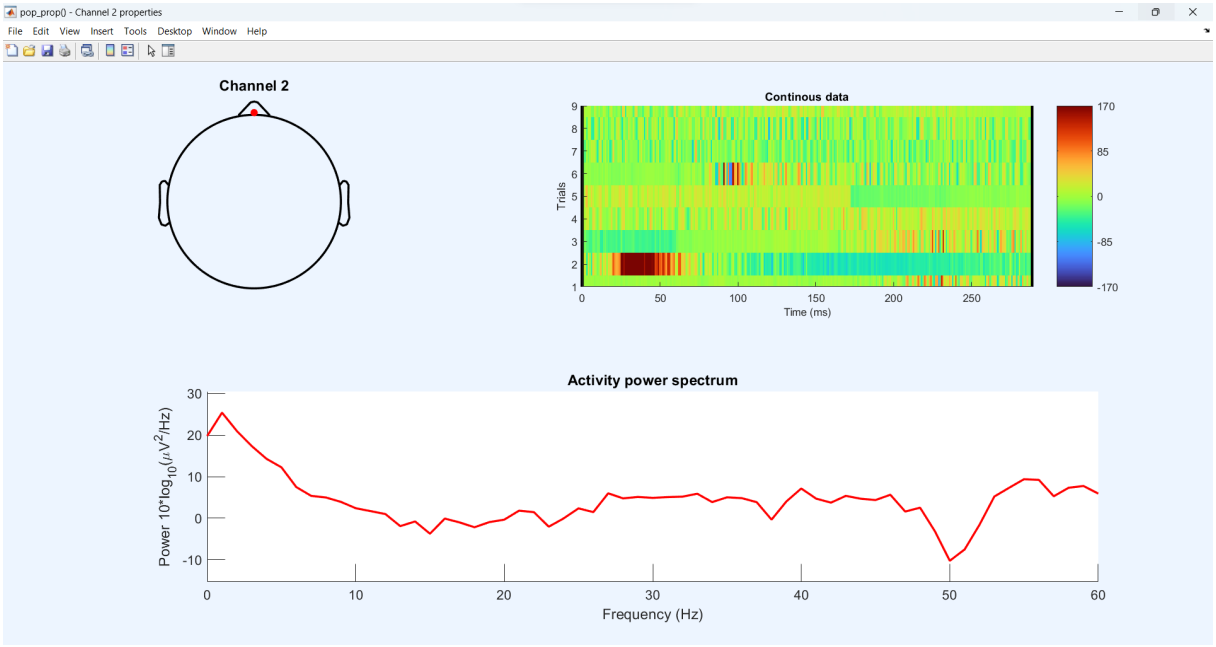


Figure 20: Channel 2 Activity Power Spectrum - 'Teeth'

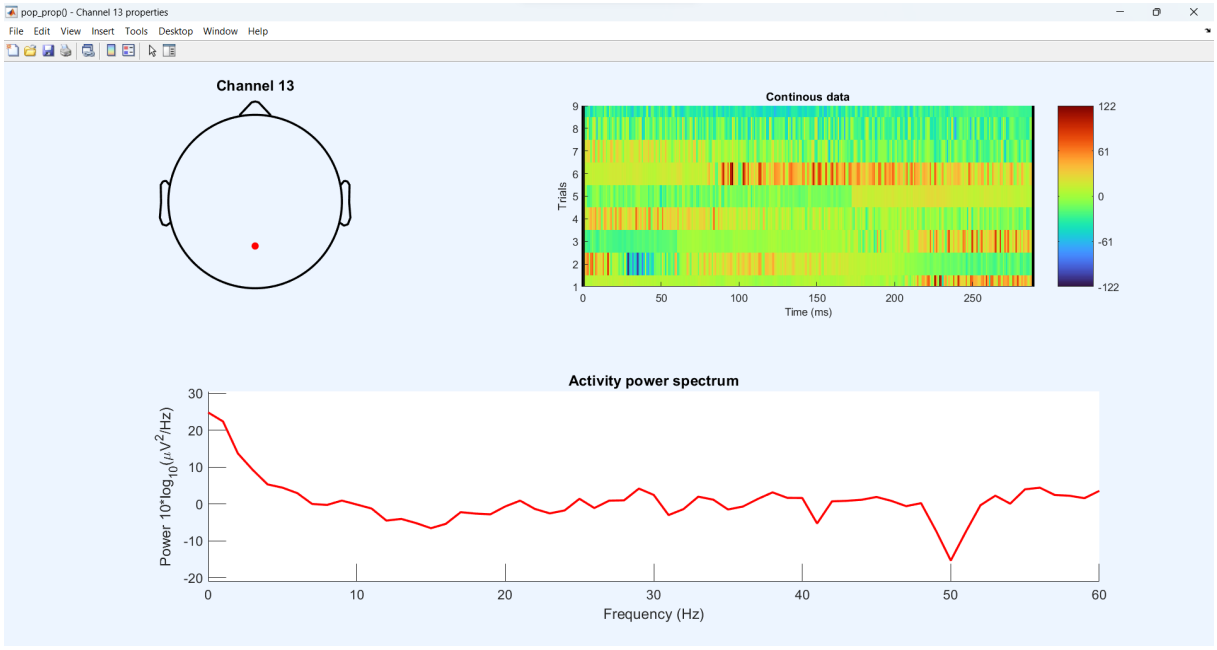


Figure 21: Channel 13 Activity Power Spectrum - 'Teeth'

Interpretation: These plots are different from the previous ones. Here, most of the signal strength (spectral power) is concentrated at higher frequencies. This is because of strong muscle activity, especially from jaw movements and clenching. In fact, the muscle signals (EMG activity) are so strong that they overshadow brain activity, which is confirmed by the Equivalent Current Dipoles (ECDs).

2.6.5 Plots of 'noise_ON'

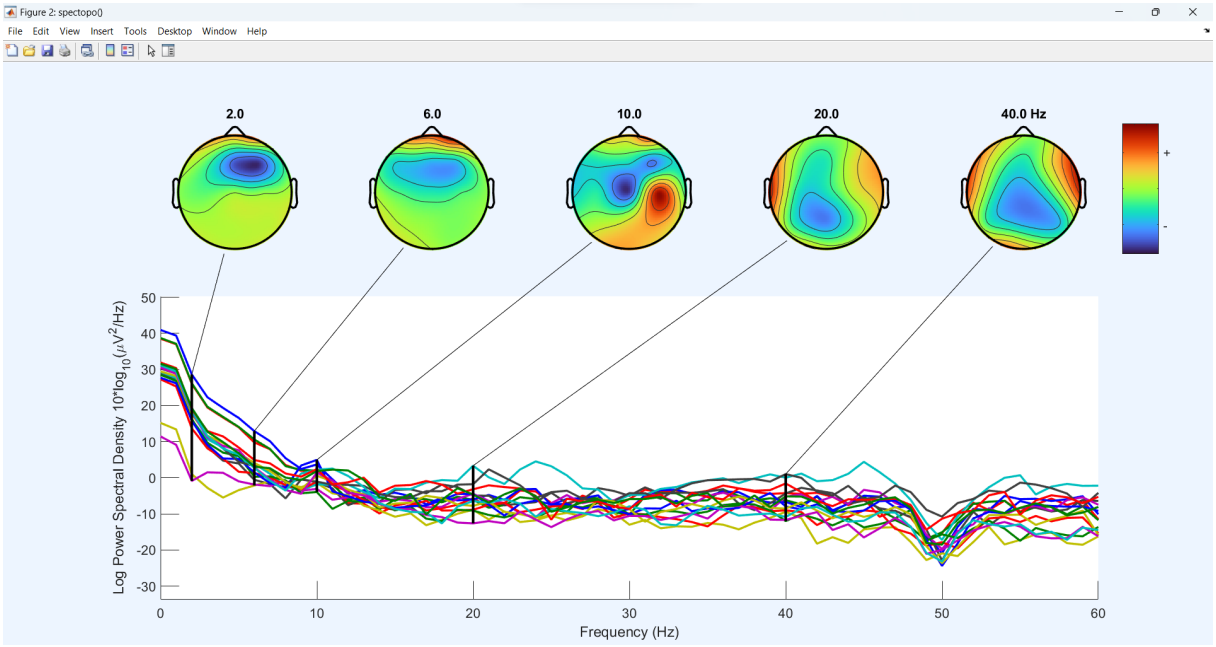


Figure 22: Spectra and Scale Maps - 'noise_ON without blinks'

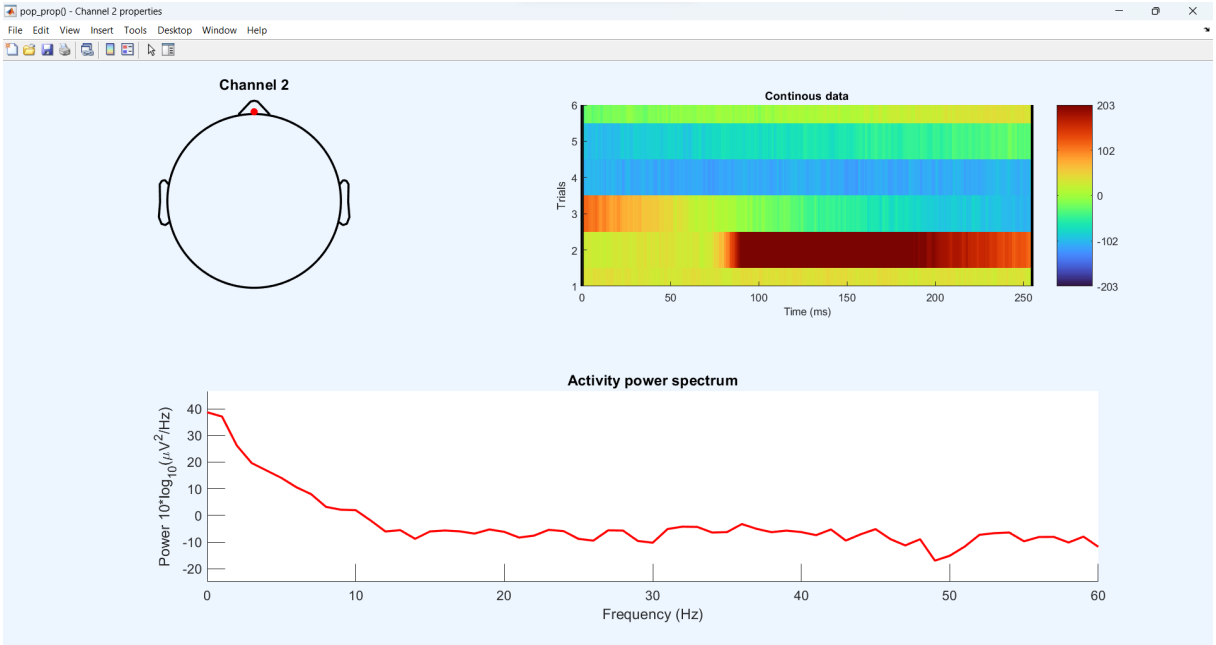


Figure 23: Channel 2 Activity Power Spectrum - 'noise_ON without blinks'

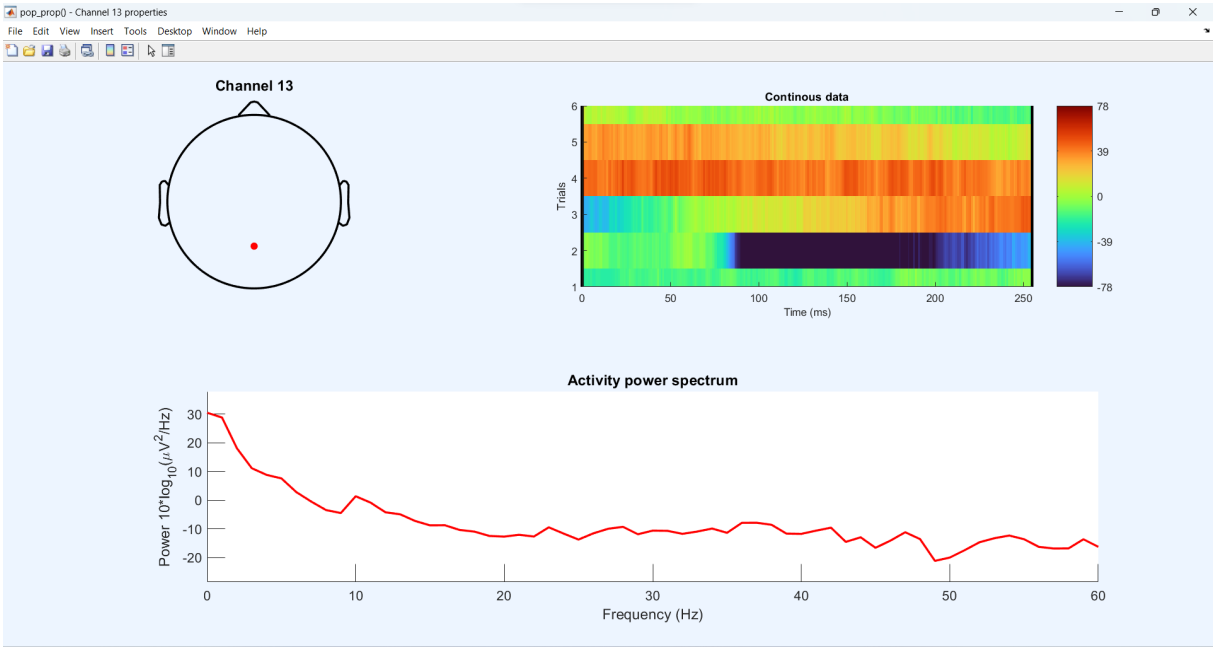


Figure 24: Channel 13 Activity Power Spectrum - 'noise_ON without blinks'

Interpretation: At first, the spectral plots show the usual pattern where signal strength (spectral magnitude) decreases as frequency increases. However, as the plot continues, this pattern flattens out, with only small fluctuations (jitters). This indicates that noise is interfering with the signal.
In this case, the noise is so strong that it has overpowered the actual signal, making it hard to see the expected peaks in the 10-30 Hz range.

