HW2: EEG Analysis

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1. Multiple Choice

Problem 1

Assume the signal-to-noise ratio is defined as $SNR \equiv \frac{\textit{the amplitude of signal in voltage}}{\textit{the amplitude of noise in voltage}}$

Imagine that we are looking for a 5 μV ERP effect, and the noise is 10 μV in the single-trial EEG, giving us a 5:10 (or 1:2) signal-to-noise ratio on single trials. How many trials would we need to average together to get a 2:1 signal-to-noise ratio in the averaged ERP waveform? (Hint: [event-related potential])

(A) 4
(B) 8
(C) 16
(D) 32
(E) 64

Answer : (C)

SNR_avg = sqr(N)*SNR_single_trail

=> 2 = sqr(N)*(1/2)

=> N = 16

Problem 2

The following are techniques that are commonly applied to EEG data. Which ones are unsupervised ? (**there may be more than one correct answer**)

(A) PCA
(B) LDA
(C) CSP
(D) ICA
(E) K-means clustering

Answer : (A) (D) (E)

PCA and ICA are used for dimensionality reduction without class labels.

K-means clustering groups similar data points together without using predefined labels.

LDA is well-known for classification tasks, and CSP is commonly applied to EEG data in the context of motor imagery classification.

2. Programming Problem

1.1. EEG Dataset Preprocessing

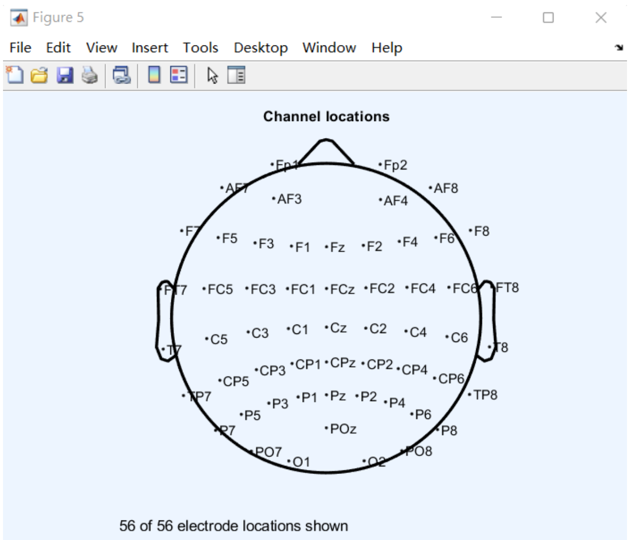
Problem 1-1

Please follow the following steps for **Dataset 1**:

1. Plot 2D channel location map
2. Run ICA and record computational time of ICA by code.
3. Plot component maps in 2D.
4. Indicate noise component(s) if they exist and explain the reason why you identify this component as noise or artifacts.
5. Plot first 10-second channel data before and after deleting noise/artifact component(s).

Answer :

