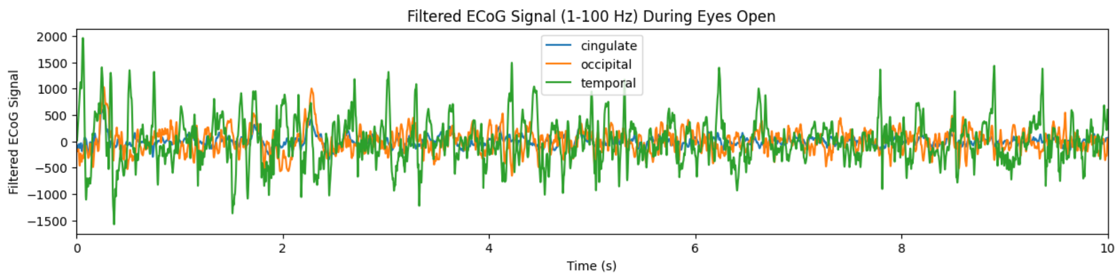
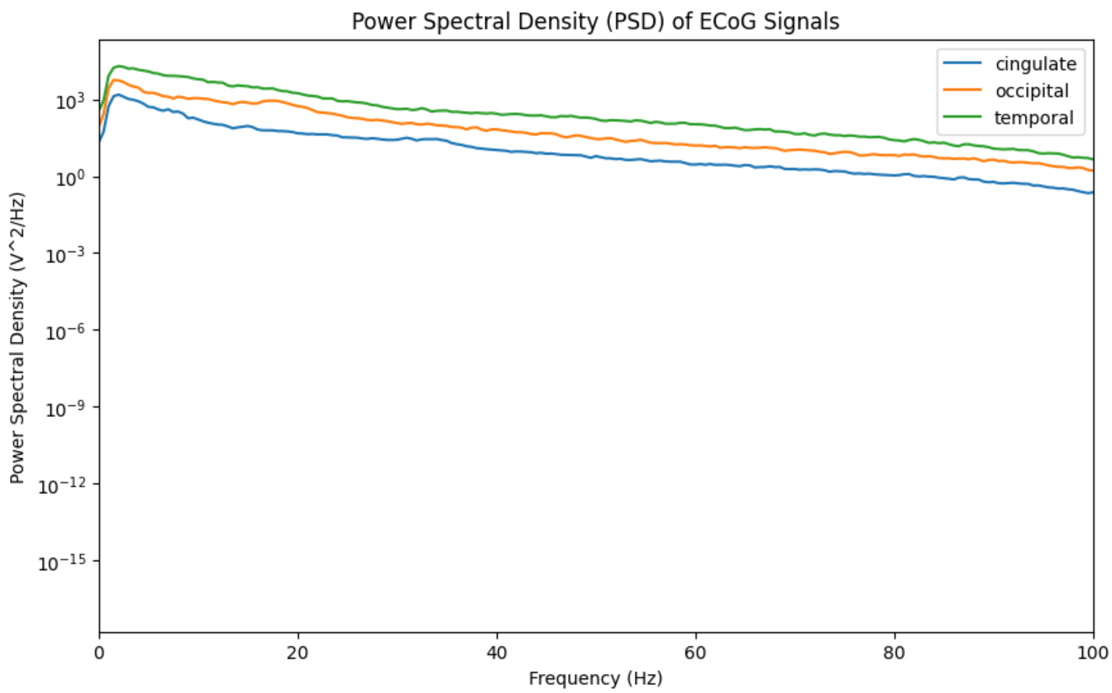
Final Project