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

3.1 Blinking

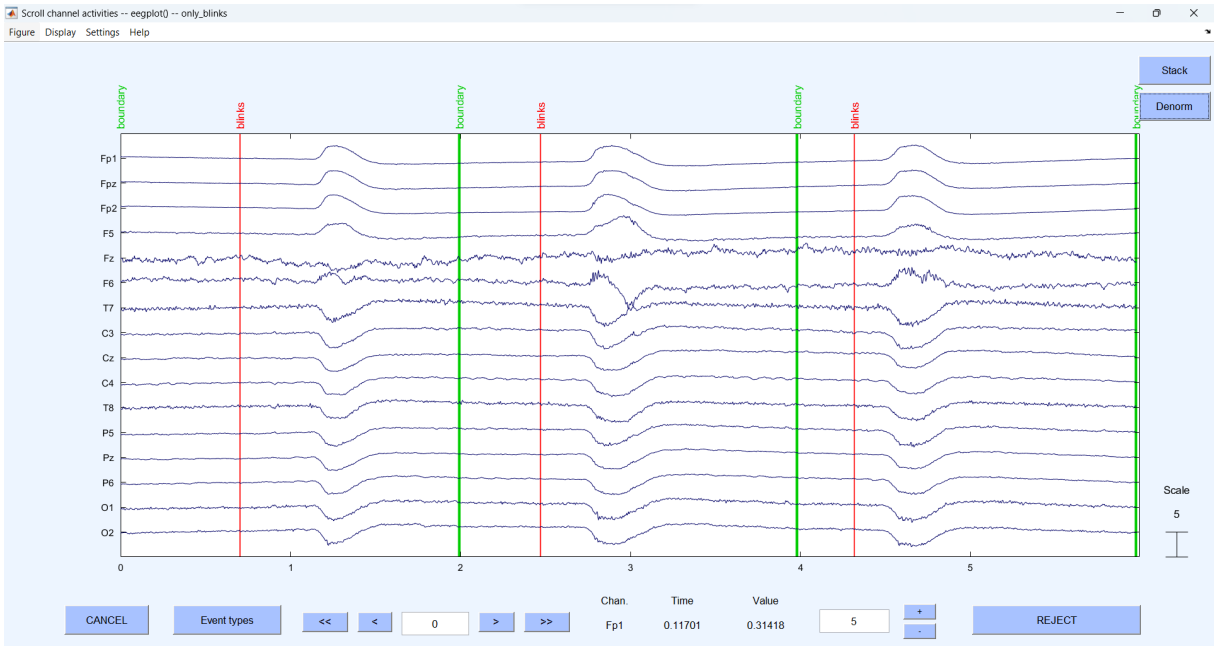


Figure 25: Raw EEG Data - Blinking (Normalized)

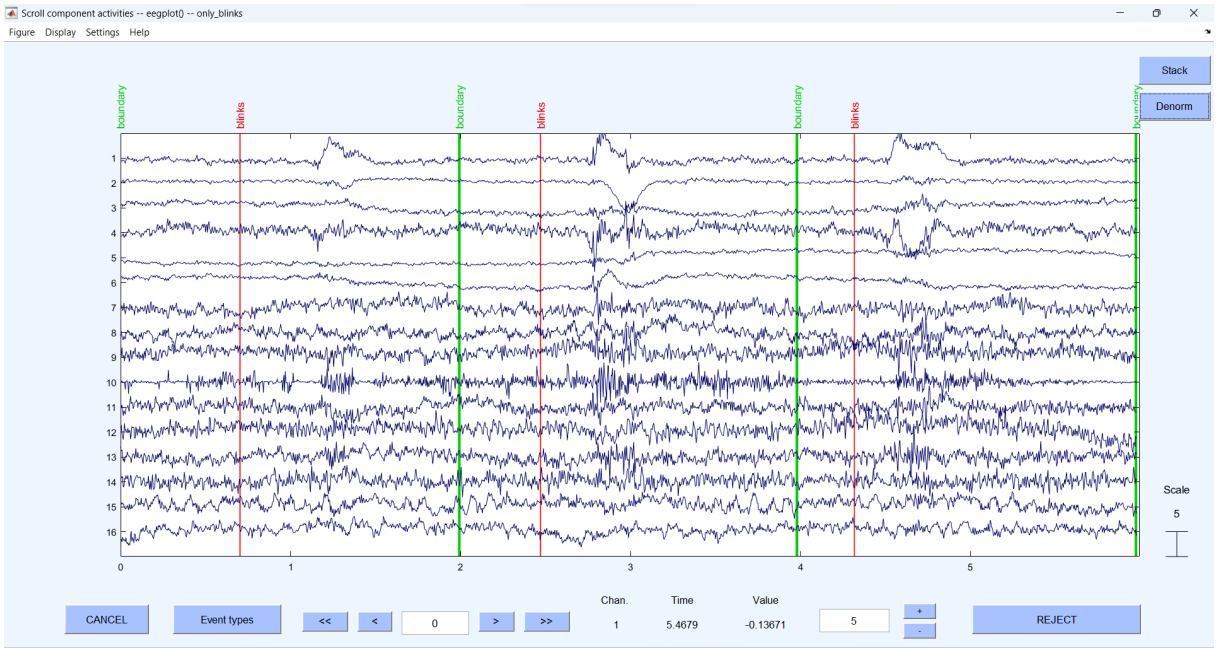
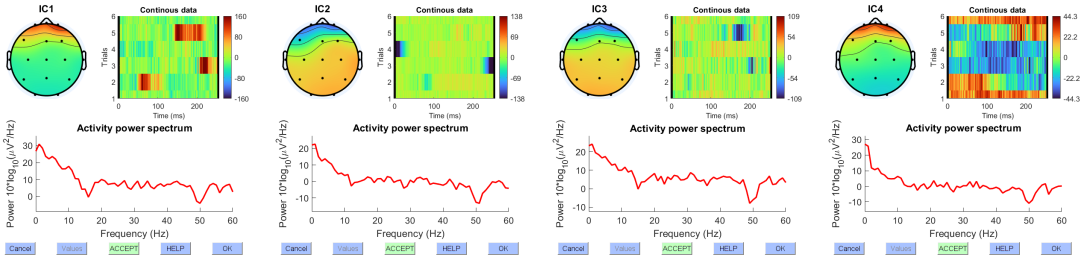


Figure 26: Normalized ICA components - Blinking

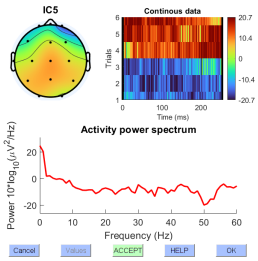


(a) IC01

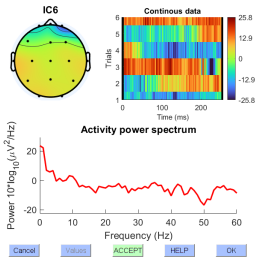
(b) IC02

(c) IC03

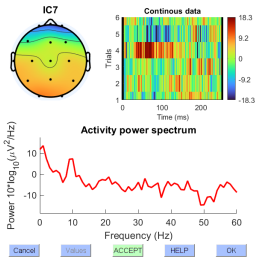
(d) IC04



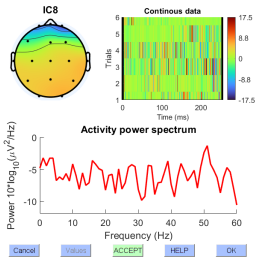
(e) IC05



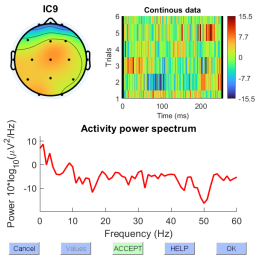
(f) IC06



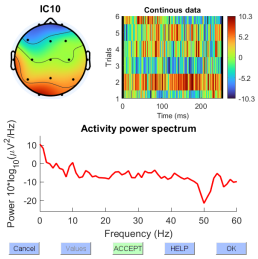
(g) IC07



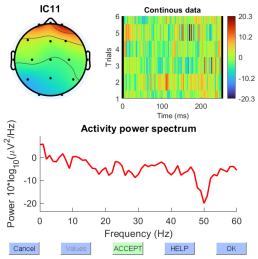
(h) IC08



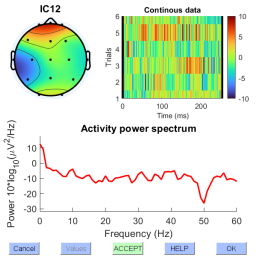
(i) IC09



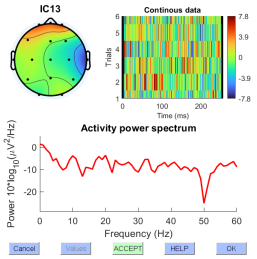
(j) IC10



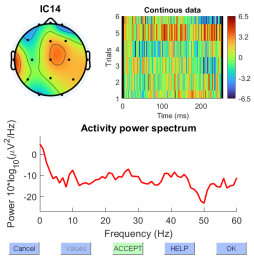
(k) IC11



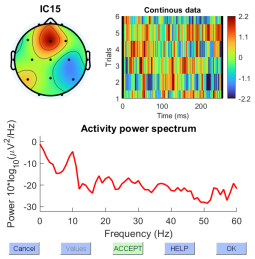
(l) IC12



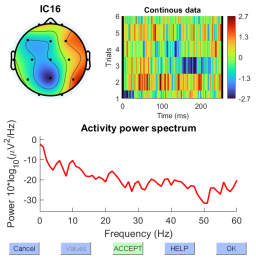
(m) IC13



(n) IC14



(o) IC15



(p) IC16

Figure 27: Independent Component Analysis - Blinking

Table 3: ICA categorization summery - Blinking

Component	Label	Reason	Status
1	Eye	Scalp topology localized at the front. Power is concentrated in low frequencies.	Removed
2	Eye	Same as 1	Removed
3	Eye	Same as 1	Removed
4	Eye	Same as 1	Removed
5	Eye	Same as 1	Removed
6	Brain, Eye	Scalp topology localized at the font, and also some mid-areas. Small peak around 10Hz. Most of the power is concentrated in low frequencies.	Removed
7	Brain	Peak around 10Hz which is generally significant in brain activities. Power concentrated in high-frequencies is low.	Retained
8	Muscle	High power in high frequencies.	Removed
9	Brain	Scalp topology localized at the font, and also some mid-areas. Small peak around 10Hz.	Retained
10	Brain, Eye	Same as 9	Removed
11	Muscle	High power in high frequencies.	Removed
12	Brain	Peak around 10Hz. Scalp topology localized front and mid areas.	Retained
13	Brain, Muscle	Peak around 10Hz which is significant in brain activities. High power in high frequencies.	Removed
14	Brain, Muscle	Same as 13	Removed
15	Brain	Peak around 10Hz which is generally significant in brain activities. Power concentrated in high-frequencies is low.	Retained
16	Brain	Same as 15	Retained