1. Plot 2D channel location map

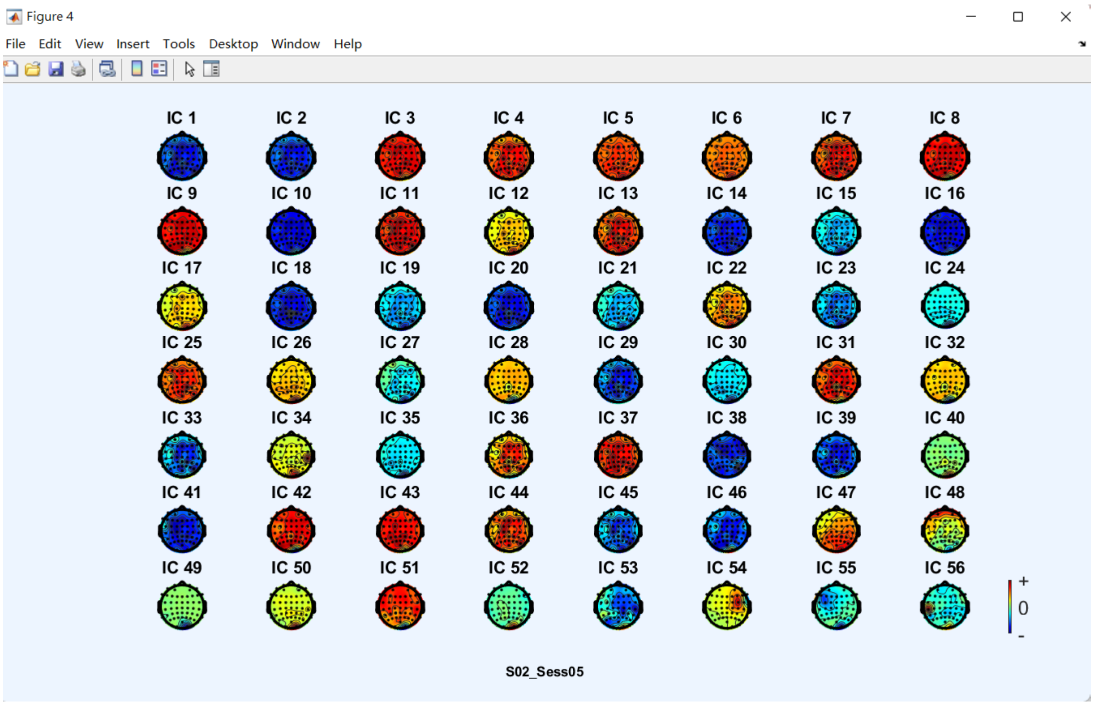


2. Run ICA and record computational time of ICA by code.

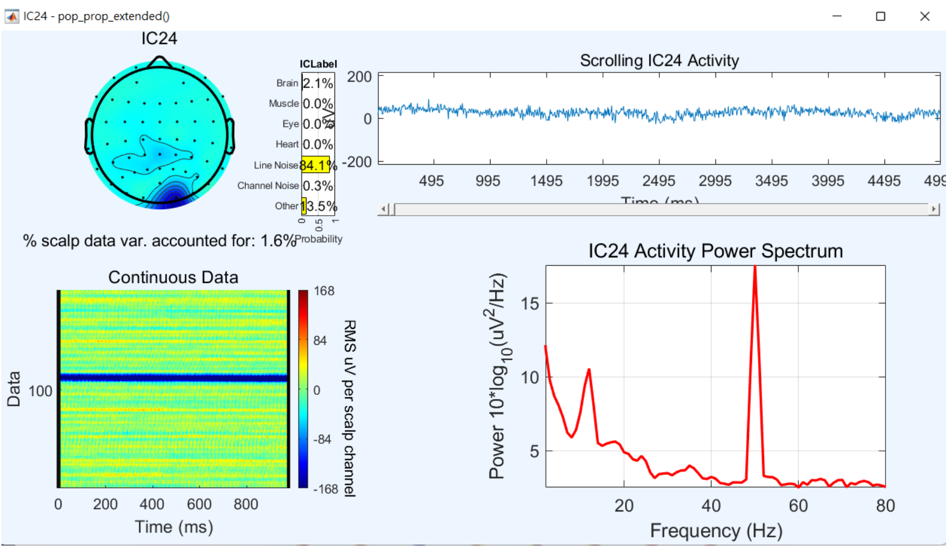
```
% Start the timer
tic;
EEG = pop_runica(EEG, 'icatype', 'runica', 'extended', 1, 'interrupt', 'on');
% stop the timer and print the elapsed time in second
elapsed_time = toc;
disp(['ICA running time: ', num2str(elapsed_time), ' seconds']);
```

```
ICA running time: 306.1334
```