March 21, 2025

[41]:
```python
import scipy.io as io
import numpy as np
import matplotlib.pyplot as plt
from scipy.signal import welch, butter, filtfilt

# Load the dataset
monkey_ecog_data = io.loadmat('ECoG_monkey/ECoG_monkey.mat', squeeze_me=True)

# Extract necessary data
fs = monkey_ecog_data['fs']  # Sampling frequency
ecog_eyesopen = monkey_ecog_data['ecog_eyesopen']  # ECoG data
labels = monkey_ecog_data['labels']  # Brain region labels

# Define time axis
time_axis = np.arange(0, ecog_eyesopen.shape[1]) / fs

# **1. Bandpass Filtering (1-100 Hz)**
def bandpass_filter(data, lowcut, highcut, fs, order=4):
    nyquist = 0.5 * fs
    low = lowcut / nyquist
    high = highcut / nyquist
    b, a = butter(order, [low, high], btype='band')
    return filtfilt(b, a, data, axis=1)

filtered_ecog = bandpass_filter(ecog_eyesopen, 1, 100, fs)

# **2. Time-Domain Visualization (Filtered Signal)**
plt.figure(figsize=(15, 3))
plt.plot(time_axis[:fs*10], filtered_ecog[:, :fs*10].T)
plt.xlim([0, 10])
plt.xlabel("Time (s)")
plt.ylabel("Filtered ECoG Signal")
plt.title("Filtered ECoG Signal (1-100 Hz) During Eyes Open")
plt.legend(labels)
plt.show()

# **3. Power Spectral Density (PSD) Analysis using Welch's method**
```

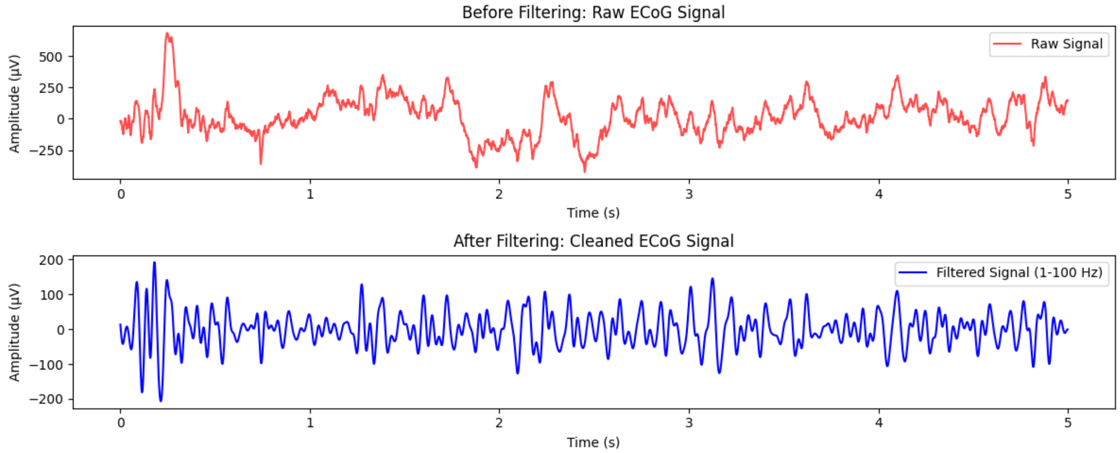
```
plt.figure(figsize=(10, 6))
for i in range(ecog_eyesopen.shape[0]):
    freqs, psd = welch(filtered_ecog[i], fs, nperseg=fs*2)
    plt.semilogy(freqs, psd, label=labels[i])

plt.xlabel("Frequency (Hz)")
plt.ylabel("Power Spectral Density (V^2/Hz)")
plt.title("Power Spectral Density (PSD) of ECoG Signals")
plt.legend()
plt.xlim([0, 100])
plt.show()
```





[42]:

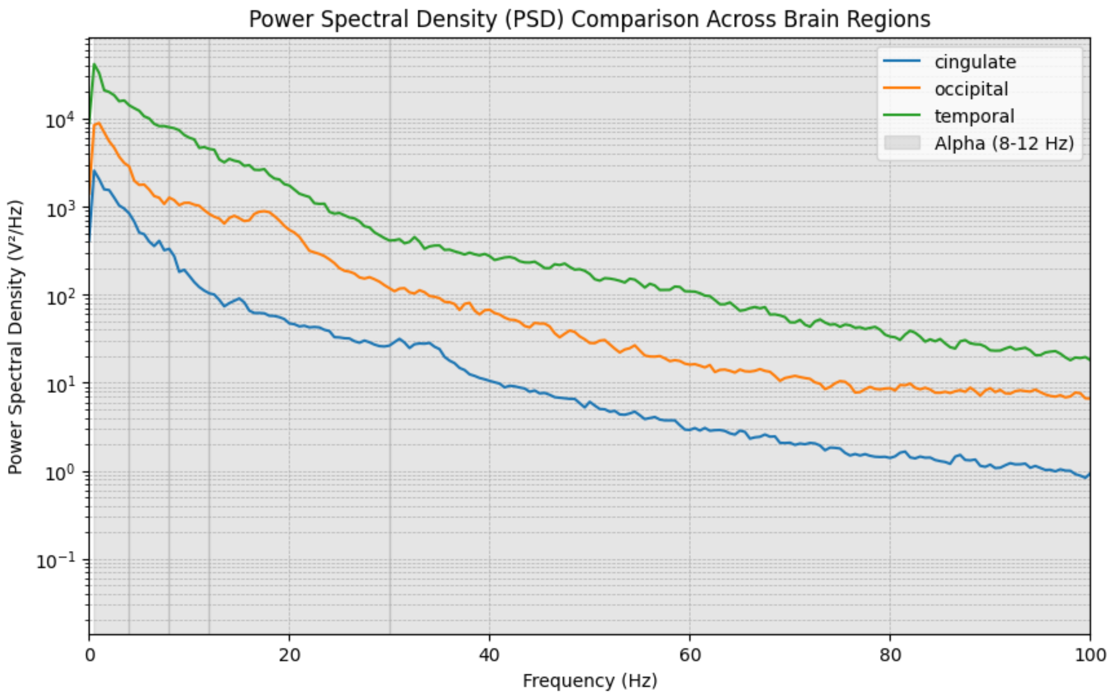
```python
# Select a single electrode for visualization (e.g., first electrode)
raw_signal = ecog_eyesopen[0, :fs*5]  # Extract first 5 seconds of data

# Define a bandpass filter function (1-100 Hz)
def bandpass_filter(data, lowcut, highcut, fs, order=4):
    nyquist = 0.5 * fs
    low = lowcut / nyquist
    high = highcut / nyquist
    b, a = butter(order, [low, high], btype='band')
    return filtfilt(b, a, data)

# Apply the bandpass filter
filtered_signal = bandpass_filter(raw_signal, 8, 30, fs)

# Create before-and-after plots
plt.figure(figsize=(12, 5))

# Plot raw signal
plt.subplot(2, 1, 1)
plt.plot(np.arange(len(raw_signal)) / fs, raw_signal, color='red', alpha=0.7,␣
 ↪label="Raw Signal")
plt.xlabel("Time (s)")
plt.ylabel("Amplitude (µV)")
plt.title("Before Filtering: Raw ECoG Signal")
plt.legend()

# Plot filtered signal
plt.subplot(2, 1, 2)
plt.plot(np.arange(len(filtered_signal)) / fs, filtered_signal, color='blue',␣
 ↪label="Filtered Signal (1-100 Hz)")
plt.xlabel("Time (s)")
plt.ylabel("Amplitude (µV)")
plt.title("After Filtering: Cleaned ECoG Signal")
plt.legend()

# Show and save the figure
plt.tight_layout()
plt.savefig("before_after_filtering.png")  # Saves the plot as an image
plt.show()
```