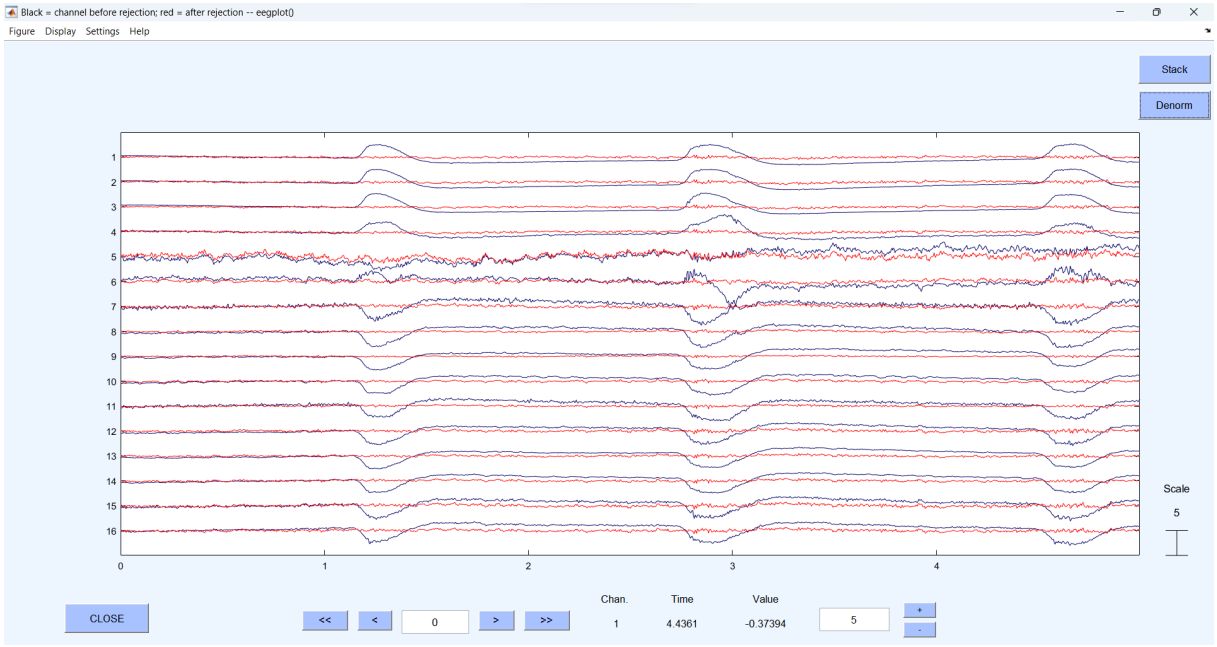


Figure 28: Comparison before and after ICA - Blinking

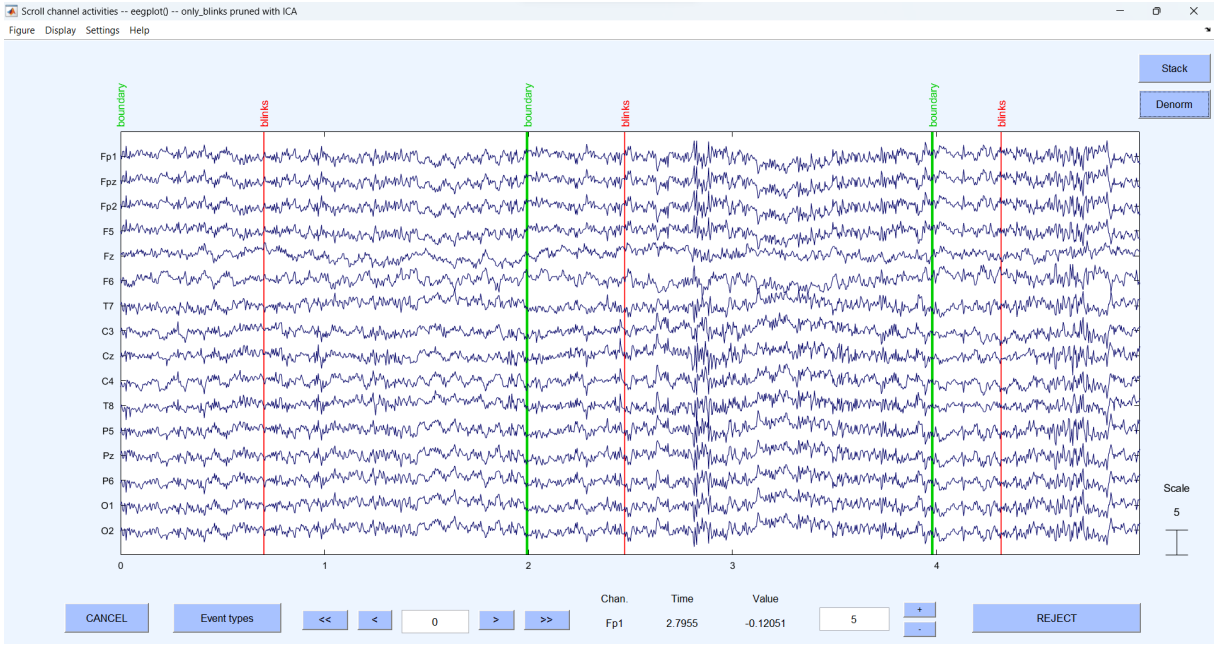


Figure 29: Reconstructed Signals - Blinking

3.2 Left-to-Right Eye Movement

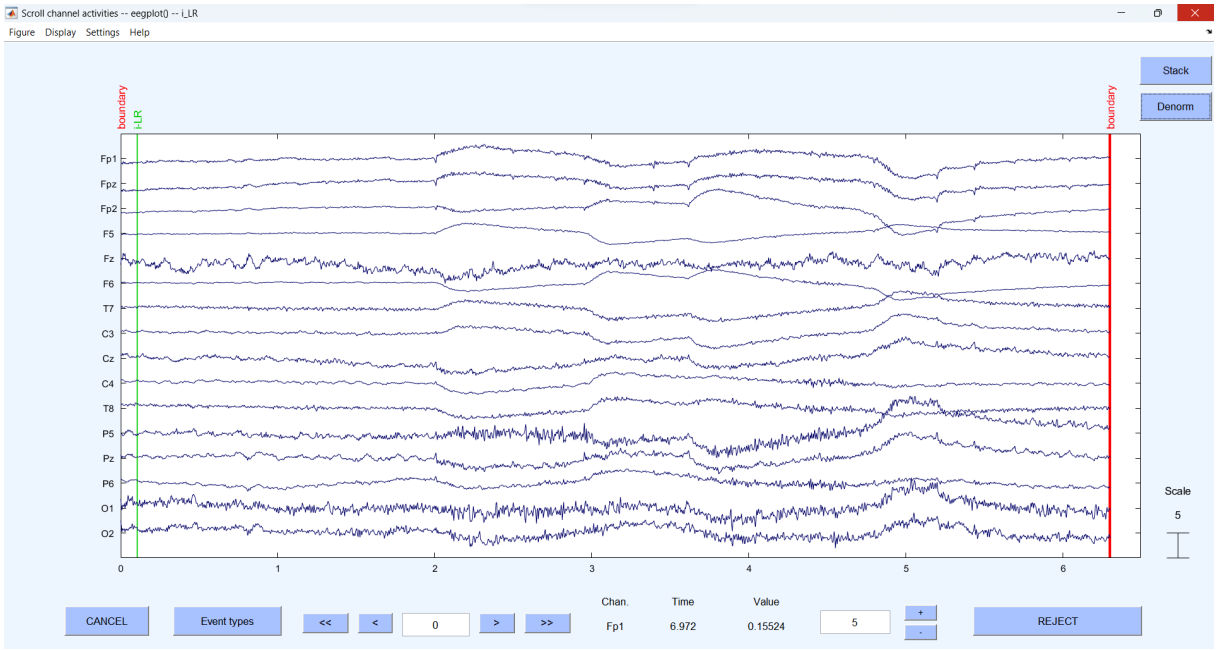


Figure 30: Raw EEG Data - Left-to-Right Eye Movement (Normalized)

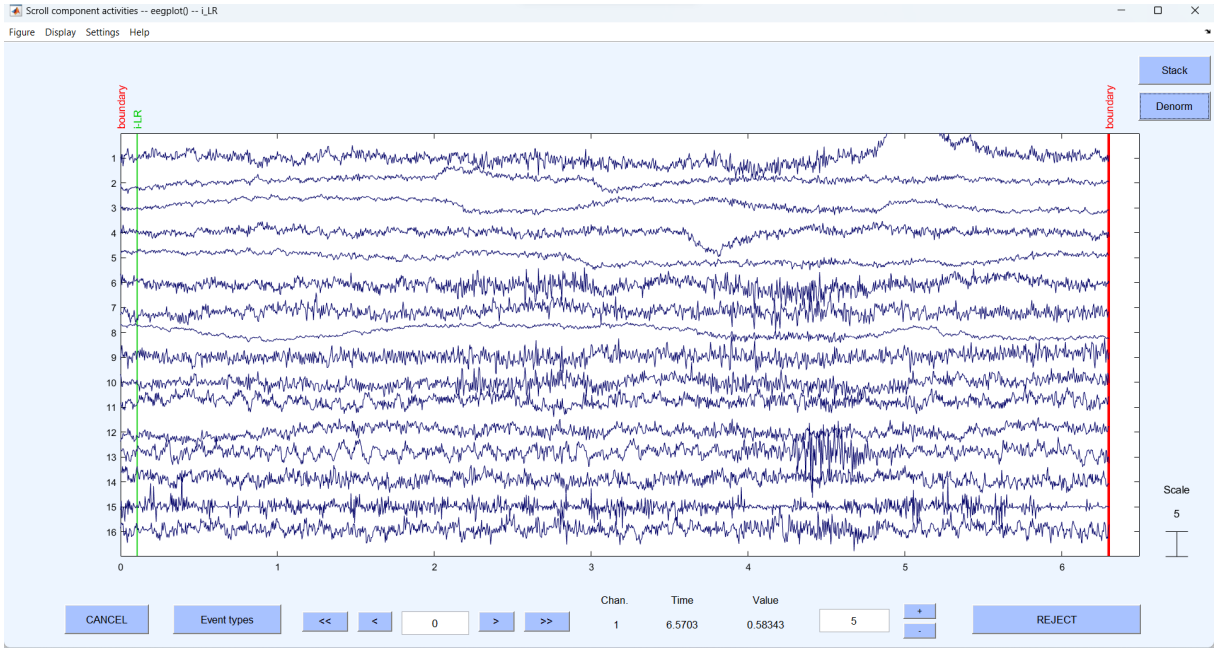
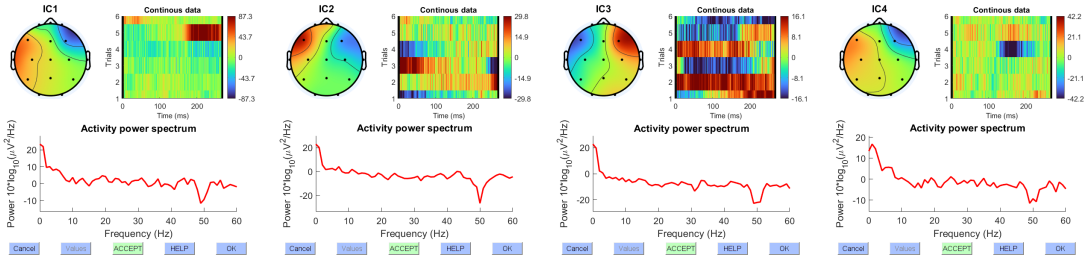


Figure 31: Normalized ICA components - Left-to-Right Eye Movement

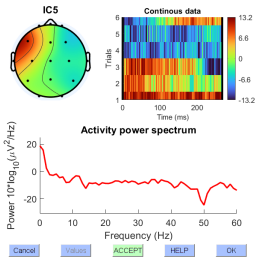


(a) IC01

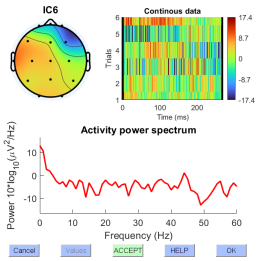
(b) IC02

(c) IC03

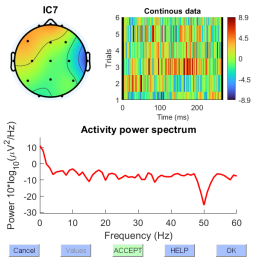
(d) IC04



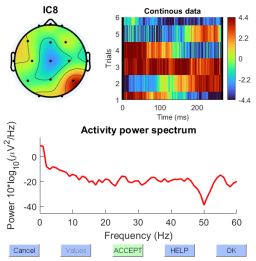
(e) IC05



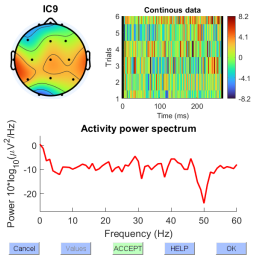
(f) IC06



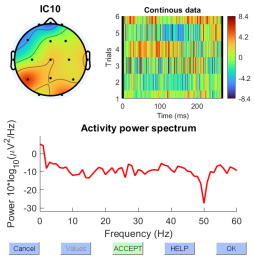
(g) IC07



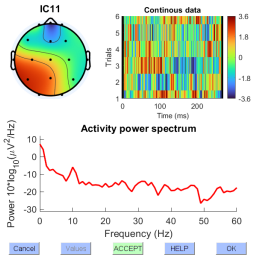
(h) IC08



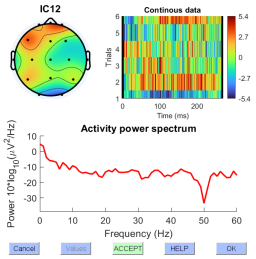
(i) IC09



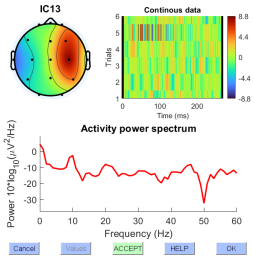
(j) IC10



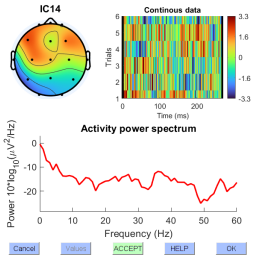
(k) IC11



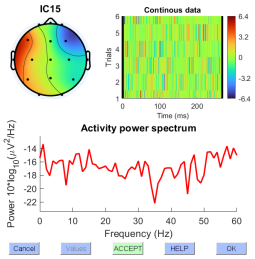
(l) IC12



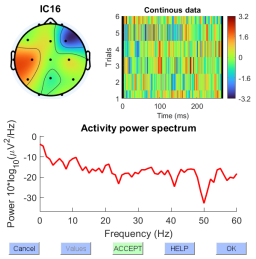
(m) IC13



(n) IC14



(o) IC15



(p) IC16

Figure 32: Independent Component Analysis - Left to Right Eye Movement

Table 4: ICA categorization summery - Left-to-right eye movement

Component	Label	Reason	Status
1	Eye	Scalp topology localized at the front with a dipole that denotes the horizontal eye movements	Removed
2	Eye	Same as 1	Removed
3	Eye	Same as 1	Removed
4	Eye	Same as 1	Removed
5	Brain	There is a clear peak around 10Hz.	Retained
6	Eye, Muscle	Scalp topology localized at the front. And also high power in high-frequencies.	Removed
7	Brain, Muscle	Peak around 10Hz in the spectrum. Have a considerable amount of power in high-frequencies.	Removed
8	Brain, Muscle	Same as 7.	Removed
9	Brain, Muscle	Same as 7.	Removed
10	Brain, Muscle	Same as 7.	Removed
11	Brain	Clear peak around 10Hz. High power in low-frequencies.	Retained
12	Brain, Eye, Muscle	Peak around 10Hz. Scalp topology localized at the front. Power is almost the same across all frequencies.	Removed
13	Brain	Peak around 10Hz which is significant in brain activities. High power concentration around 10Hz and low-frequencies.	Retained
14	Muscle	High power concentration in high-frequencies	Removed
15	Brain, Muscle	High power concentration around 10Hz, low-frequencies and high-frequencies	Removed
16	Brain	High power concentration around 10Hz. Clear spike in 10Hz.	Retained