3. Plot component maps in 2D.



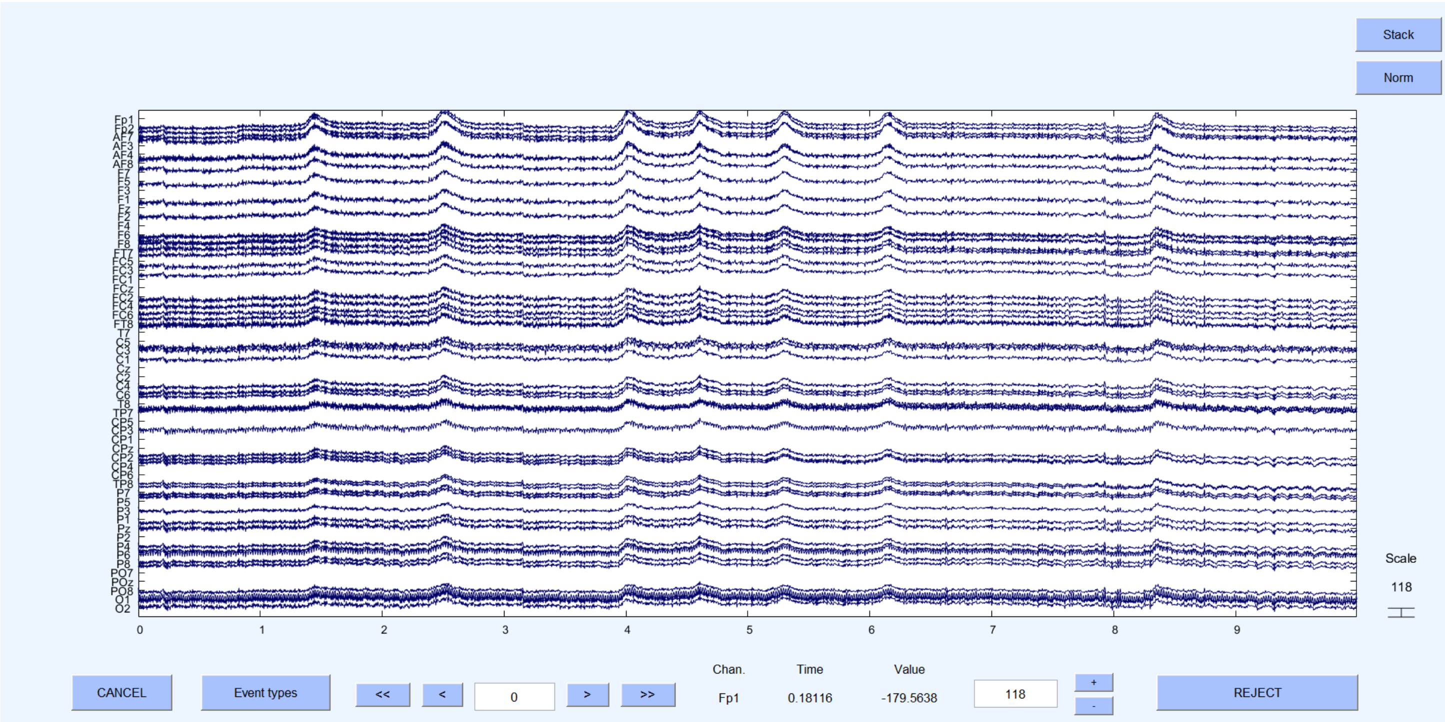
4.



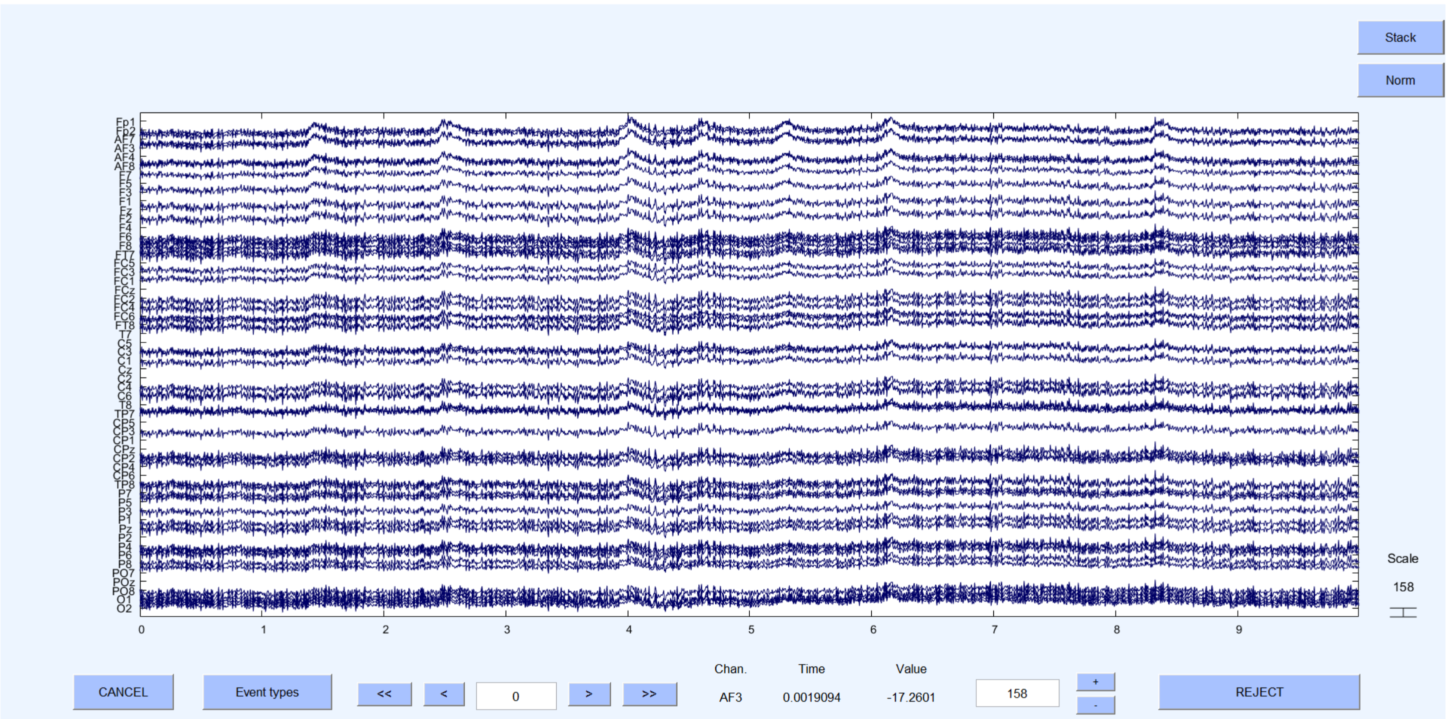
After decomposing data by ICA and classifying components with ICLabel, there exist 7 line noise/artifacts (24,30,32,34,42,49,51). Above figures are given as examples. We can observe that at 50(Hz) has a high peak and hence this component will be classified as line noise.

