Brain Computer Interface-HW2: EEG Analysis

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1. Multiple Choice

Problem 1

Assume the signal-to-noise ratio is defined as SNRthe amplitude of signal in voltagethe 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

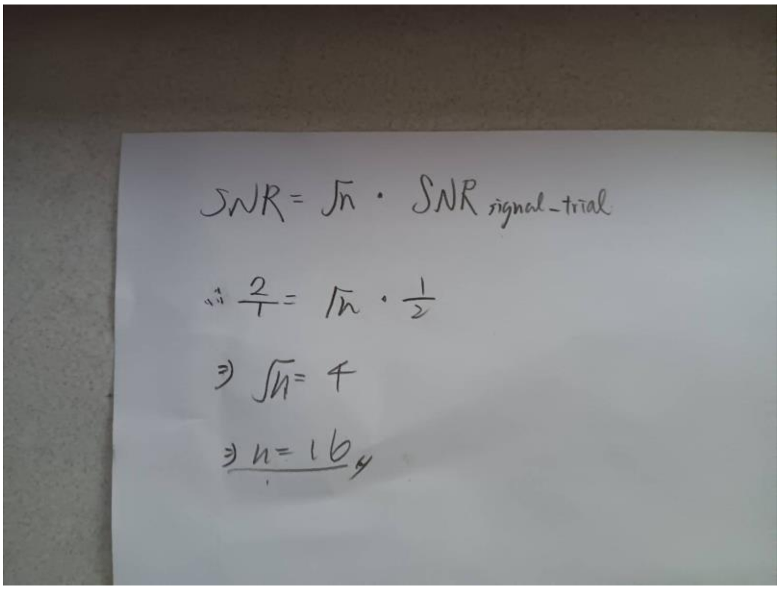
B. 8

C. 16

D. 32

E. 64

Ans. C



(n is number of trials)

Problem 2

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

A. PCA

B. LDA

C. CSP

D. ICA

E. K-means clustering

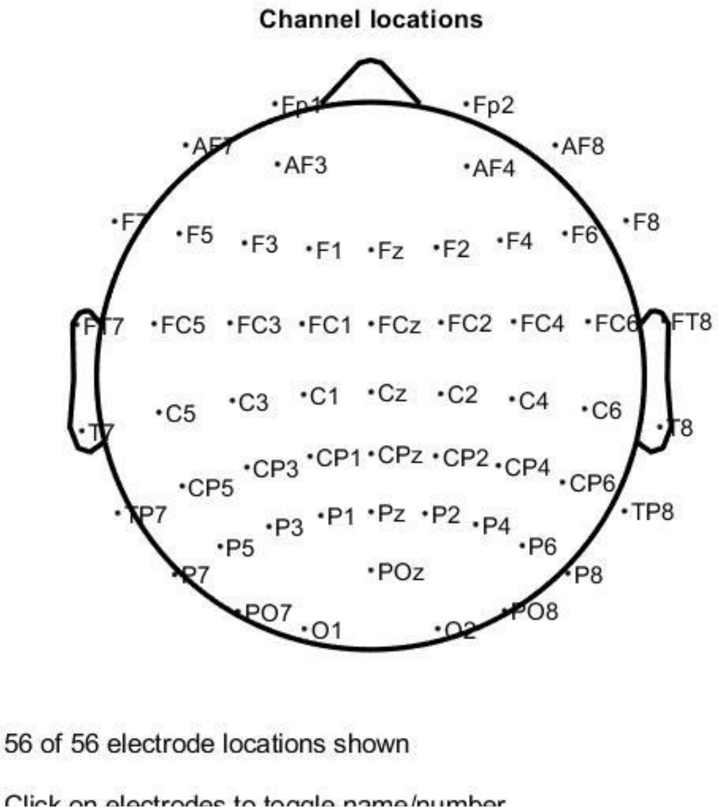
Ans. A, D, E

2. Programming Problem

Problem 1-1

Please follow the following steps for Dataset 1:

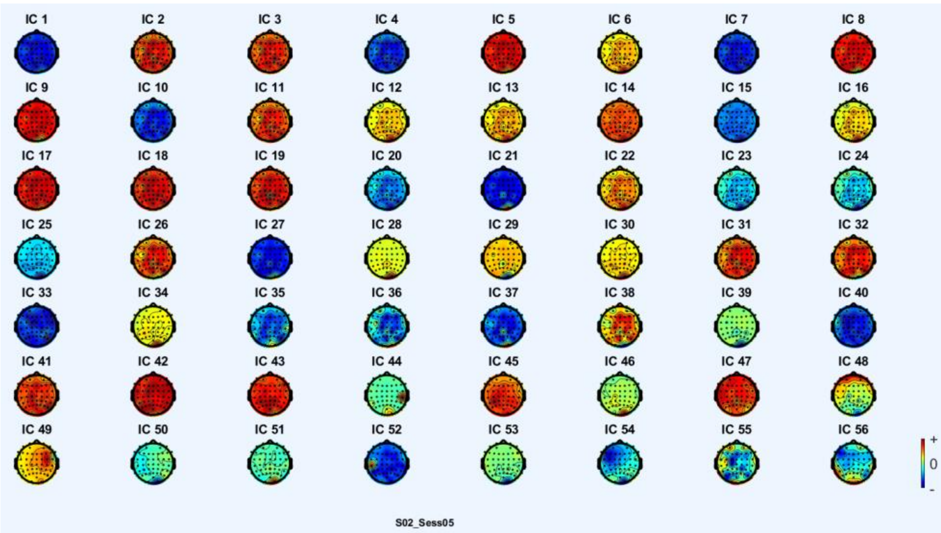
1. Plot 2D channel location map



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

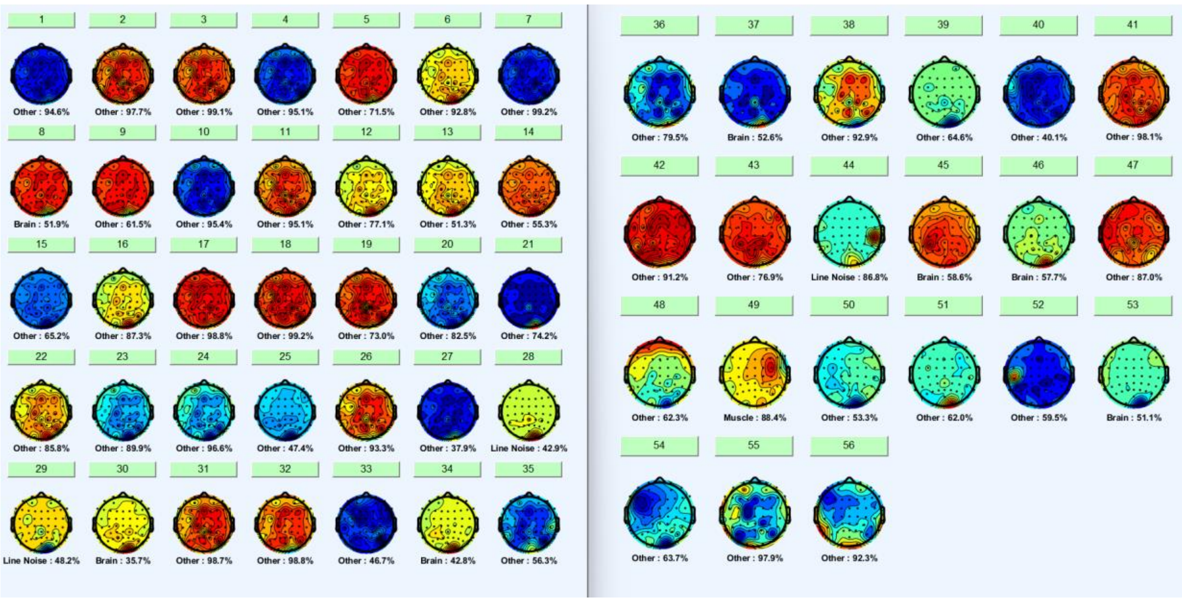
```
step 387 - lrate 0.000000, wchange 0.00000024, angledelta 94.3 deg
step 388 - lrate 0.000000, wchange 0.00000025, angledelta 94.2 deg
step 389 - lrate 0.000000, wchange 0.00000023, angledelta 98.8 deg
step 390 - lrate 0.000000, wchange 0.00000022, angledelta 100.5 deg
step 391 - lrate 0.000000, wchange 0.00000021, angledelta 103.0 deg
step 392 - lrate 0.000000, wchange 0.00000015, angledelta 95.1 deg
step 393 - lrate 0.000000, wchange 0.00000016, angledelta 97.2 deg
step 394 - lrate 0.000000, wchange 0.00000016, angledelta 96.2 deg
step 395 - lrate 0.000000, wchange 0.00000016, angledelta 97.2 deg
step 396 - lrate 0.000000, wchange 0.00000013, angledelta 104.6 deg
step 397 - lrate 0.000000, wchange 0.00000012, angledelta 93.6 deg
step 398 - lrate 0.000000, wchange 0.00000012, angledelta 96.3 deg
step 399 - lrate 0.000000, wchange 0.00000010, angledelta 104.5 deg
Sorting components in descending order of mean projected variance .
Scaling components to RMS microvolt
Scaling components to RMS microvolt
Scaling components to RMS microvolt
>> toc
Elapsed time is 216.482270 seconds.
fx >>
```

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.

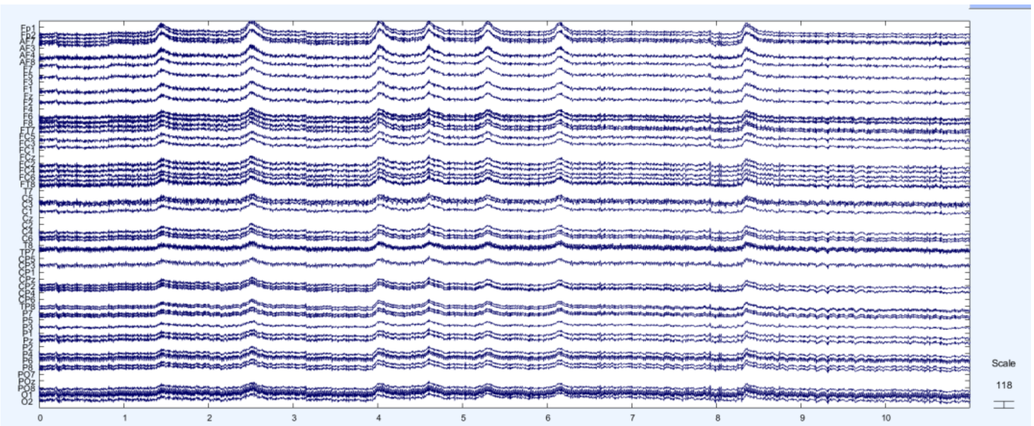
By the “classify component with ICLabel”, I get the following result:



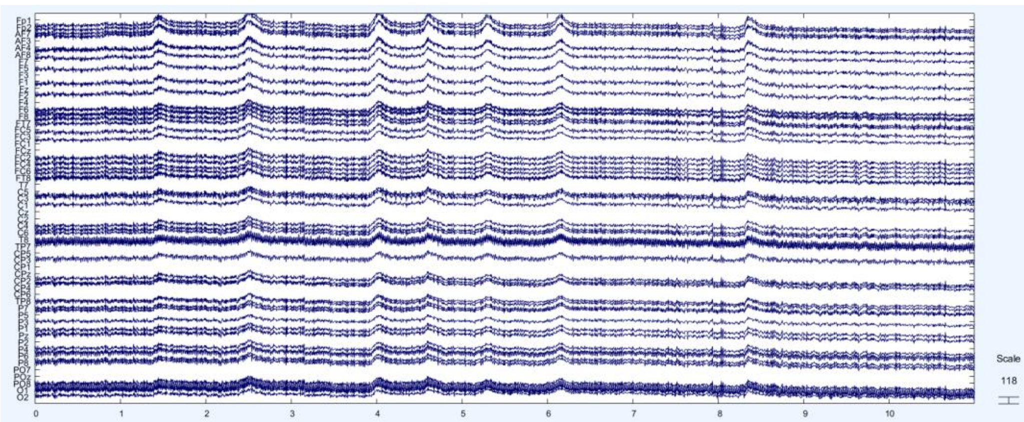
We can see that the channel 28(Line noise) 29(Line noise) 44(Line Noise) 49(Muscle) is classified as artifact. Therefore I remove them.