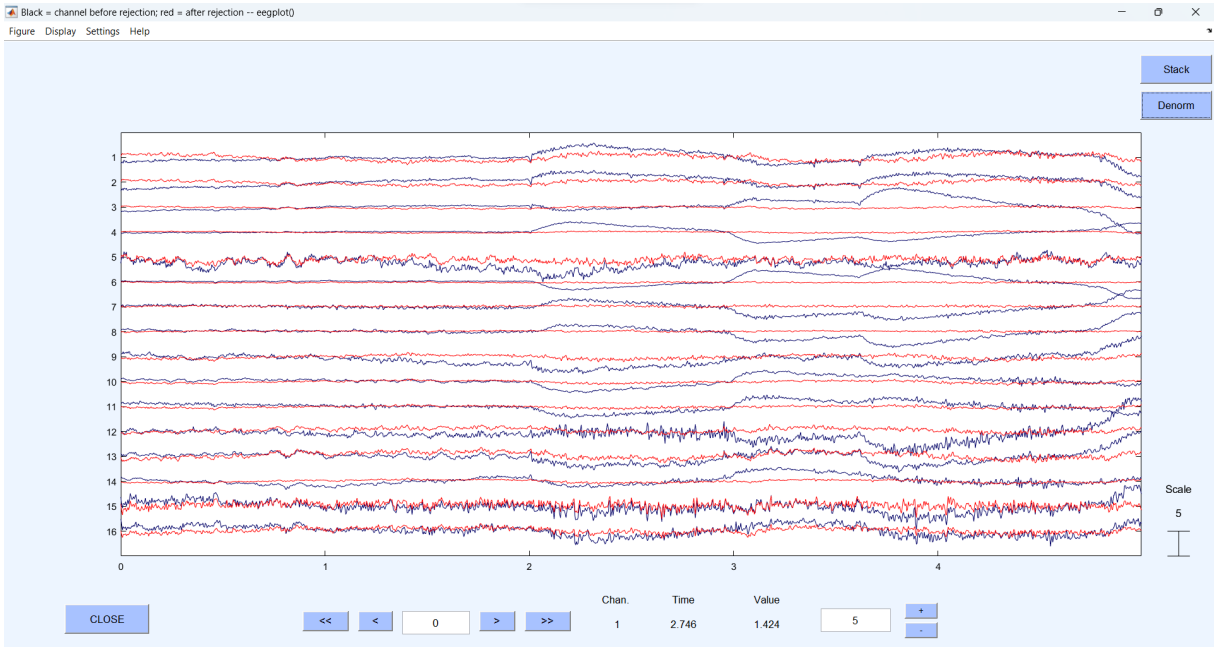


Figure 33: Comparison before and after ICA - Left to Right Eye Movement

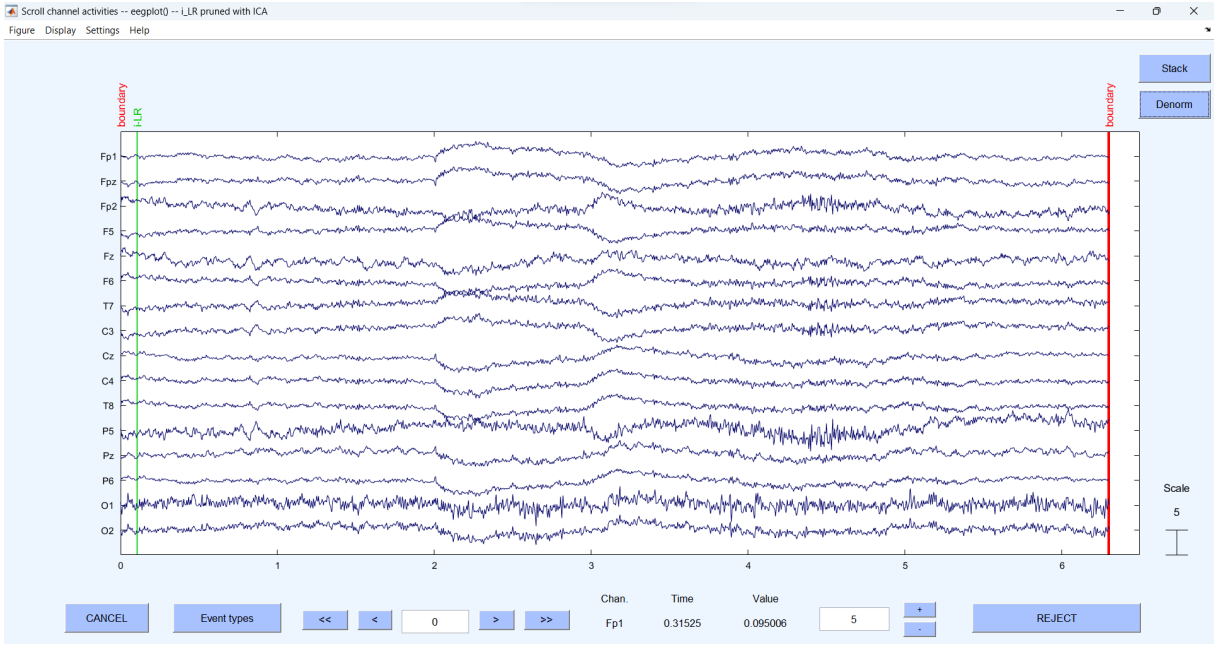


Figure 34: Reconstructed Signals - Left to Right Eye Movement

3.3 Up-to-Down Eye Movement

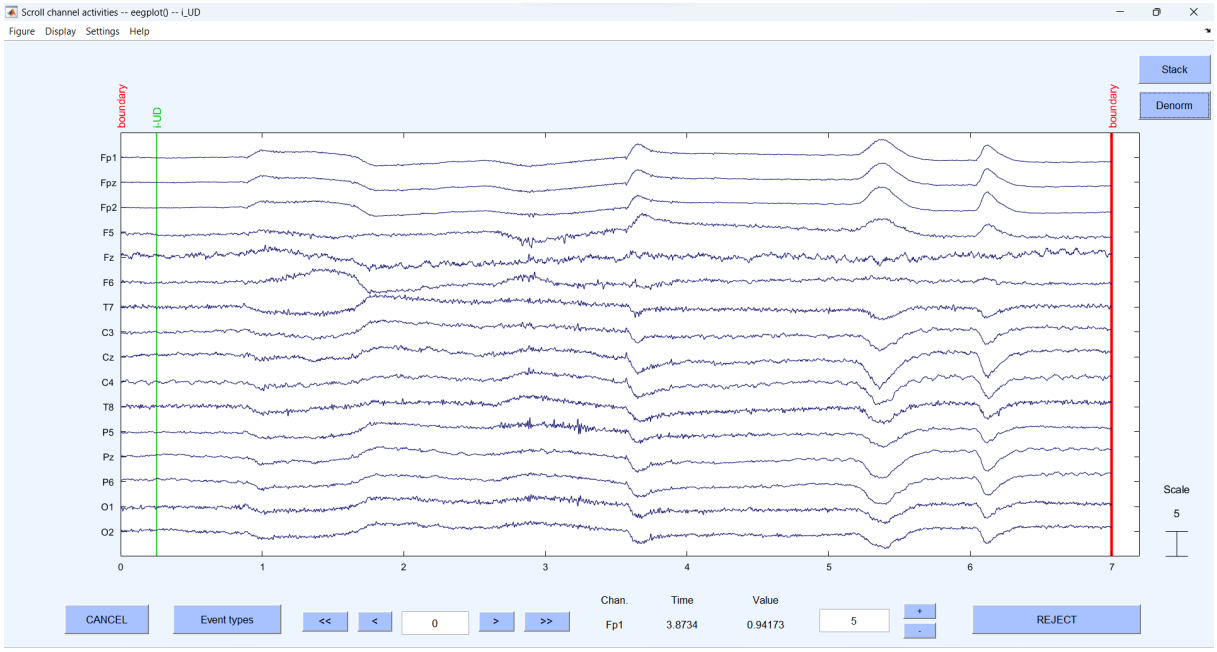


Figure 35: Raw EEG Data - Up-to-Down Eye Movement (Normalized)

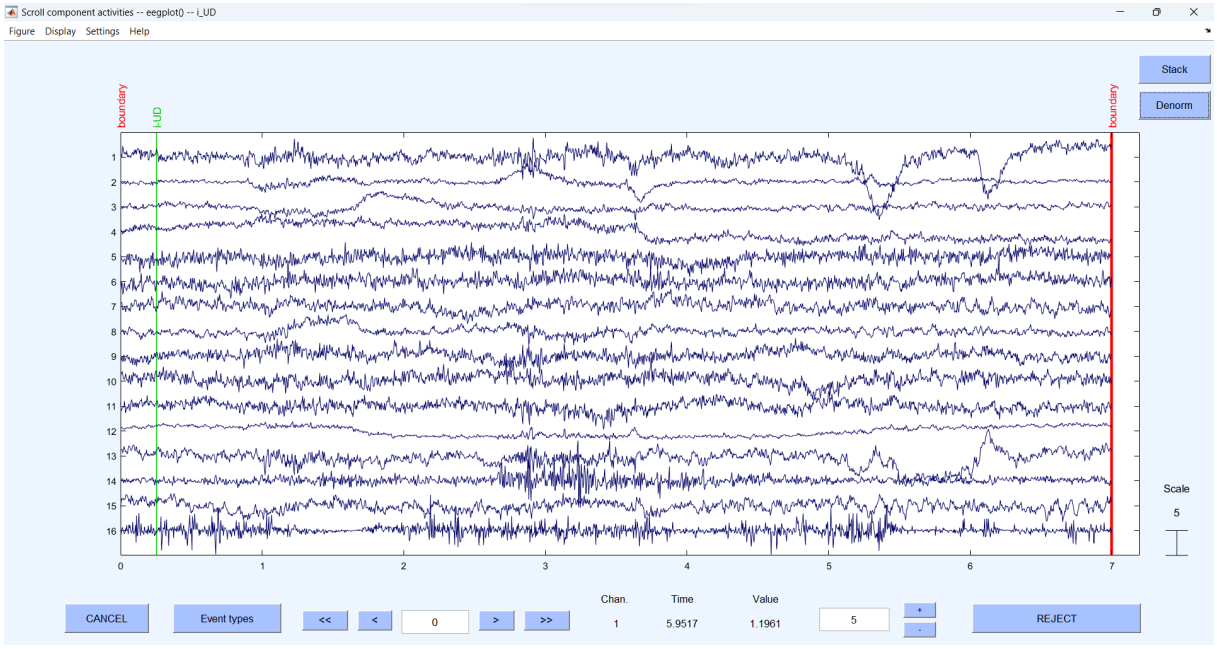
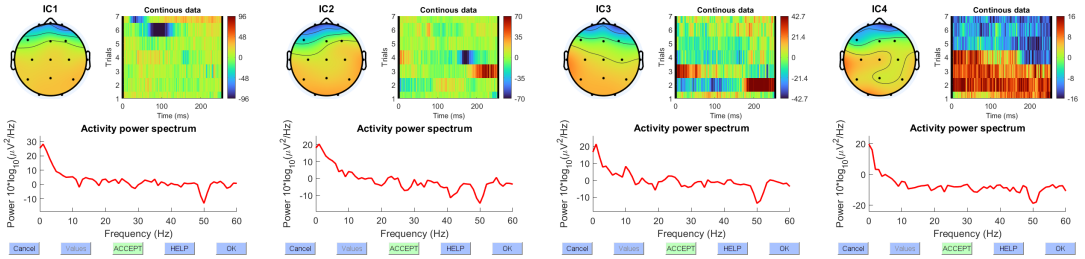


Figure 36: Normalized ICA components - Up-to-Down Eye Movement

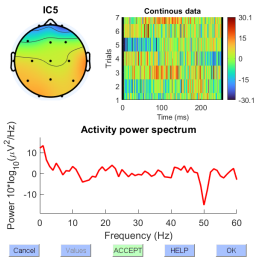


(a) IC01

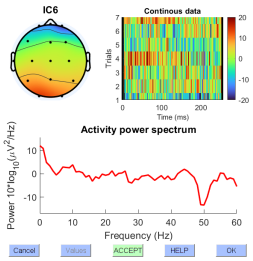
(b) IC02

(c) IC03

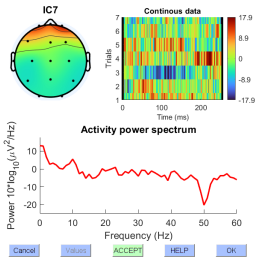
(d) IC04



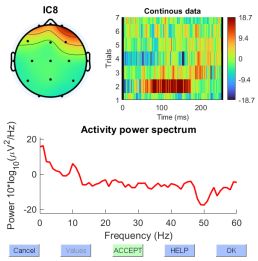
(e) IC05



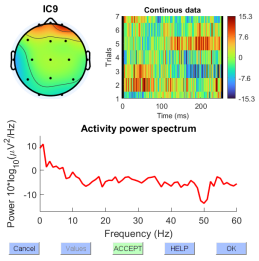
(f) IC06



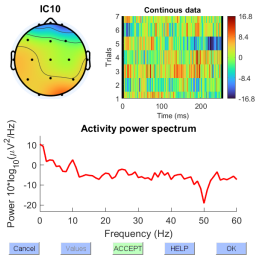
(g) IC07



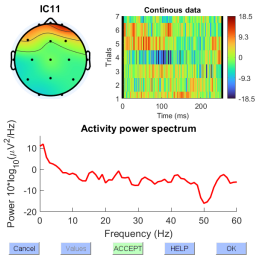
(h) IC08



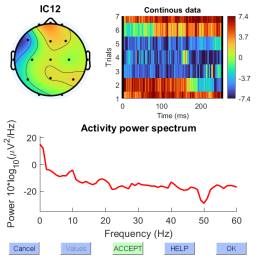
(i) IC09



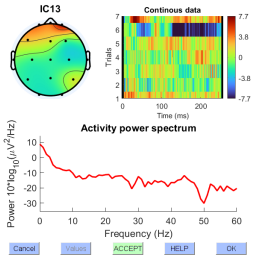
(j) IC10



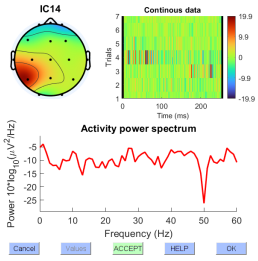
(k) IC11



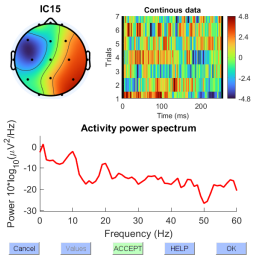
(l) IC12



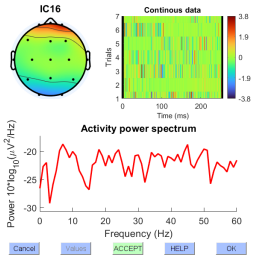
(m) IC13



(n) IC14



(o) IC15



(p) IC16

Figure 37: Independent Component Analysis - Up-to-Down Eye Movement

Table 5: ICA categorization summery - Up-to-down eye movement

Component	Label	Reason	Status
1	Eye	Scalp topology localized at the front. Decreasing spectrum with high-power in low-frequencies.	Removed
2	Eye	Same as 1	Removed
3	Brain, Eye	Same as 1 & peak around 10Hz.	Removed
4	Eye	Same as 1	Removed
5	Brain, Eye	Scalp topology localized at the front. Peak around 10Hz and considerable power concentration in low-frequencies.	Removed
6	Brain, Muscle	Peak around 10Hz. High power concentration in high-frequencies.	Removed
7	Brain	Peak around 10Hz in the spectrum. High power concentration in low-frequencies.	Retained
8	Brain	Same as 7.	Retained
9	Eye, Muscle	Scalp topology localized at the front. Some peaks in high-frequencies.	Removed
10	Brain	Same as 7.	Retained
11	Eye, Muscle	Same as 9.	Removed
12	Brain	Peak around 10Hz. High power concentration in low-frequencies	Retained
13	Eye	Scalp topology localized at the front. Decreasing spectrum with high-power in low-frequencies.	Removed
14	Brain, Muscle	High power concentration around 10Hz as well as high-frequencies.	Removed
15	Brain	Clear peak around 10Hz and significant power concentration in low-frequencies.	Retained
16	Brain, Muscle	High power concentration around 10Hz and in high-frequencies.	Removed