5.

Before:



After deleting noise

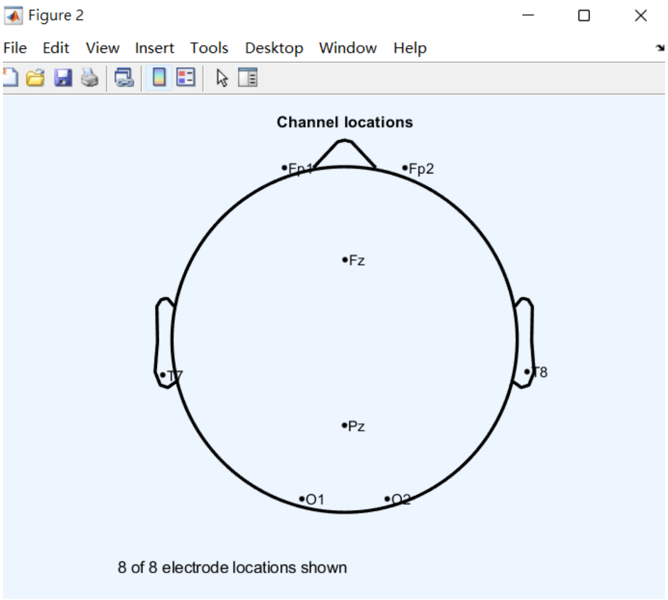


Problem 1-2

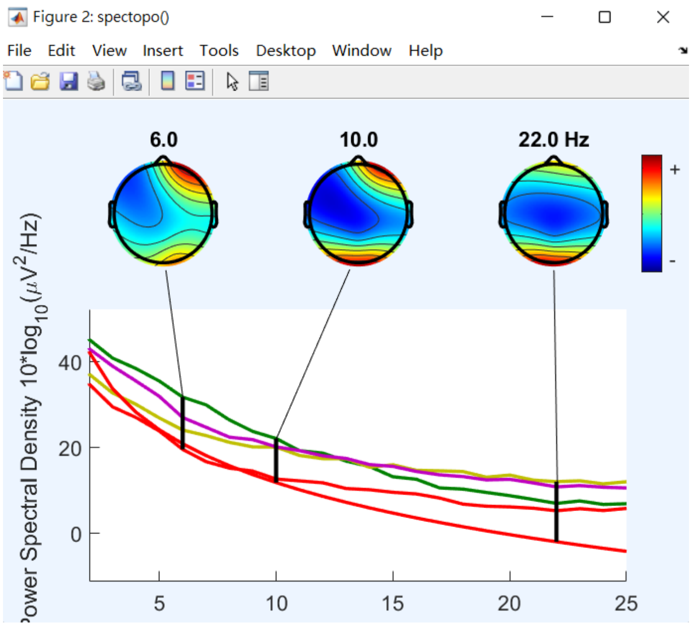
Please follow the following steps for **Dataset 2**:

1. Plot 2D channel location map
2. Plot spectra and map in 2D.
3. Plot first 10-second channel data, and discuss anything you observed.