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

Before



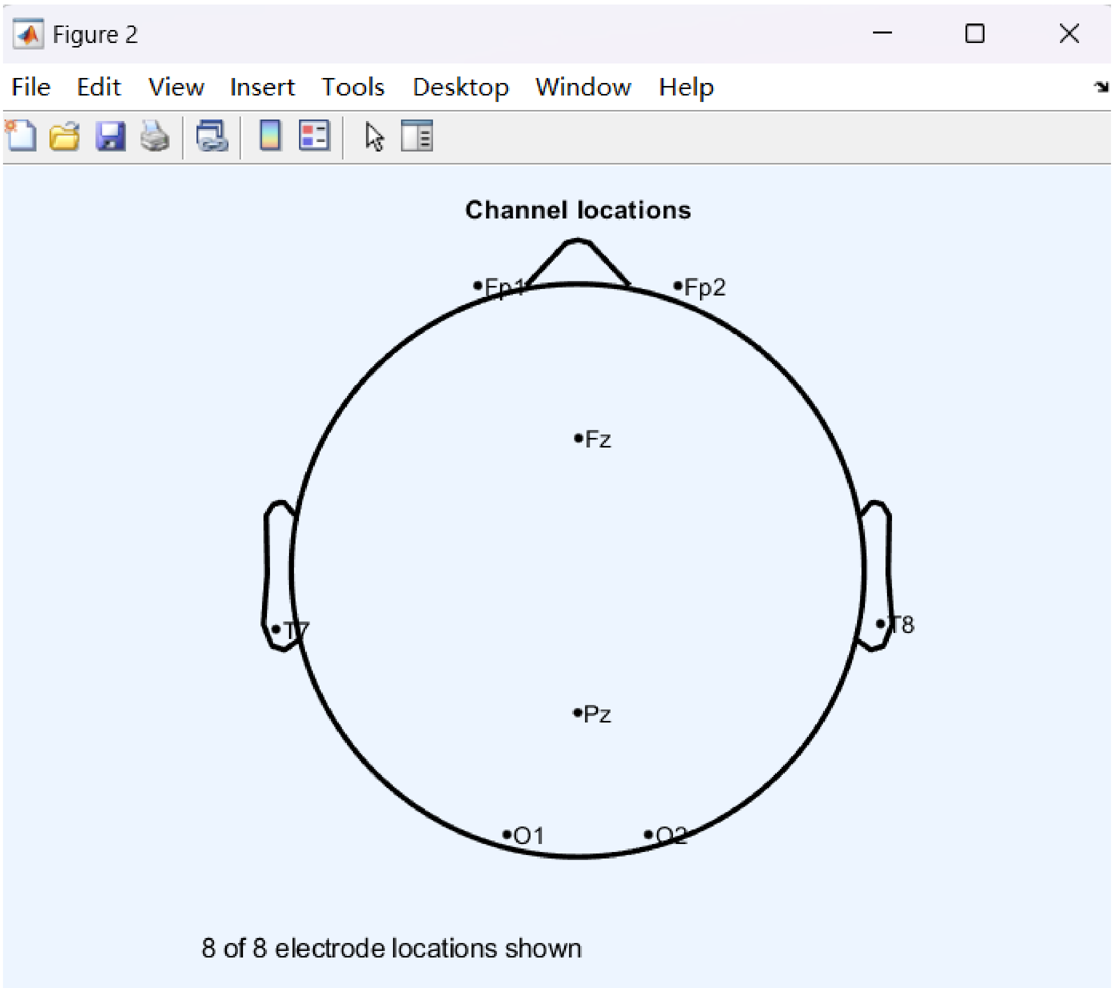
After



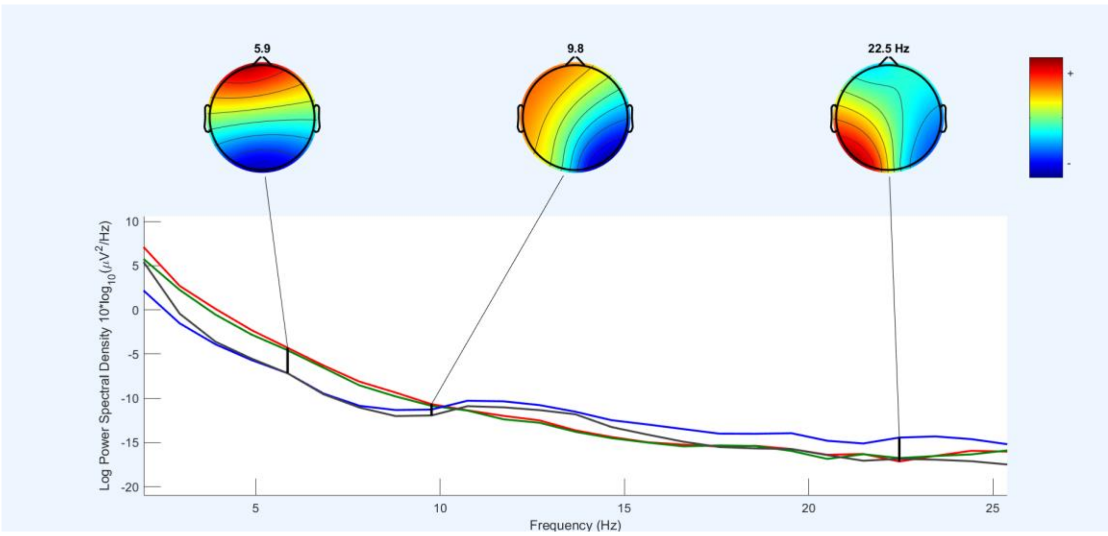
Problem 1-2

Please follow the following steps for Dataset 2:

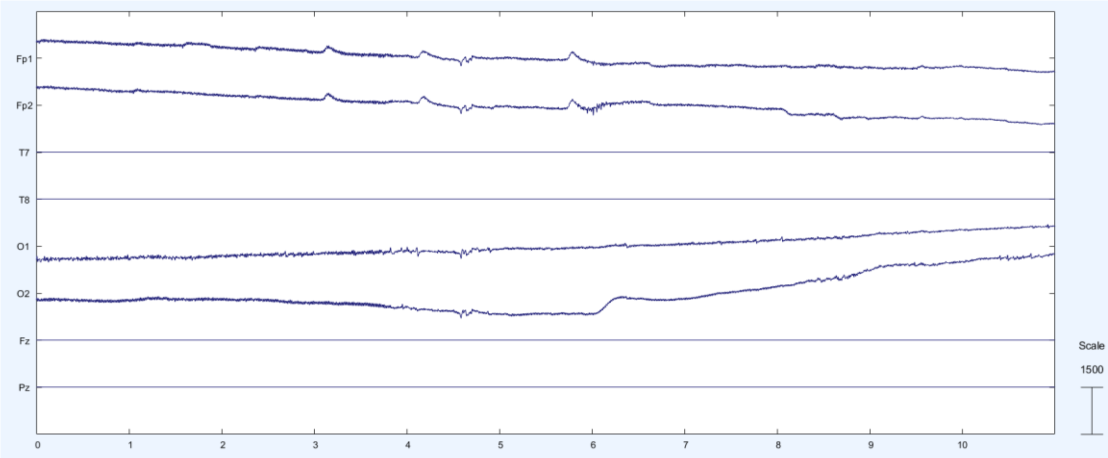
1. Plot 2D channel location map



2. Plot spectra and map in 2D.



3. Plot first 10-second channel data, and discuss anything you observed.



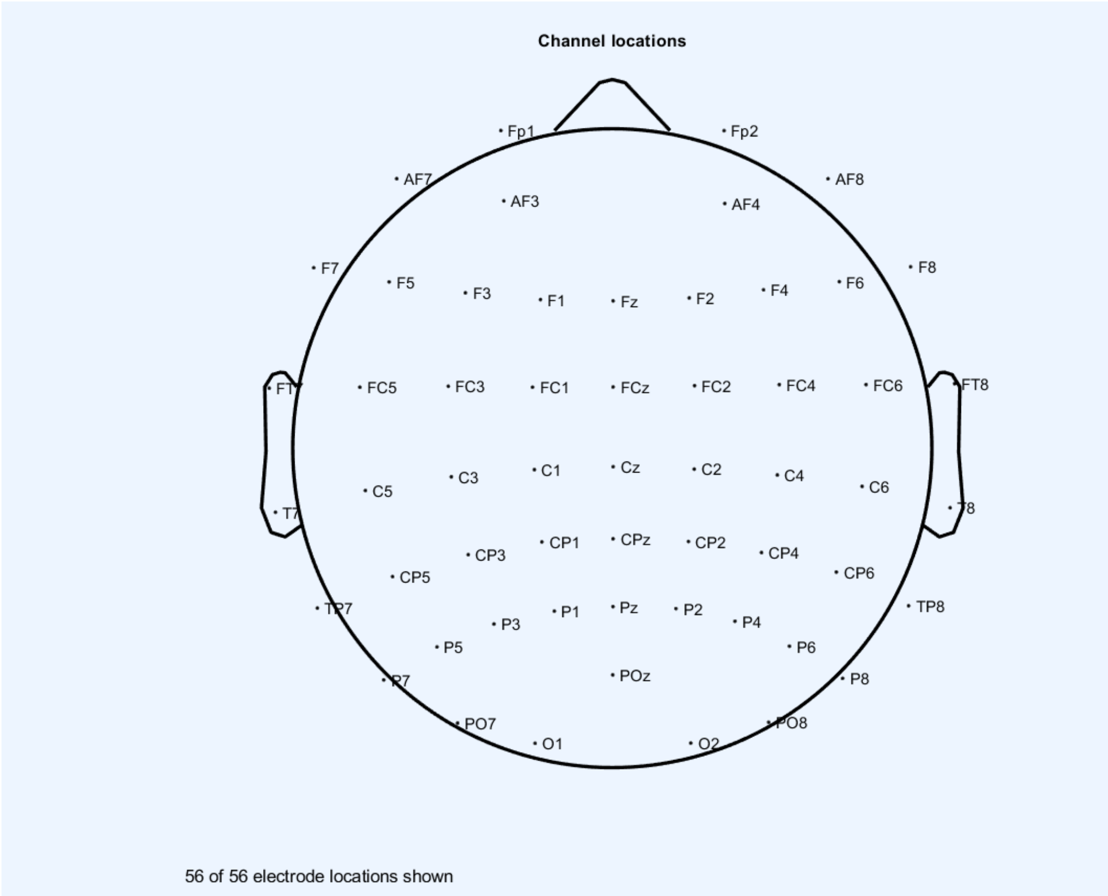
Upon observation, it is evident that the waveforms of channels Fp1, Fp2, O1, and O2 exhibit notable differences from those of T7, T8, Fz, and Pz. Specifically, the waveforms of Fp1, Fp2, O1, and O2 appear more chaotic and irregular, contrasting with the relatively flat and almost linear patterns observed in T7, T8, Fz, and Pz. One potential explanation for this discrepancy could be related to the positioning of Fz and Pz directly on the crown of the head, where there is more hair. If the EEG cap is not properly secured during placement, it may fail to exert sufficient pressure, resulting in inadequate electrode contact with the scalp. This, in turn, can lead to either the absence of signal reception or the receipt of extremely weak signals from these channels. In the case of T7 and T8, I think that it is insufficient clamping of the earlobes at the beginning may have caused a delay in signal reception.

On the other hand, the waveforms of Fp1, Fp2, O1, and O2 appear highly disordered, suggesting substantial noise interference. This is likely attributed to their positioning near the periphery of the EEG cap. As the EEG cap tends to slip initially, constant readjustment becomes necessary, resulting in positional shifts and the continual need for correction. Consequently, this leads to the reception of considerable noise, presenting a visually irregular pattern.

Problem 2

Please follow the following steps for Dataset 1:

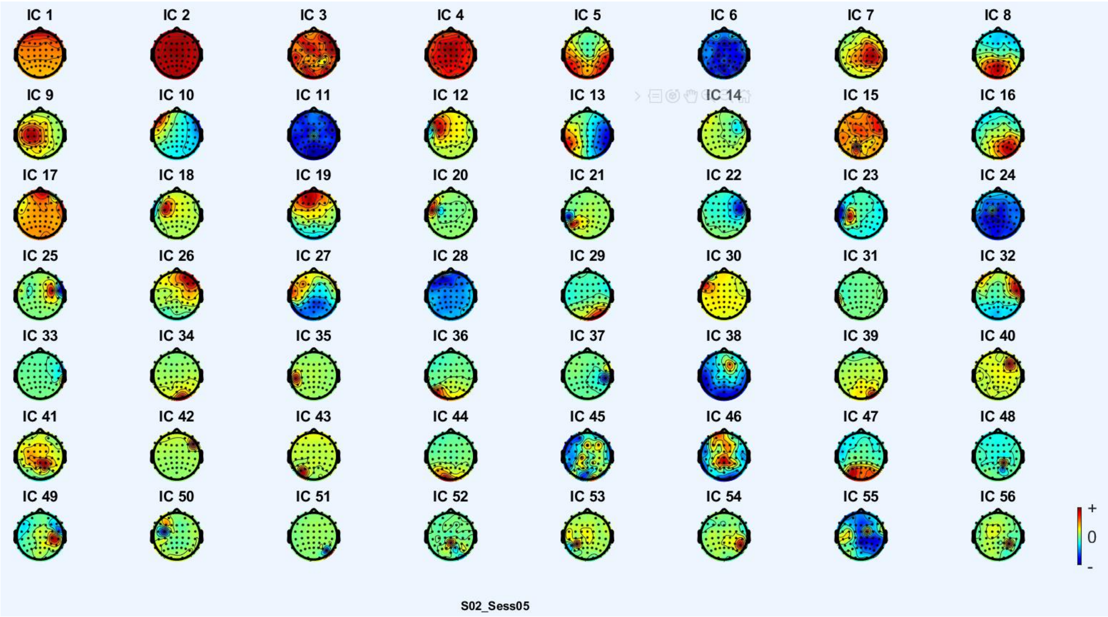
1. Plot 2D channel location map



2. Bandpass filtering [1, 48]Hz.
3. Run ICA and record computational time of ICA by code.

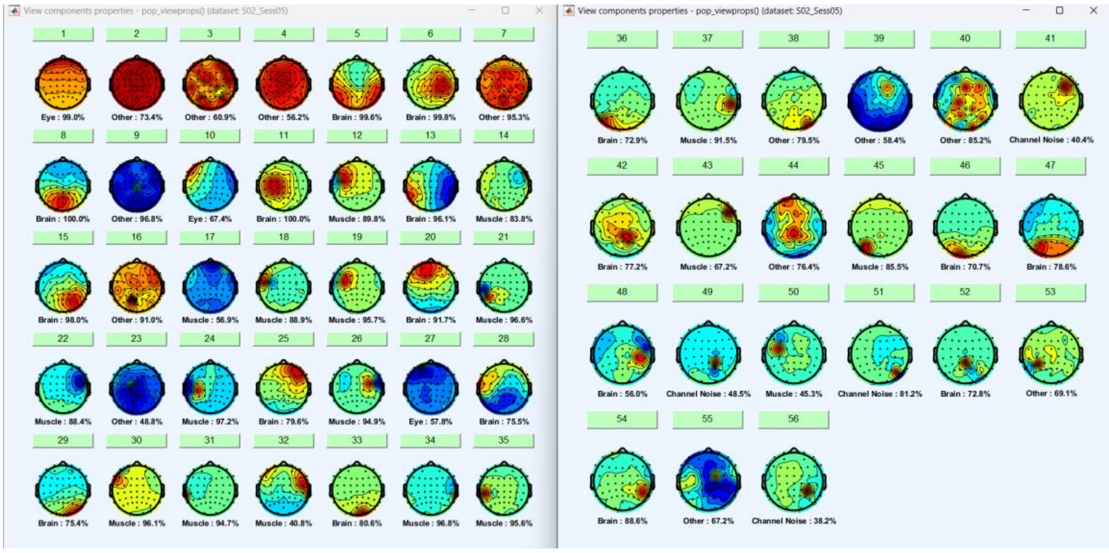
```
step 417 - lrate 0.000000, wchange 0.00000123, angledelta 19.6 deg
step 418 - lrate 0.000000, wchange 0.00000094, angledelta 23.4 deg
step 419 - lrate 0.000000, wchange 0.00000065, angledelta 19.0 deg
step 420 - lrate 0.000000, wchange 0.00000057, angledelta 32.5 deg
step 421 - lrate 0.000000, wchange 0.00000041, angledelta 32.5 deg
step 422 - lrate 0.000000, wchange 0.00000034, angledelta 38.4 deg
step 423 - lrate 0.000000, wchange 0.00000024, angledelta 36.0 deg
step 424 - lrate 0.000000, wchange 0.00000020, angledelta 44.1 deg
step 425 - lrate 0.000000, wchange 0.00000019, angledelta 50.8 deg
step 426 - lrate 0.000000, wchange 0.00000016, angledelta 53.6 deg
step 427 - lrate 0.000000, wchange 0.00000015, angledelta 56.8 deg
step 428 - lrate 0.000000, wchange 0.00000015, angledelta 62.9 deg
step 429 - lrate 0.000000, wchange 0.00000018, angledelta 99.8 deg
step 430 - lrate 0.000000, wchange 0.00000011, angledelta 63.0 deg
step 431 - lrate 0.000000, wchange 0.00000010, angledelta 94.7 deg
Sorting components in descending order of mean projected variance ...
Scaling components to RMS microvolt
Scaling components to RMS microvolt
Scaling components to RMS microvolt
>> toc
Elapsed time is 262.039901 seconds.
fx >>
```

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.

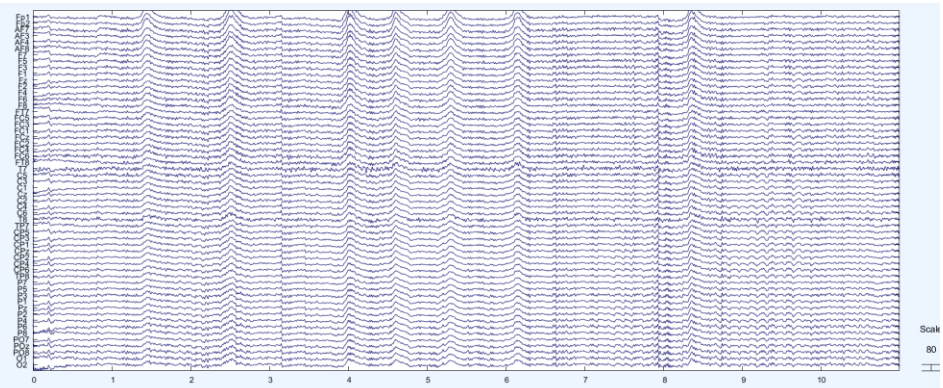
By the “classify component with ICLabel”, I get the following result:



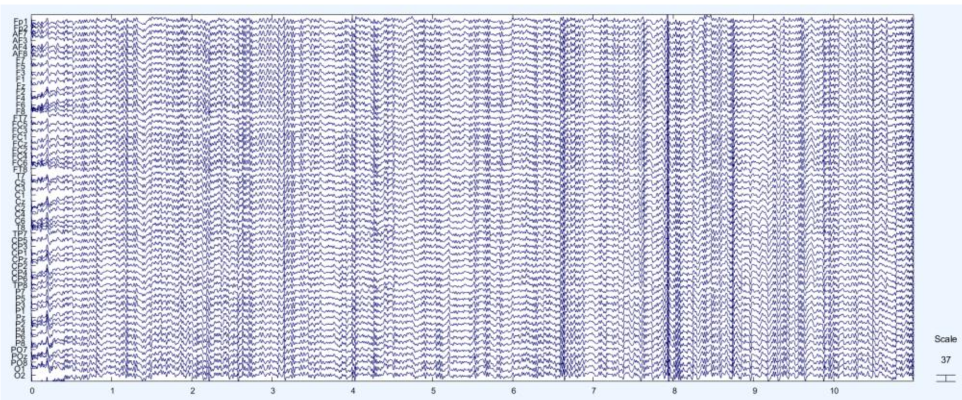
We can see that the channel 1, 10, 12, 14, 17, 18, 19, 21, 22, 24, 26, 27, 30, 31, 32, 34, 35, 37, 41, 43, 45, 49, 50, 51, 56 is classified as artifact (eye, muscle, channel noise). Therefore I remove them.

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.

- **Noise Reduction:**
  Bandpass or highpass filtering can help reduce unwanted low-frequency drifts or high-frequency noise in the EEG signal. Low-frequency drifts can be caused by electrode drift or slow physiological artifacts, while high-frequency noise can come from various sources. By filtering out frequencies outside the desired range, we can reduce these sources of noise.

- **Improved ICA Performance:**
  ICA assumes that the sources are mutually statistically independent and have non-Gaussian distributions. Filtering can help make the distribution of the EEG data closer to Gaussian and remove any strong linear trends, which can improve ICA's performance in separating the underlying independent components.

- **Focus on Relevant Frequency Bands:**
  In some cases, we may be interested in specific frequency bands of the EEG signal, such as alpha, beta, or gamma waves, for analysis. By bandpass filtering the signal, we can isolate and enhance the frequency components of interest while suppressing others, making it easier to extract meaningful independent components related to the desired frequency bands.

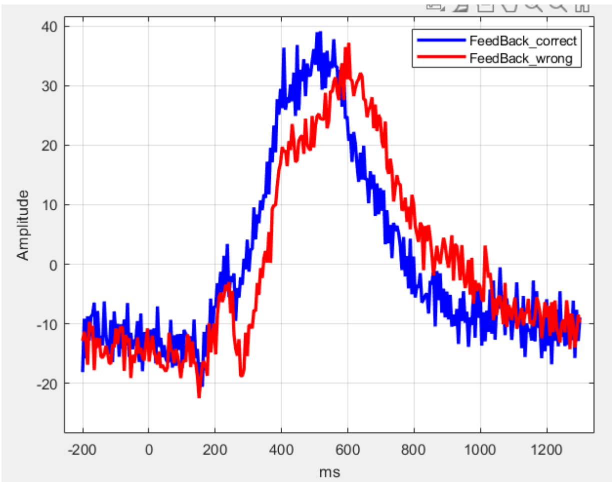
- **Artifact Removal:**
  Filtering can help remove or reduce specific artifacts that may be present in the EEG signal. For example, muscle artifacts and eye movement artifacts often have distinct frequency characteristics. Applying appropriate bandpass or highpass filters can attenuate these artifacts.

- **Reduce Computational Load:**
  Limiting the frequency range of the signal through filtering can reduce the computational load for ICA, as it focuses on a narrower range of frequencies.

Problem 3

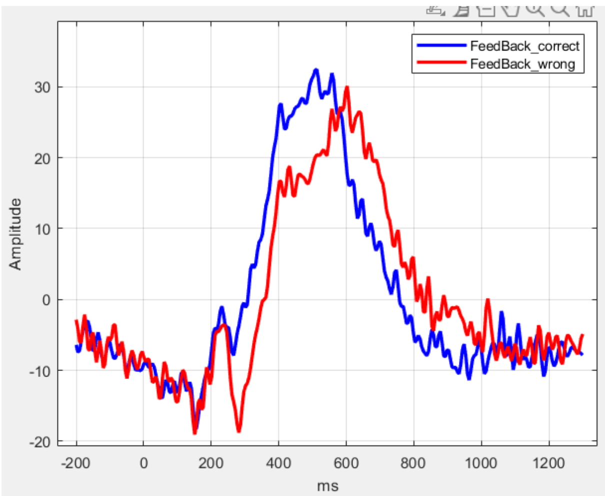
Fill out the table below

Preprocessing Methods	**ERP plot for 2 types of feedback**	**SNR(error feedback only)**