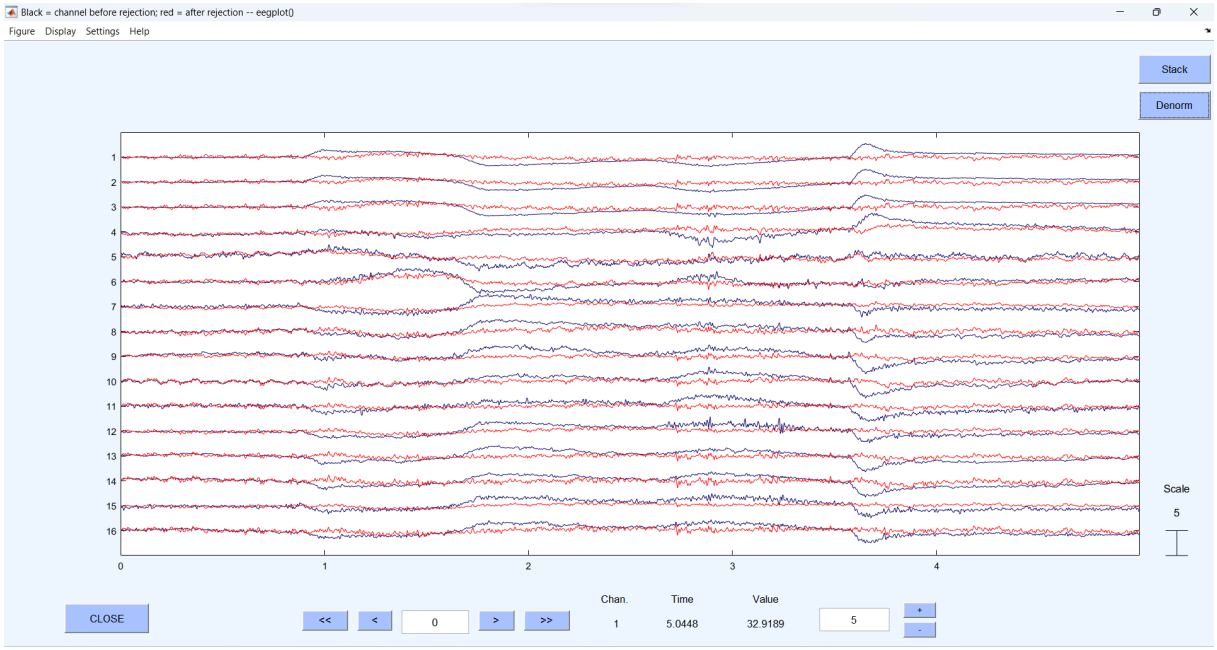


Figure 38: Comparison before and after ICA - Up-to-Down Eye Movement

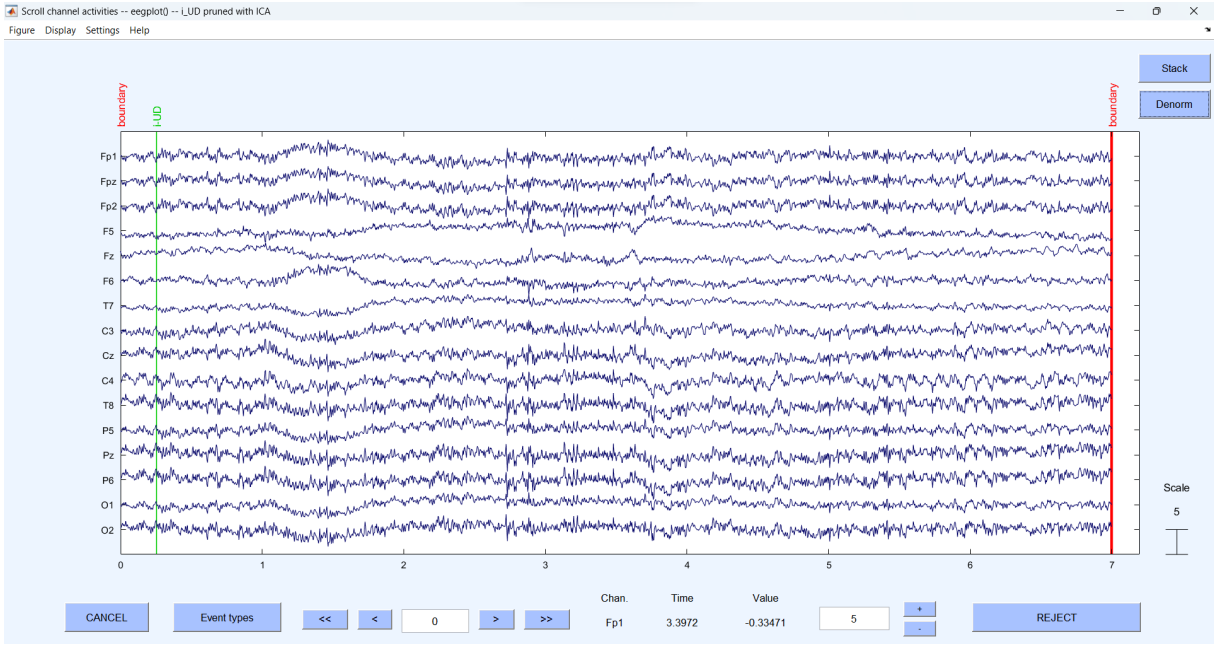


Figure 39: Reconstructed Signals - Up-to-Down Eye Movement

3.4 Simultaneous Teeth Clenching and Blinking

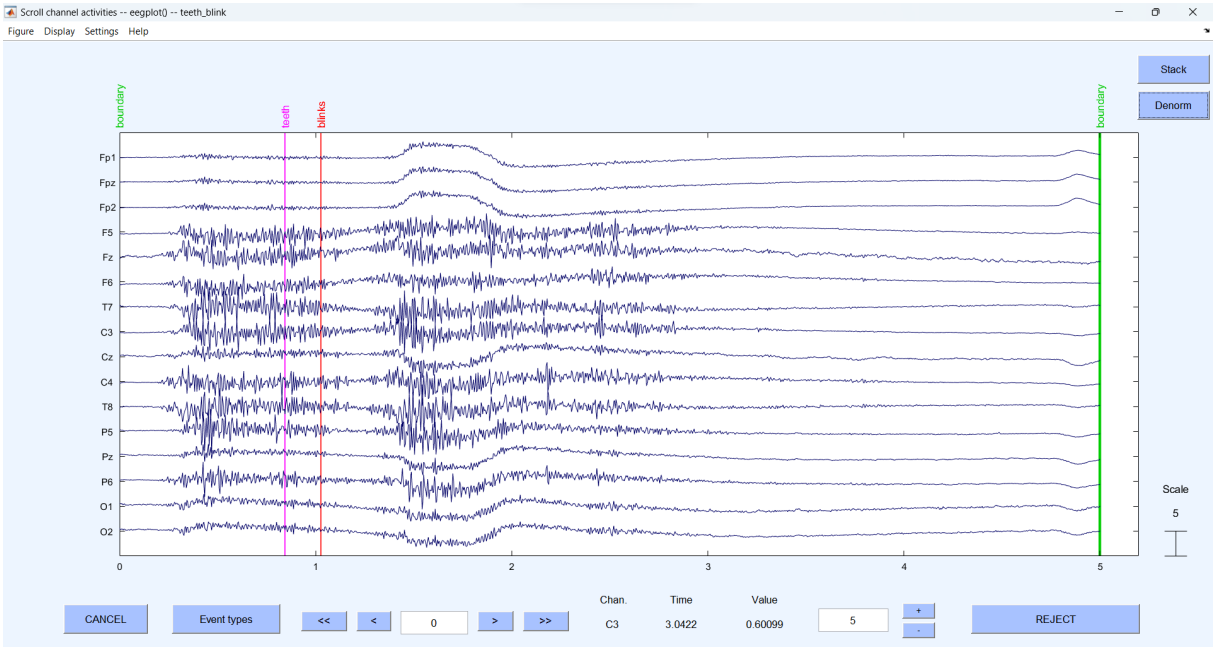


Figure 40: Raw EEG Data - Simultaneous Teeth Clenching and Blinking (Normalized)

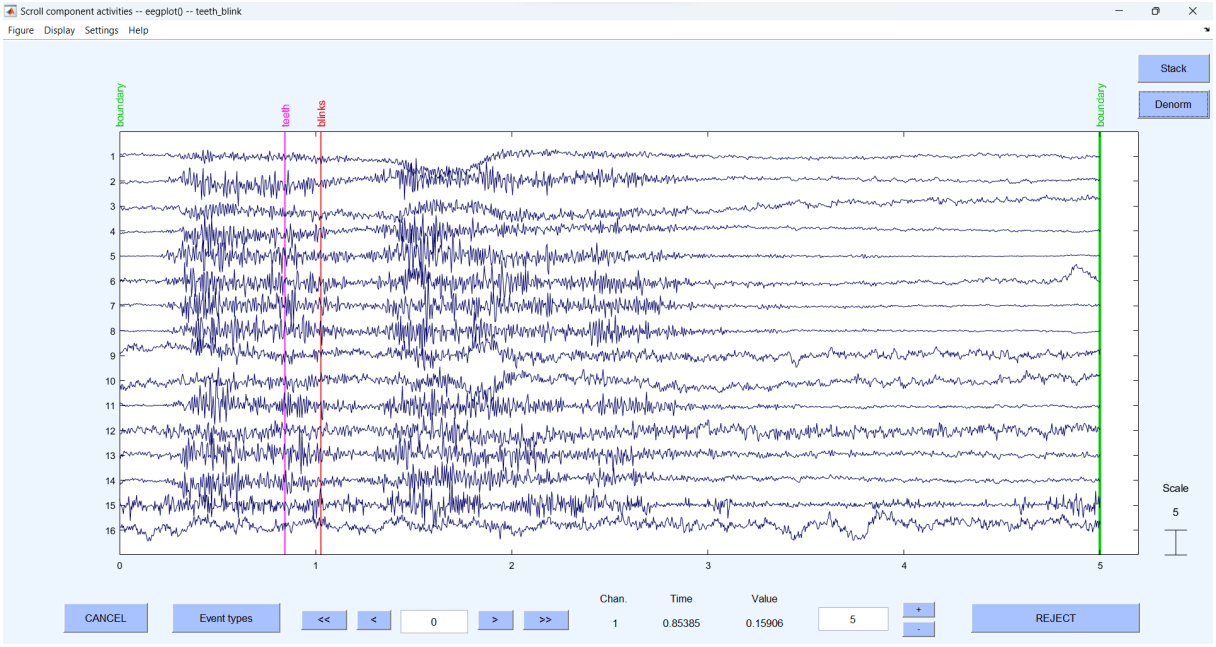
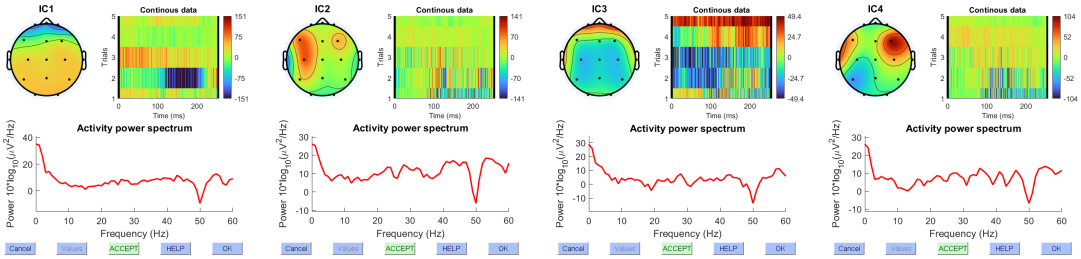