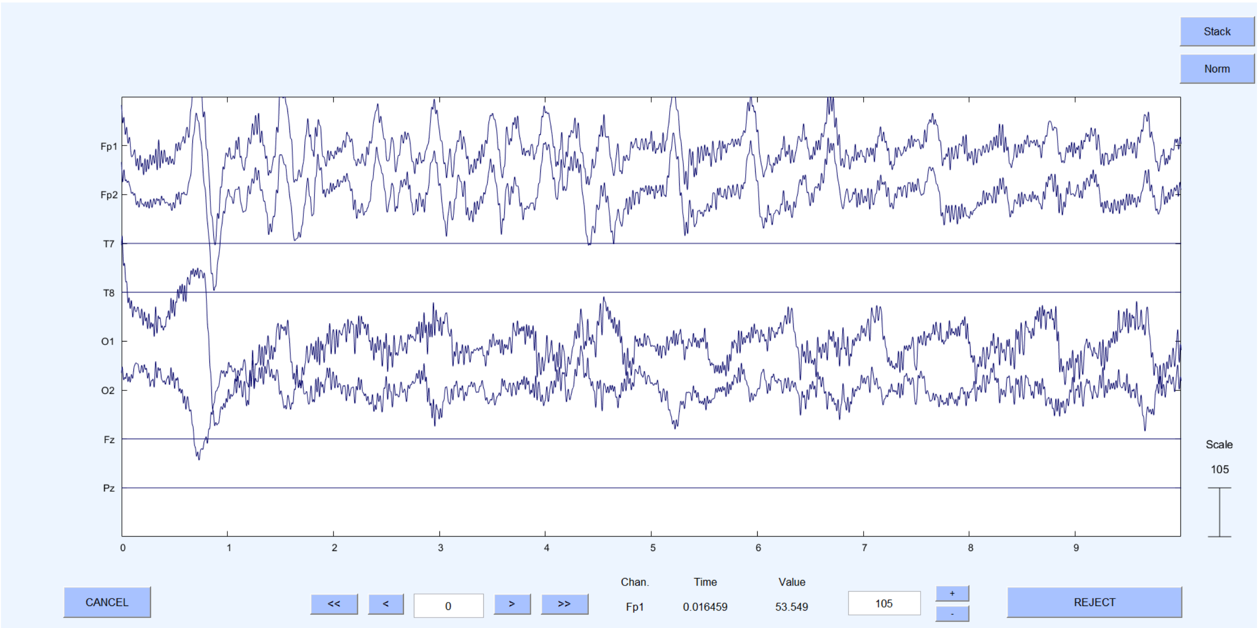
1.



2.



3.



Observation:

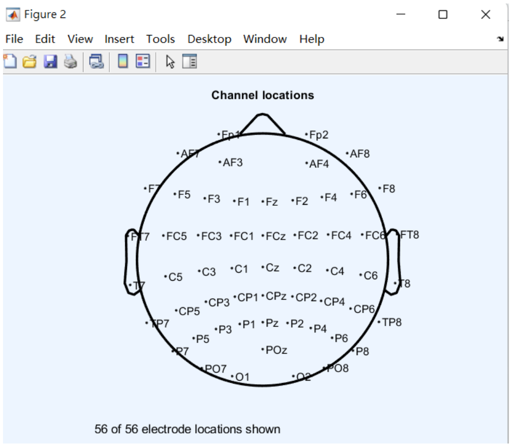
It appears that at the beginning of the 2 seconds, the waveforms from the four channels exhibit instability. However, as time progresses, the waveforms stabilize and exhibit a cyclic pattern.