<table>
<tr>
<td>Without any operation</td>
<td>


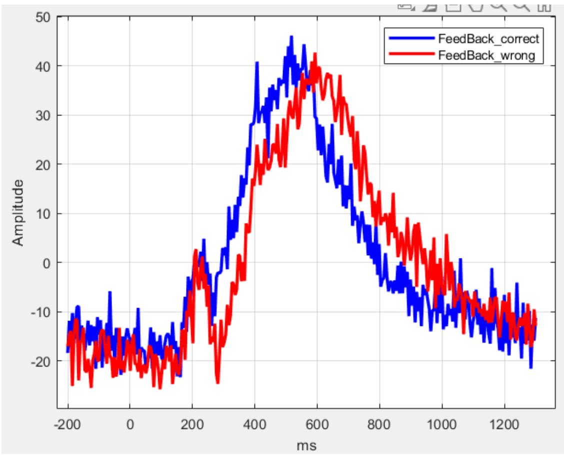
</td>
<td>
15.7007

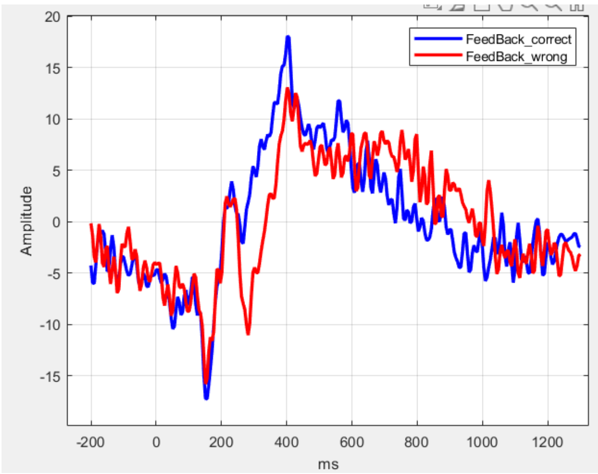
```
>> Amax = max(AWERP(:, 40:240, :))

Amax =

  single

    37.1818

>> Asd = std(AWERP(:, 1:40, :))

Asd =

  single

    2.3682

>> ASNR = Amax ./ Asd

ASNR =

  single

    15.7007
```

Because -200~1300ms mapping to row 0:300, therefore
0~1000(ms) is row 20:240
-200~0(ms) is row 1:40
</td>
</tr>
<tr>
<td>Bandpass only</td>
<td>


</td>
<td>
13.9165

```
>> Bmax = max(BWERP(:, 40:240, :))

Bmax =

  single

    30.1103

>> Bsd = std(BWERP(:, 1:40, :))

Bsd =

  single

    2.1636

>> BSNR = Bmax ./ Bsd

BSNR =

  single

    13.9165
```
</td>
</tr>
</table>

IC removal only		11.3189
		`>> Cmax = max(CWERP(:, 40:240, :))`
		`Cmax =`
		`single`
		`42.6415`
		`>> Csd = std(CWERP(:, 1:40, :))`
		`Csd =`
		`single`
		`3.7673`
		`>> CSNR = Cmax ./ Csd`
		`CSNR =`
		`single`
		`11.3189`

Bandpass+IC removal		7.2859
		`Dmax =`
		`single`
		`13.0511`
		`>> Dsd = std(DWERP(:, 1:40, :))`
		`Dsd =`
		`single`
		`1.7913`
		`>> DSNR = Dmax ./ Dsd`
		`DSNR =`
		`single`
		`7.2859`

Bonus Problem : Solving ICA problem by kurtosis (z is white signal)

$$argmax_w \|kurt(w^T z)\| \; with \; w^T w = 1$$

Ans.

Bouns Problem:

Q. $\underset{w}{\operatorname{argmax}} \| Kurt(w^T z) \|$

constraint $w^T w = 1$

z is white signal

$\therefore$ want to maximize $f(w) = \| Kurt(w^T z) \|$

with constraint : $C(w) = \|w\|^2 - 1 = 0$

$\Rightarrow J(w) = f(w) + \lambda C(w)$ (λ is Lagrange multiplier)

$\Rightarrow J'(w) = f'(w) + \lambda C'(w) = 0$

$= 4E[(w^T z)^3 z] + 2\lambda w = 0$

$\therefore$ We have to solve $F(w) = 4E[(w^T z)^3 z] + 2\lambda w = 0$

$\Rightarrow$ By Newton - Raphson's method.

$$\Rightarrow w_{n+1} = w_n - \frac{F(w_n)}{F'(w_n)}$$

$$\Rightarrow w_{n+1} = w_n - \frac{4E[(w_n^T z)^3 z] + 2\lambda w_n}{12 + 2\lambda}$$

$$\Rightarrow \frac{-(12+2\lambda)}{4} w_{n+1} = -3 w_n + E[(w_n^T z)^3 z]$$

$F'(w) = 12 E[(w^T z)^2 z z^T] + 2\lambda I$

$\approx 12 E[(w^T z)^2] E[z z^T] + 2\lambda I$

$\overset{E(zz^T)=I}{=} 12 E[w^T \overset{I}{z z^T} w] I + 2\lambda I$

$= 12 E[w^T w] I + 2\lambda I$

$= 12 I + 2\lambda I$

Let w_1 be the fix point of:

$$\tilde{w}_{n+1} = E[(w_n^T z)^3 z] - 3 w_n$$

$$w_{n+1} = \frac{\tilde{w}_{n+1}}{\|\tilde{w}_{n+1}\|}$$