Figure 41: Normalized ICA components - Simultaneous Teeth Clenching and Blinking

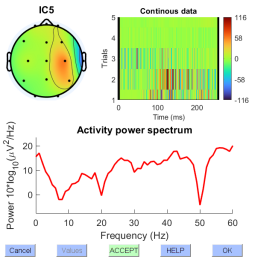


(a) IC01

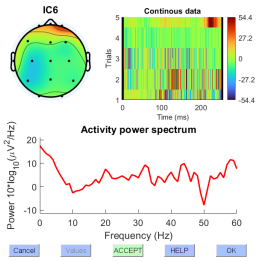
(b) IC02

(c) IC03

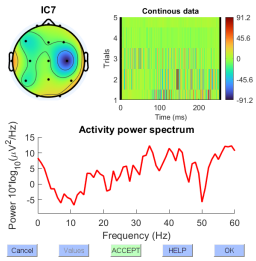
(d) IC04



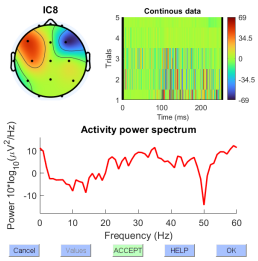
(e) IC05



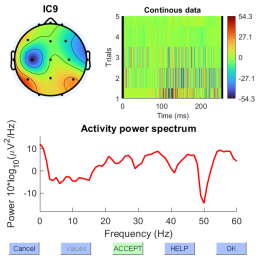
(f) IC06



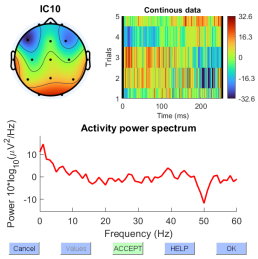
(g) IC07



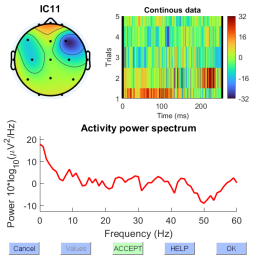
(h) IC08



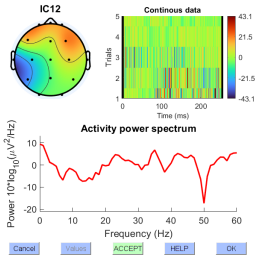
(i) IC09



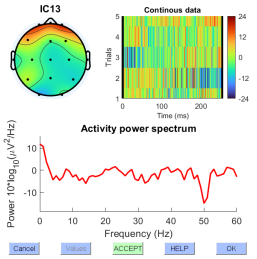
(j) IC10



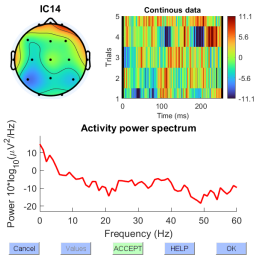
(k) IC11



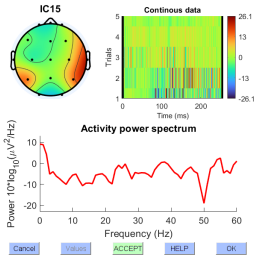
(l) IC12



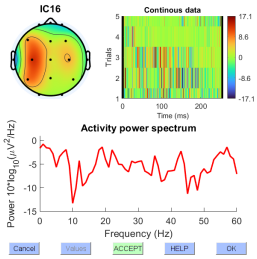
(m) IC13



(n) IC14



(o) IC15



(p) IC16

Figure 42: Independent Component Analysis - Simultaneous teeth clenching and blinking

Table 6: ICA categorization summery - Simultaneous teeth clenching and blinking

Component	Label	Reason	Status
1	Eye	Scalp topology localized at the front. Decreasing spectrum with high-power in low-frequencies.	Removed
2	Muscle	High power in high-frequencies	Removed
3	Eye, Muscle	Scalp topology localized at the front. Peaks in some high-frequencies.	Removed
4	Muscle	High power concentrated in high-frequencies.	Removed
5	Muscle	Same as 4.	Removed
6	Muscle	Same as 4.	Removed
7	Muscle	Same as 4.	Removed
8	Muscle	Same as 4.	Removed
9	Muscle	Same as 4.	Removed
10	Brain	Lots of activities around 10Hz.	Retained
11	Brain	Peak around 10Hz.	Retained
12	Brain, Muscle	Peak around 10Hz. High power concentration in high-frequencies	Removed
13	Brain	Same as 11.	Retained
14	Muscle	High power concentration around high-frequencies.	Removed
15	Brain, Muscle	Peak around 10Hz and high power concentration in high-frequencies	Removed
16	Muscle	High power concentration in high-frequencies.	Removed

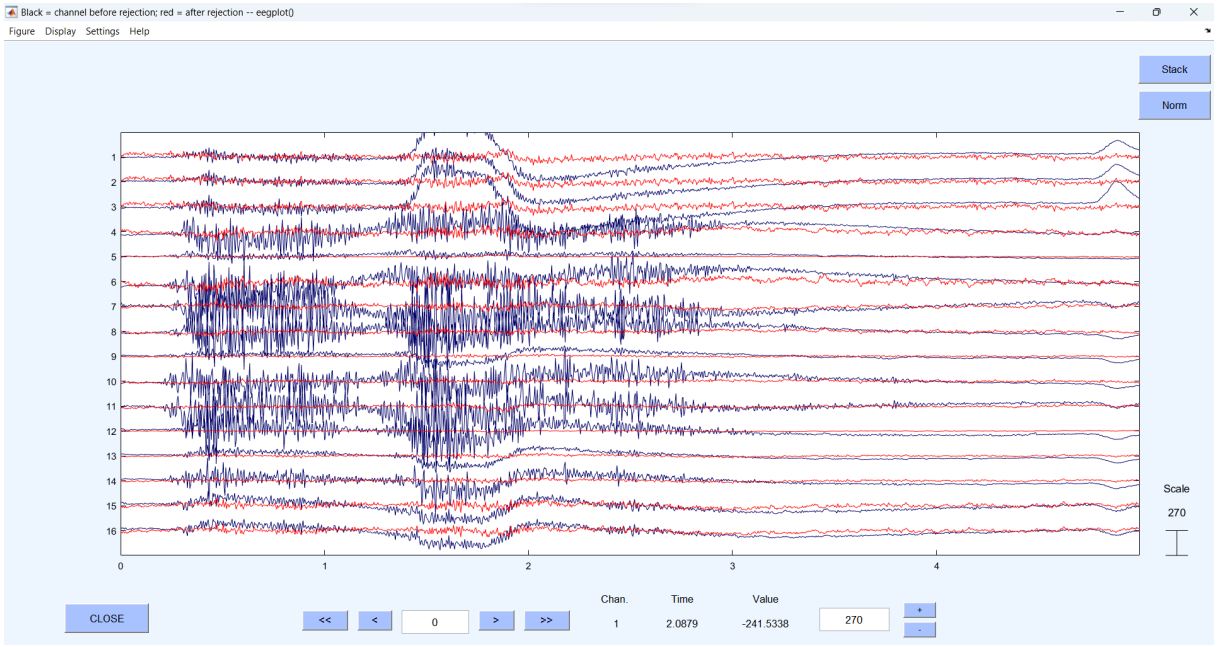


Figure 43: Comparison before and after ICA - Simultaneous Teeth Clenching and Blinking

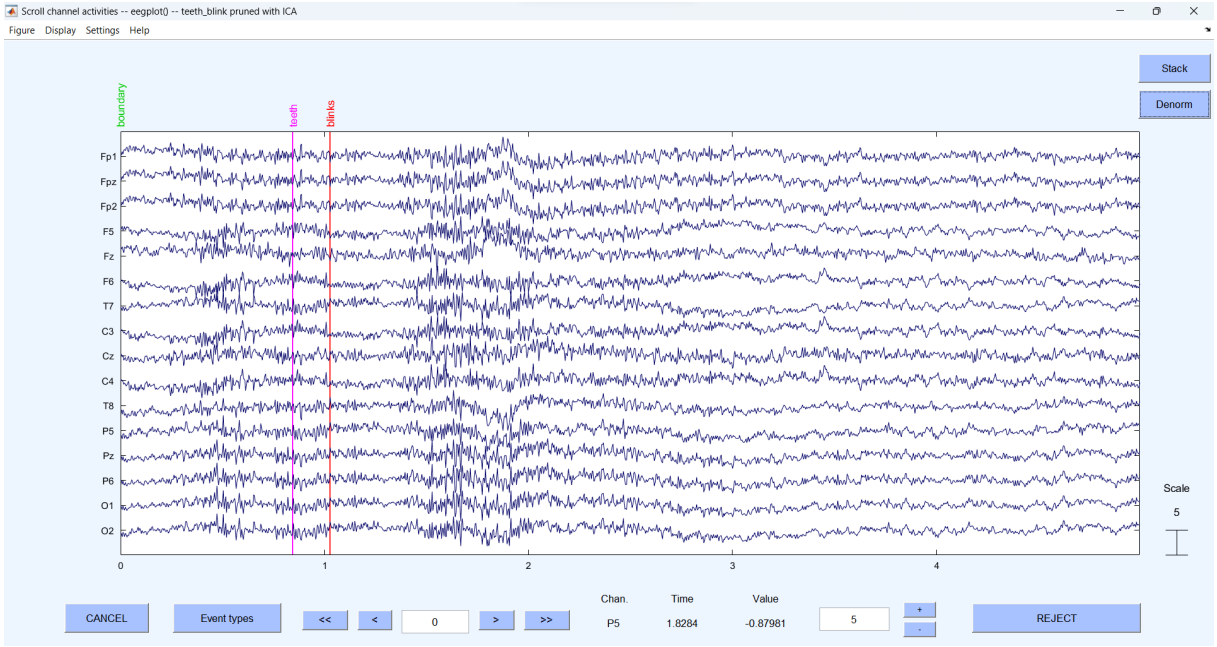


Figure 44: Reconstructed Signals - Simultaneous Teeth Clenching and Blinking

3.5 Blinking in the Presence of Noise

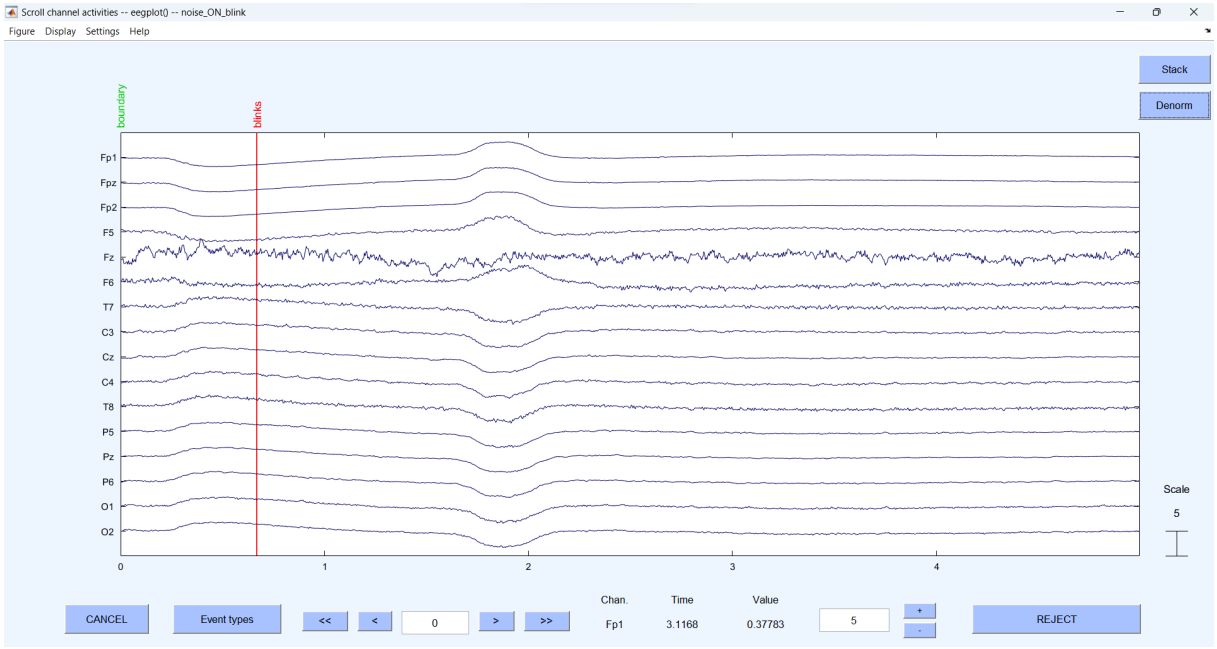


Figure 45: Raw EEG Data - Blinking in the Presence of Noise (Normalized)