Problem 2

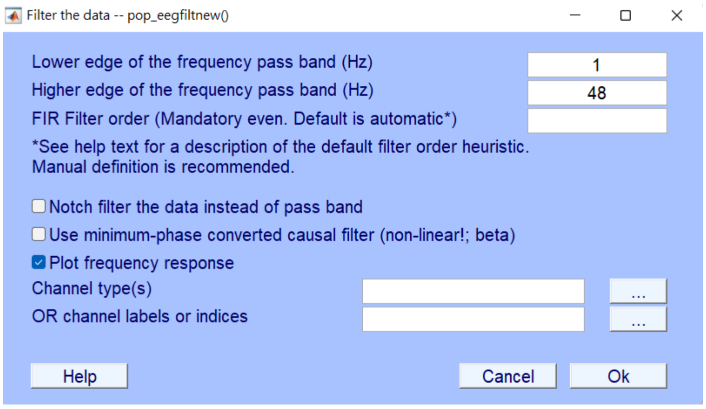
Please follow the following steps for **Dataset 1**:

1. Plot 2D channel location map
2. **Bandpass filtering [1, 48]*Hz*.**
3. Run ICA and record computational time of ICA by code.
4. Plot component maps in 2D.
5. Indicate noise component(s) if they exist and explain the reason why you identify this component as noise or artifacts.
6. Plot first 10-second channel data before and after deleting noise/artifact component(s).
7. **Discuss the effect of bandpassing(highpassing) the signal before running ICA.**

1. Plot 2D channel location map



2. Bandpass filtering [1, 48]Hz.

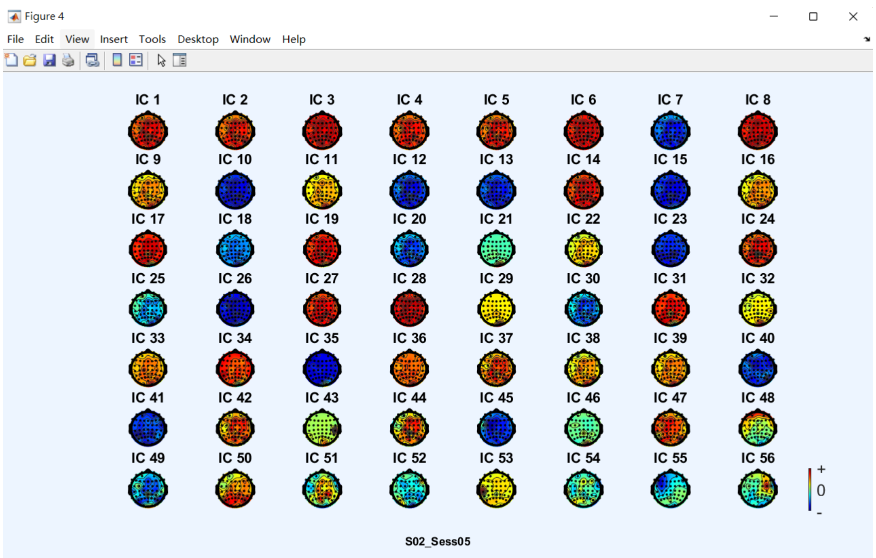


3. Run ICA and record computational time of ICA by code.

```
% Start the timer
tic;
EEG = pop_runica(EEG, 'icatype', 'runica', 'extended', 1, 'interrupt', 'on');
% stop the timer and print the elapsed time in second
elapsed_time = toc;
disp(['ICA running time: ', num2str(elapsed_time), ' seconds']);
```

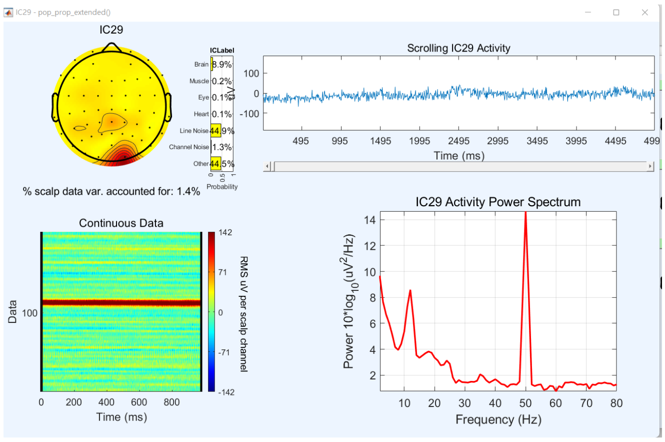
```
ICA running time: 260.1334
```

4. Plot component maps in 2D.



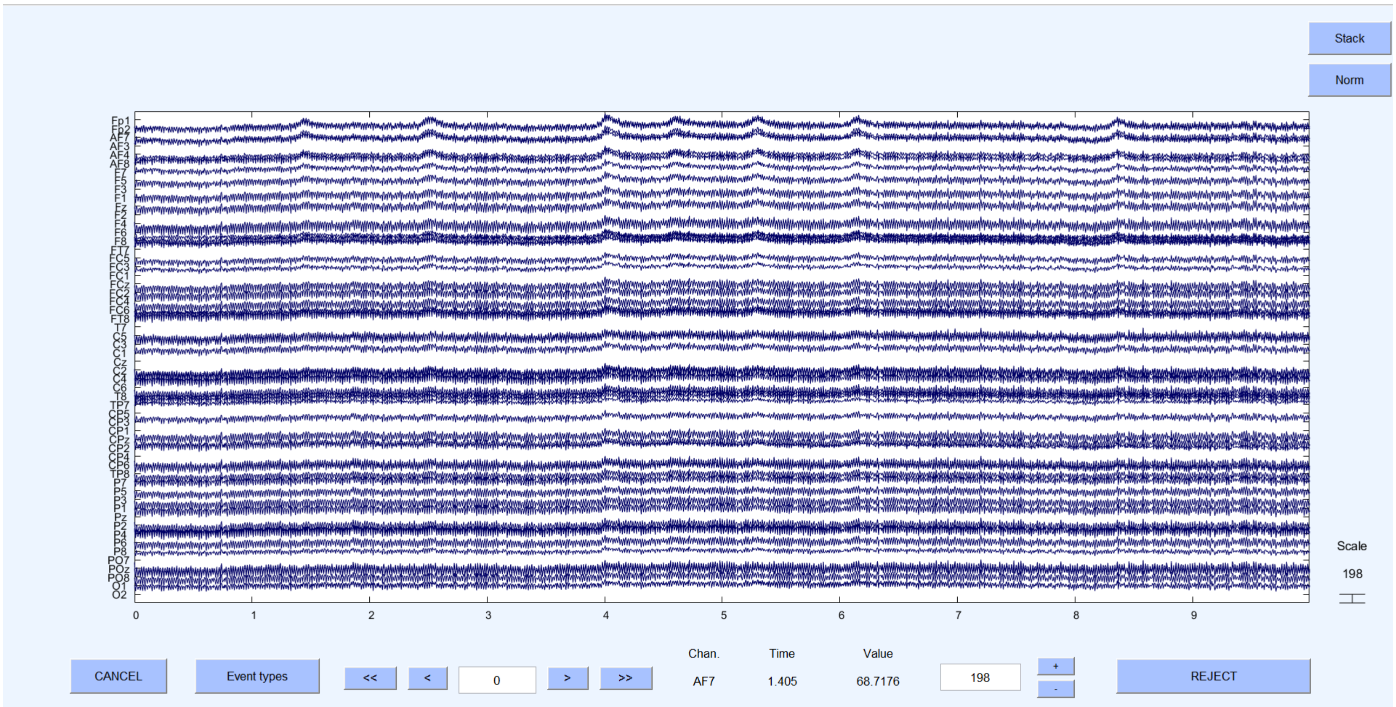
5. Indicate noise component(s) if they exist and explain the reason why you identify this component as noise or artifacts.

   For instance, when labeling this component as line noise, the rationale stems from an observation in the power spectrum graph. A notable high peak at 50 Hz is evident, leading to the characterization of this component as line noise.



6. Plot first 10-second channel data before and after deleting noise/artifact component(s).
   before:

after:



7. **Discuss the effect of bandpassing(highpassing) the signal before running ICA.**

   After applying bandpass filtering to the signal, I observed an enhanced separation of signals from different sources. Additionally, bandpassing led to alterations in the topography of the components. However, it's worth noting that there could be information loss, especially when the signal components are situated close to the frequency cutoff.