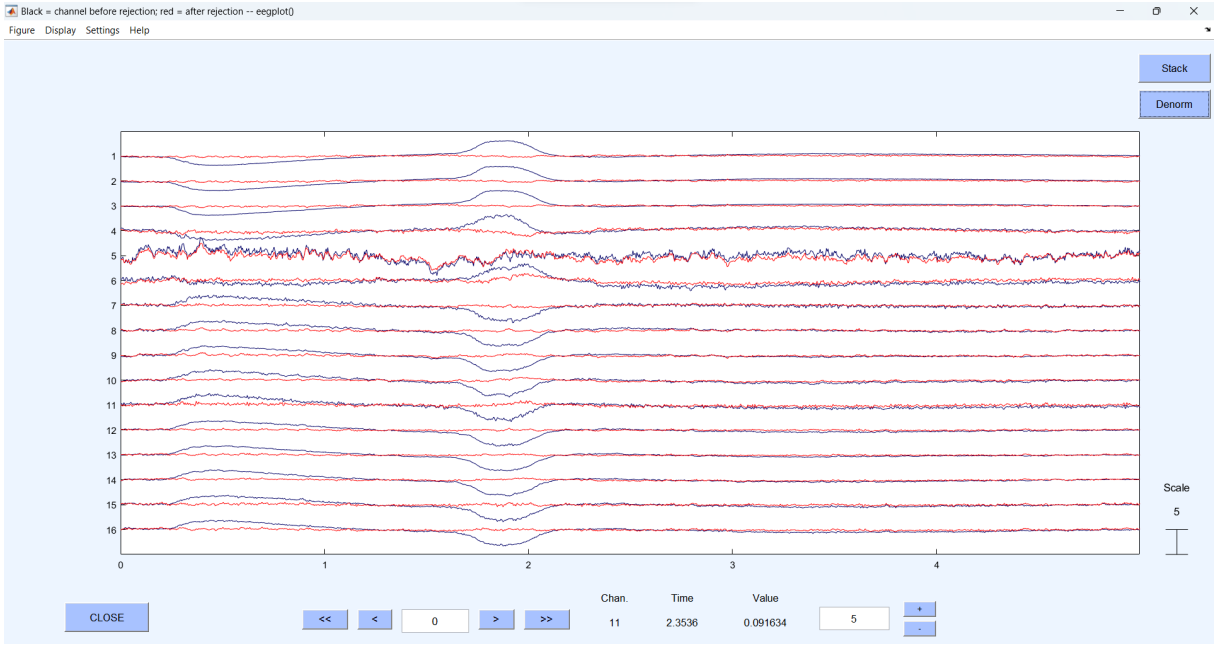
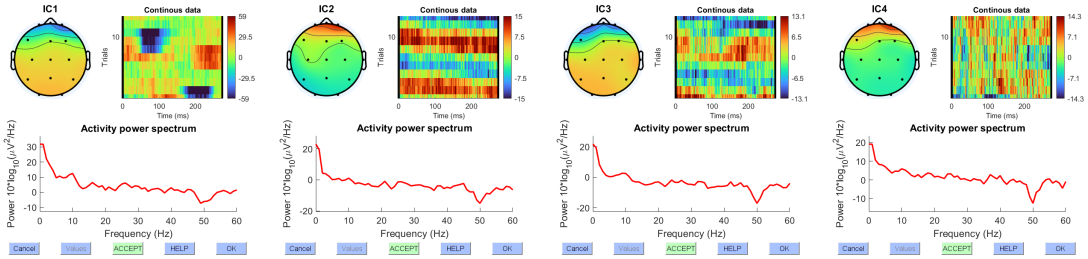


Figure 46: Normalized ICA components- Blinking in the Presence of Noise

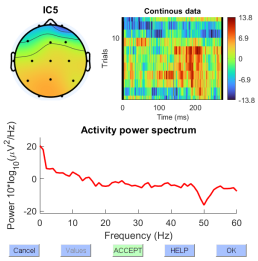


(a) IC01

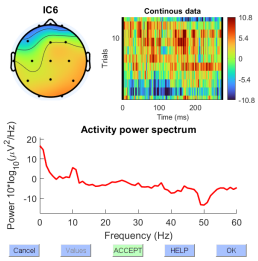
(b) IC02

(c) IC03

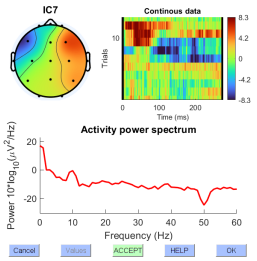
(d) IC04



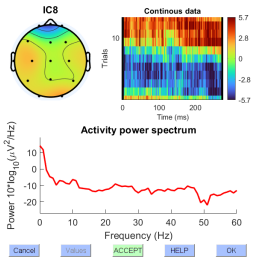
(e) IC05



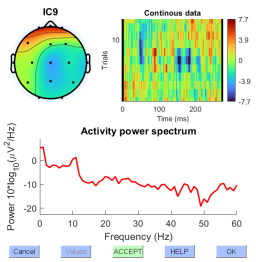
(f) IC06



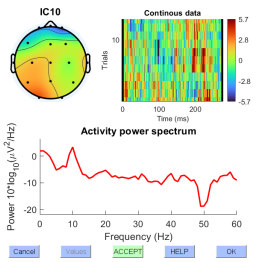
(g) IC07



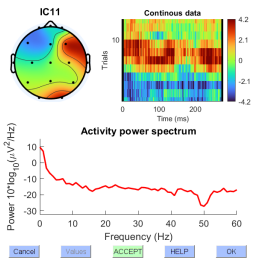
(h) IC08



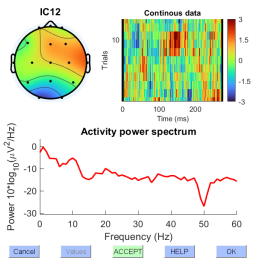
(i) IC09



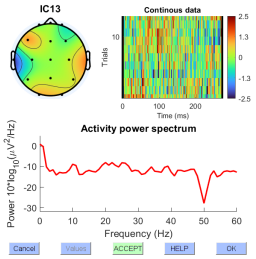
(j) IC10



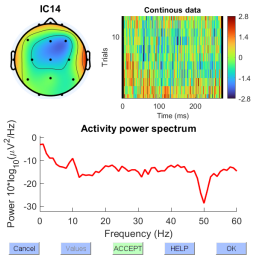
(k) IC11



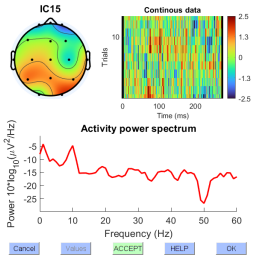
(l) IC12



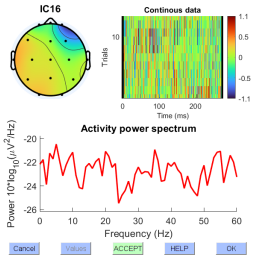
(m) IC13



(n) IC14



(o) IC15



(p) IC16

Figure 47: Independent Component Analysis - Blinking in the Presence of Noise

Table 7: ICA categorization summery - Blinking in the Presence of Noise

Component	Label	Reason	Status
1	Brain, Eye	Scalp topology localized at the front. Visible spike around 10Hz.	Removed
2	Eye	Scalp topology localized at the front. Decreasing activity spectrum.	Removed
3	Brain, Eye	Same as 1.	Removed
4	Brain, Eye	Same as 1.	Removed
5	Brain, Eye	Same as 1.	Removed
6	Brain	Clear peak around 10Hz. High power concentration in low-frequencies.	Retained
7	Brain	Same as 6.	Retained
8	Brain, Eye	Same as 1.	Removed
9	Brain	Same as 6.	Retained
10	Brain	Same as 6.	Retained
11	Eye	Same as 1.	Removed
12	Brain	High power concentration in low-frequencies & mostly around 10Hz.	Retained
13	Brain, Muscle	High power concentration around 10Hz and in high-frequencies.	Removed
14	Brain	Same as 6.	Retained
15	Brain	Same as 12.	Retained
16	Noise	No identifiable pattern.	Removed

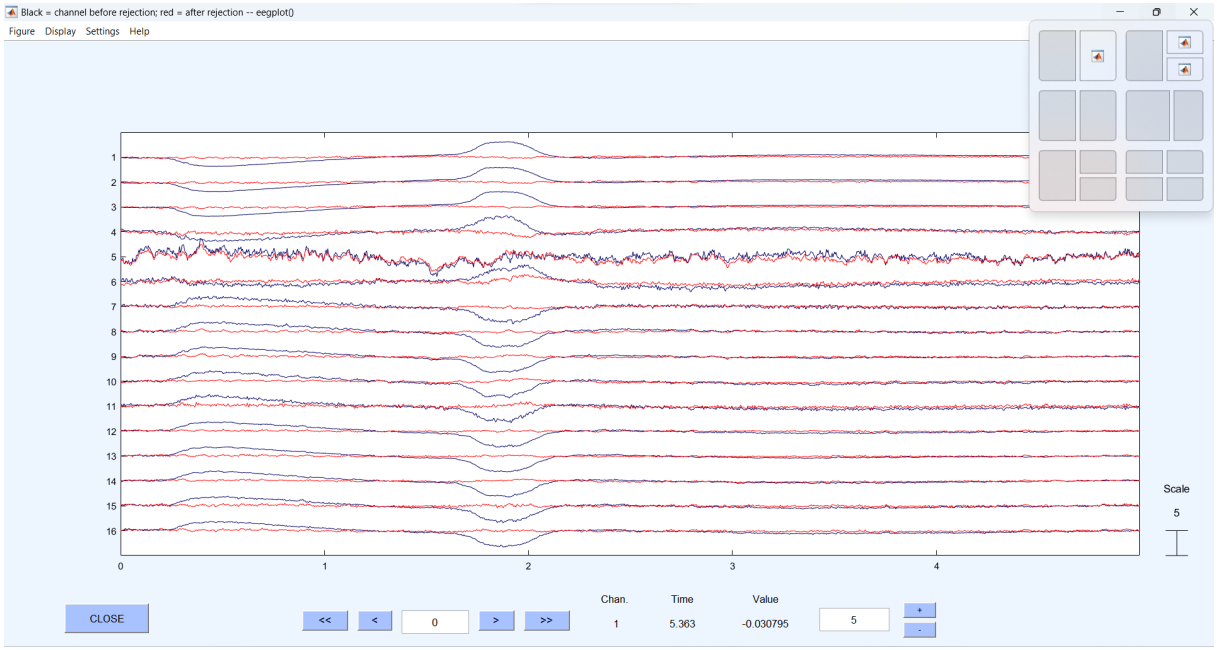


Figure 48: Comparison before and after ICA - Blinking in the Presence of Noise

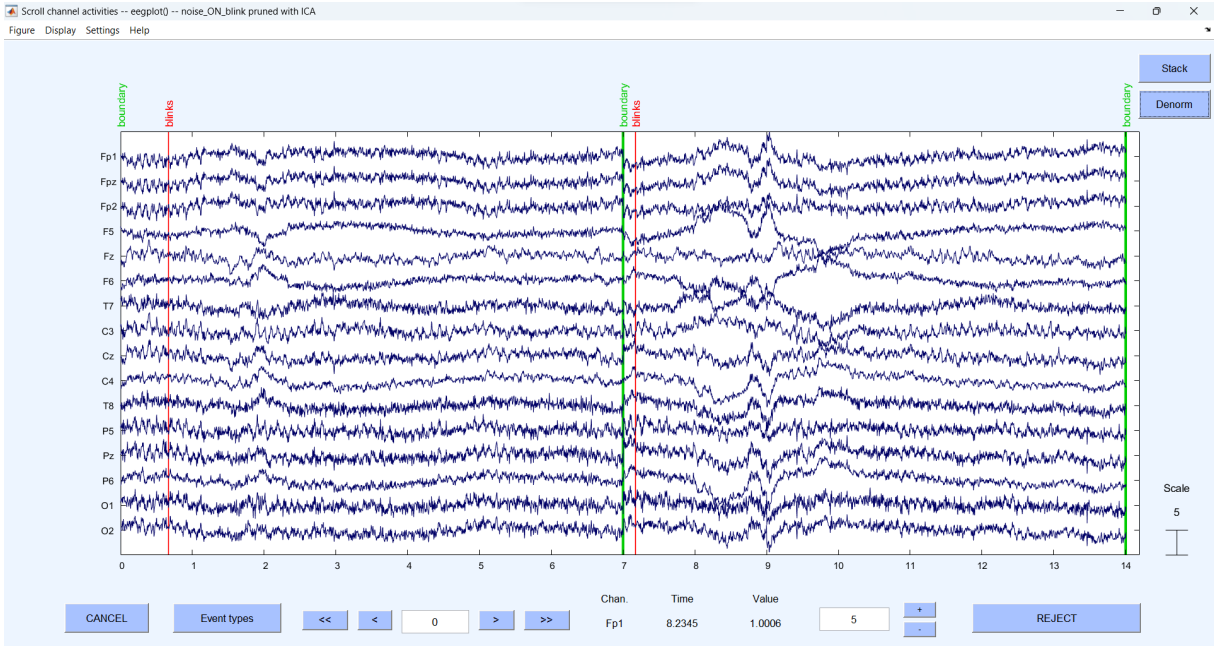


Figure 49: Reconstructed Signals - Blinking in the Presence of Noise

3.6 Noise OFF

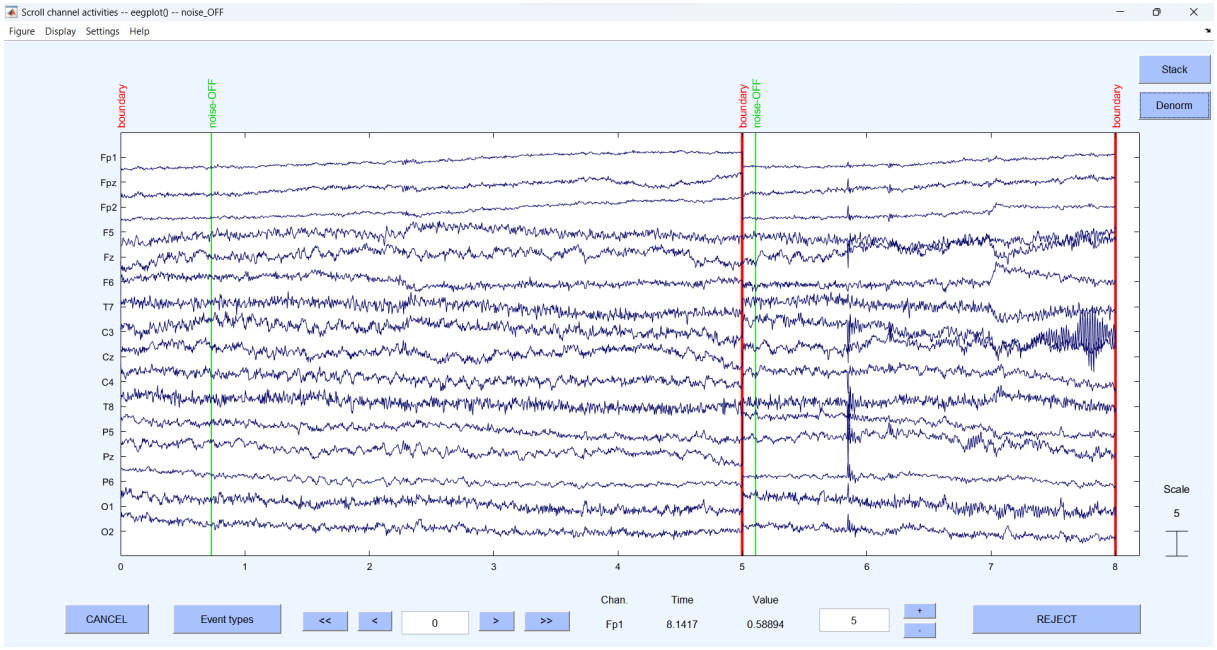


Figure 50: Raw EEG Data - Noise OFF (Normalized)