2.3. Independent Component Analysis and Artifact Removal

Problem 3

Please follow the following steps for **Dataset 1**:

According to Hu et al, SNR of an ERP waveform can be defined as below:

$$SNR = \frac{peak\ amplitude\ of\ error-related\ potential\ (0\ to\ 1000ms)}{standard\ deviation\ of\ the\ ERP\ waveform\ in\ the\ pre-stimulus\ interval(-200\ to\ 0\ ms)}$$

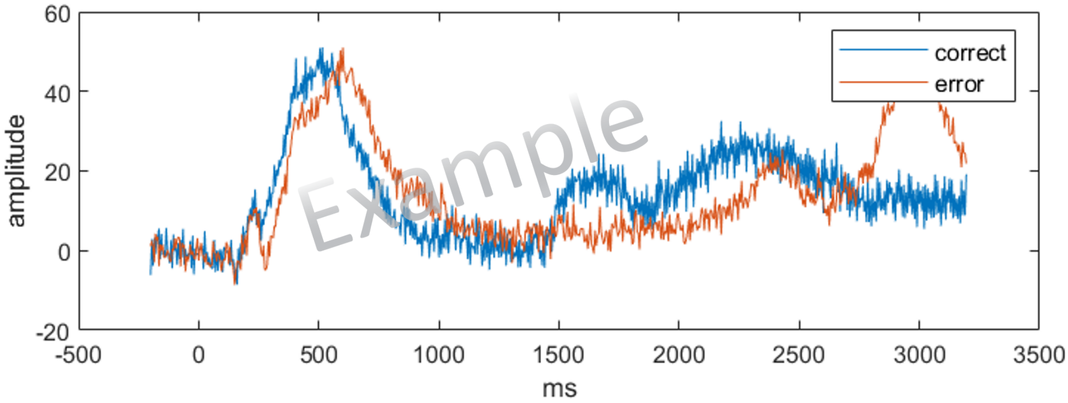
Since the error-related potential originates from the **anterior cingulate cortex(ACC)**, we focus on the **FCz** channel.

1. Apply all four following preprocessing flows before calculating ERP at FCz:
   A. Without any operation
   B. Bandpass the signal (1~48 Hz)
   C. Run ICA and remove bad components(Hint: using ICLabels)
   D. Bandpass the signal (1~48 Hz) first and run ICA to remove bad components

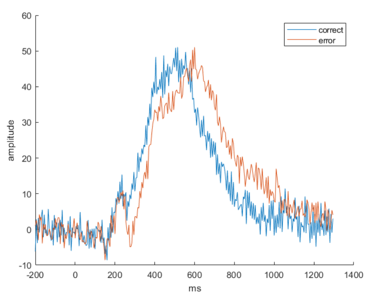
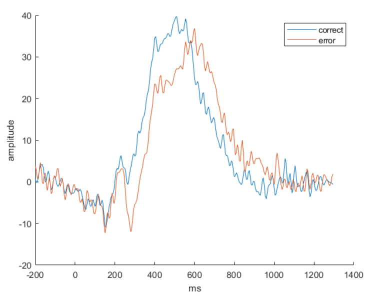
2. After the preprocessing, epoch the continuous EEG with a time interval [-0.2 1.3] sec, where t=0 is the feedback onset. (Hint: EEGLAB epoch)

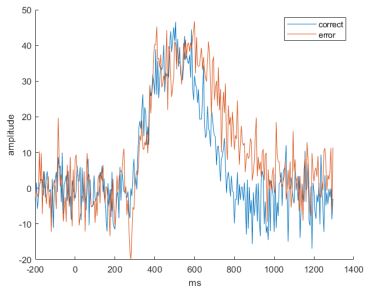
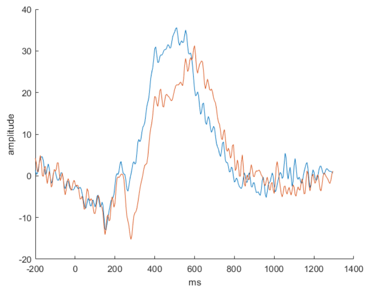
3. Remove the epoch baseline mean.

4. Plot the ERP at FCz time-locked to the two different events(i.e the correct and error feedbacks) (Hint: In the MATLAB workspace, you can see an EEG structure that contains all the information of the current EEGLAB dataset. EEG.data is an array of shape (num_channel, num_sample, num_trial))
Example:



5. Fill out the table below

Preprocessing Methods	**ERP plot for 2 types of feedback**	**SNR(error feedback only)**
Without any operation		21.5509
Bandpass only		17.0426

IC removal only		7.3879
Bandpass+IC removal		13.5661