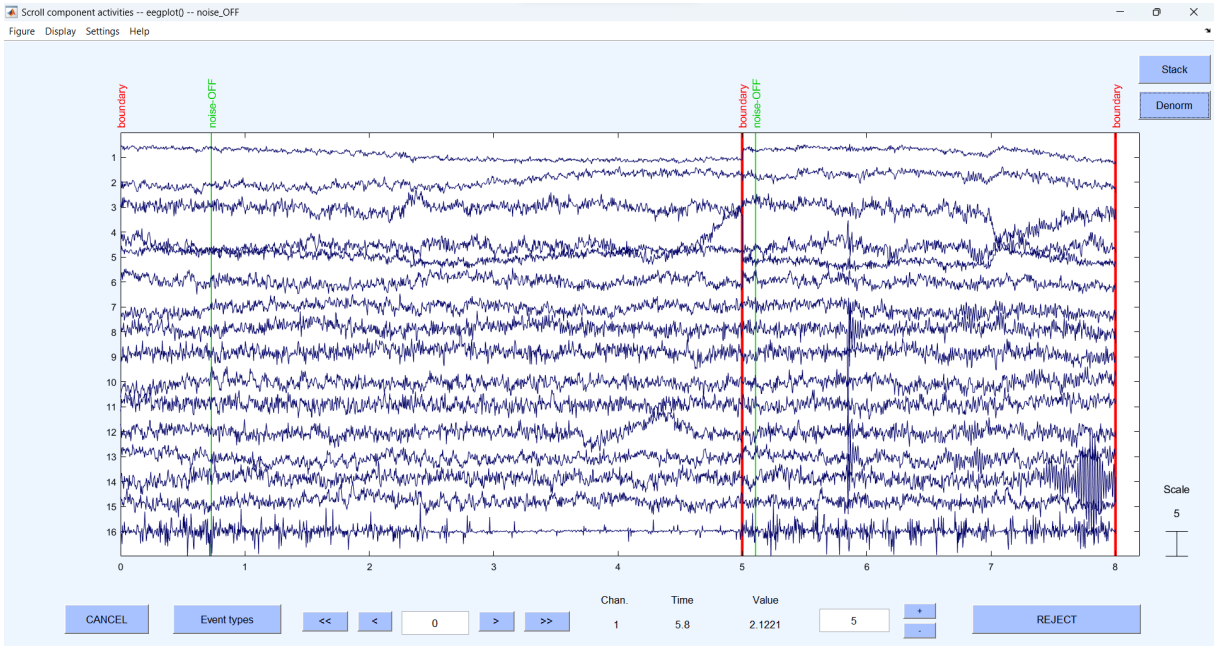
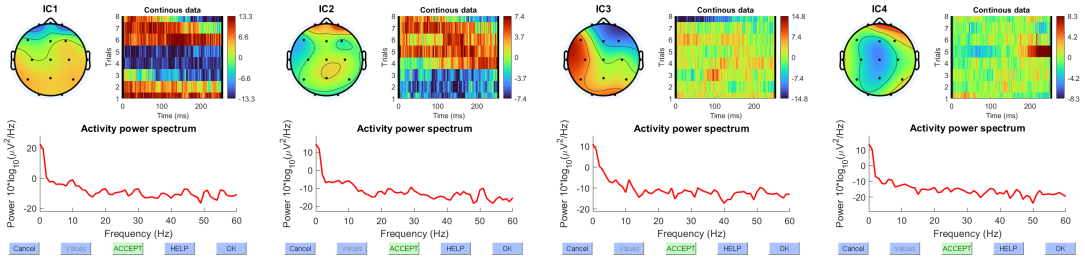


Figure 51: Normalized ICA components - Noise OFF

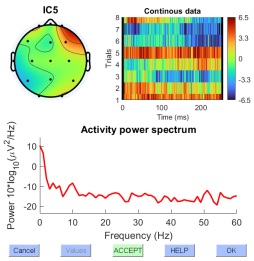


(a) IC01

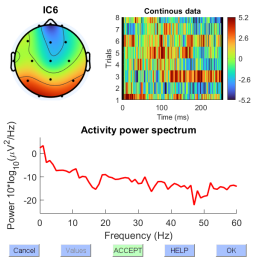
(b) IC02

(c) IC03

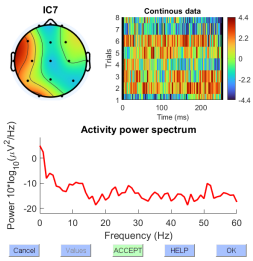
(d) IC04



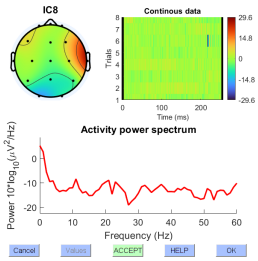
(e) IC05



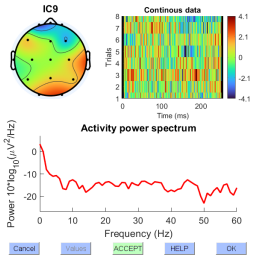
(f) IC06



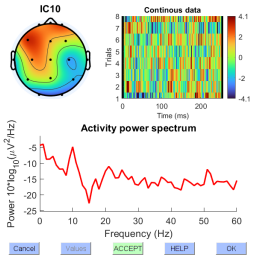
(g) IC07



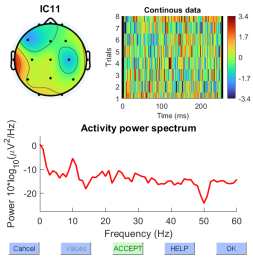
(h) IC08



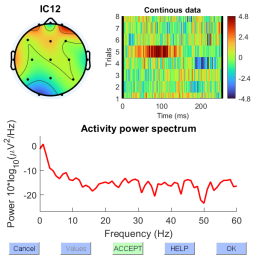
(i) IC09



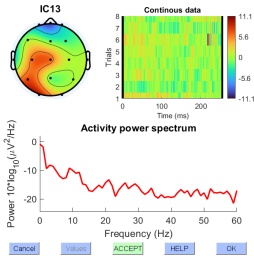
(j) IC10



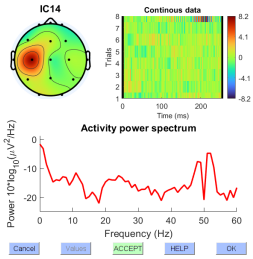
(k) IC11



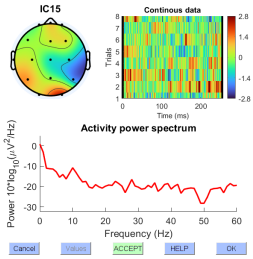
(l) IC12



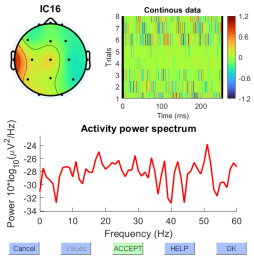
(m) IC13



(n) IC14



(o) IC15



(p) IC16

Figure 52: Independent Component Analysis - Noise OFF

Table 8: ICA categorization summery - Noise OFF

Component	Label	Reason	Status
1	Brain, Eye	Scalp topology localized at the front. Visible spike around 10Hz.	Removed
2	Brain, Eye	Same as 1.	Removed
3	Eye	Scalp topology localized at the front. Decreasing power spectrum.	Removed
4	Eye	Same as 3.	Removed
5	Brain	Clear peak around 10Hz. High power concentration in low-frequencies.	Retained
6	Eye, Muscle	Scalp topology localized at the front. Peaks at high-frequencies.	Removed
7	Brain	Same as 5.	Retained
8	Brain	Same as 5.	Retained
9	Brain, Muscle	Visible peak around 10Hz. Increase of activities in high-frequencies.	Removed
10	Brain	Same as 5.	Retained
11	Brain	Same as 5.	Retained
12	Eye, Muscle	Same as 6.	Removed
13	Brain	Same as 5.	Retained
14	Other	Huge activities in high-frequencies.	Removed
15	Brain	Same as 5.	Retained
16	Other	No identifiable pattern.	Removed

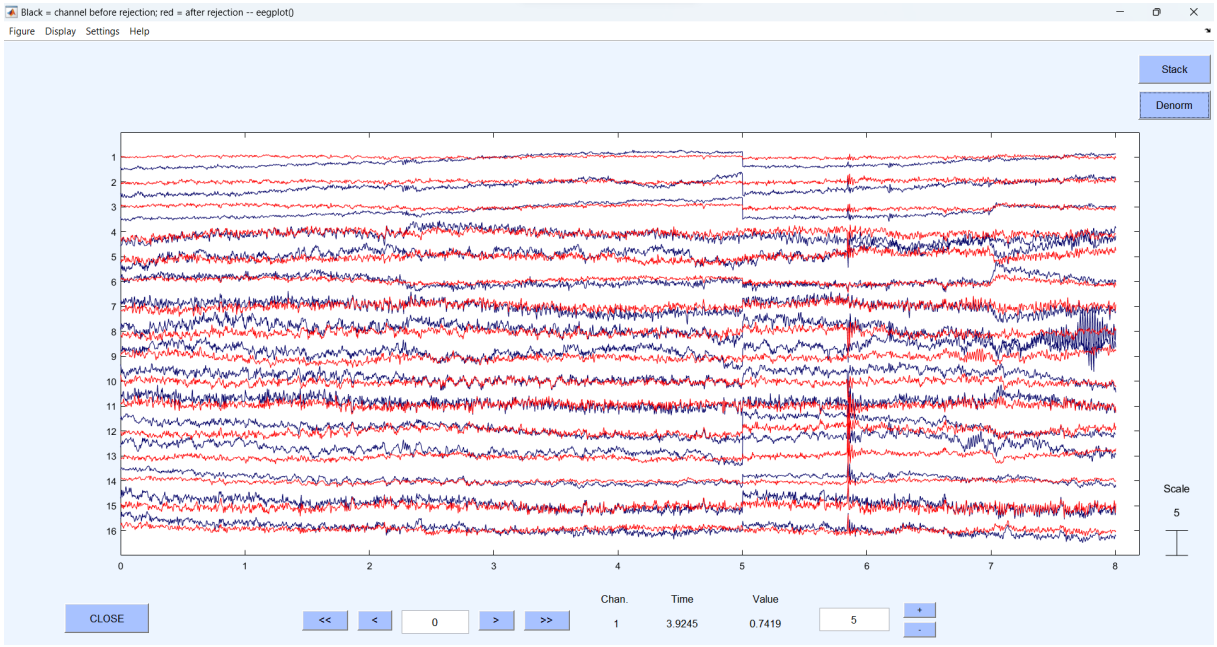


Figure 53: Comparison before and after ICA - Noise OFF

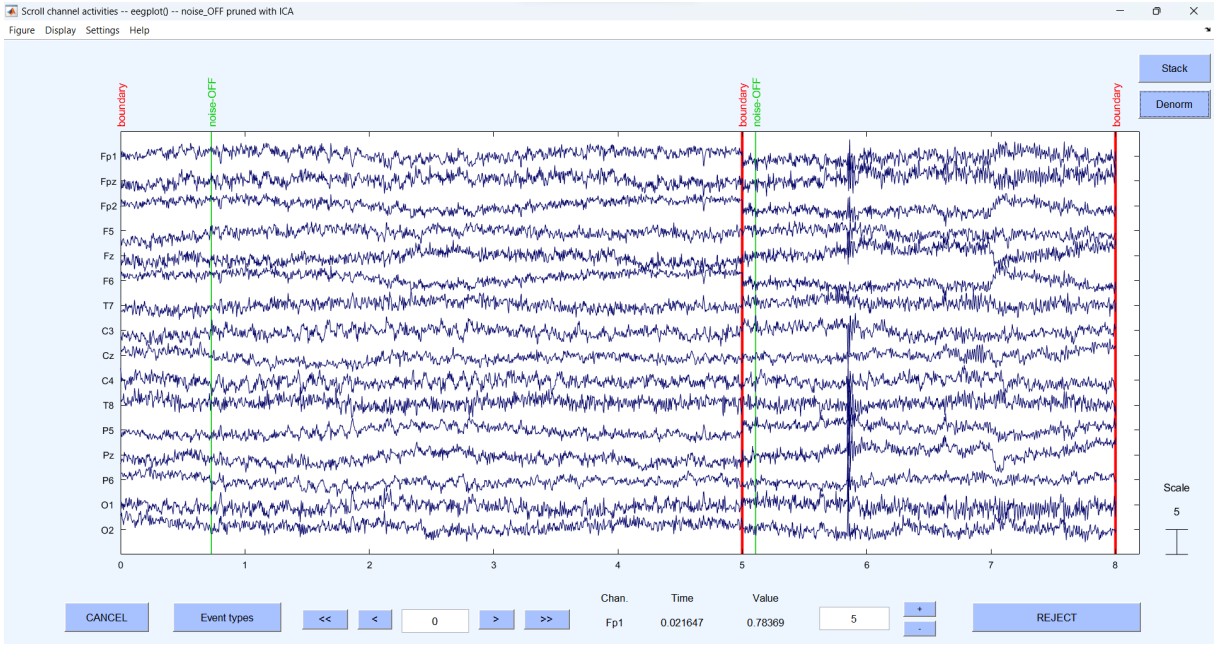


Figure 54: Reconstructed Signals - Noise OFF