[43]:

```
# Define frequency bands for visualization
freq_bands = {
    "Delta (0.5-4 Hz)": (0.5, 4),
    "Theta (4-8 Hz)": (4, 8),
    "Alpha (8-12 Hz)": (8, 12),
    "Beta (12-30 Hz)": (12, 30),
    "Gamma (30-100 Hz)": (30, 100)
}

# Plot Power Spectral Density (PSD) for each region
plt.figure(figsize=(10, 6))

for i in range(ecog_eyesopen.shape[0]):
    freqs, psd = welch(ecog_eyesopen[i], fs, nperseg=fs*2)
    plt.semilogy(freqs, psd, label=labels[i])

# Highlight frequency bands with shaded regions
for band, (low, high) in freq_bands.items():
    plt.axvspan(low, high, color='gray', alpha=0.2, label=band if band ==␣
 ↪"Alpha (8-12 Hz)" else "")

# Formatting the plot
plt.xlabel("Frequency (Hz)")
plt.ylabel("Power Spectral Density (V²/Hz)")
plt.title("Power Spectral Density (PSD) Comparison Across Brain Regions")
plt.legend()
plt.xlim([0, 100])  # Focus on relevant frequency range
plt.grid(True, which="both", linestyle="--", linewidth=0.5)

# Save the plot
plt.savefig("PSD_comparison.png")
```

```
plt.show()
```



Power Spectral Density (PSD) Comparison Across Brain Regions
cingulate
occipital
temporal
Alpha (8-12 Hz)
Power Spectral Density (V²/Hz)
10^4
10^3
10^2
10^1
10^0
10^{-1}
0
20
40
60
80
100
Frequency (Hz)

[ ]:

Slide 1: Title Slide

Hello everyone, my name is …(everyone say names). and our group name is JABD, today we will be discussing the Spectral Analysis of Resting-State ECoG in Monkeys Across Different Consciousness States.

Slide 2: Introduction & Motivation

Script:
"ECoG, or electrocorticography, is a technique that records electrical activity directly from the brain's surface. It provides high temporal and spatial resolution, making it a valuable tool for studying brain activity. One of the main reasons we study ECoG is to understand neural oscillations across different brain regions.

"Raw neural data is often noisy and difficult to interpret. This is where signal processing plays a crucial role. By applying techniques such as filtering and spectral analysis, we can get meaningful patterns from the data. These techniques help us uncover how different brain regions contribute to neural activity when the monkey's eyes are open."

Slide 3: Scientific Question & Engineering Goal

Script:
"Our key scientific question is: How do brain signals differ across different brain regions when the monkey's eyes are open?

Understanding the dynamics of neural oscillations in different cortical areas is crucial for decoding cognitive processes and motor functions. By analyzing the ECoG signals, we hoped to learn of the different patterns in frequency bands such as delta, theta, beta, and gamma, which are known to be associated with different cognitive and motor tasks.

To answer our question

Applied spectral analysis to extract key frequency components.

And Visualized the brain's activity in different regions and compare how neural activity varies between motor and sensory areas.

Slide 4: Dataset Description - BRANDON

Script:
"For our study, we utilized the ECoG_monkey dataset. This dataset provides neural activity data from three distinct brain regions: the cingulate cortex, occipital lobe, and temporal lobe.The signals were recorded at a sampling rate of 1000 Hz. This high temporal resolution allows for precise tracking of rapid neural fluctuations, making it well-suited for analyzing brain oscillations across different frequency bands. By using this dataset, we aim to learn how these brain regions contribute to neural oscillatory dynamics. The cingulate cortex is known for its involvement in decision-making, emotional regulation, and attention control, while the occipital lobe is primarily responsible for visual processing. Meanwhile, the temporal lobe is crucial for auditory perception, language processing, and memory functions. By analyzing neural oscillations within these regions, we hope to uncover patterns that reflect their distinct contributions to brain function, potentially offering insights into the underlying mechanisms of cognition and perception."

Slide 5: Signal Processing Techniques

To analyze the data, we applied three key signal processing techniques. We first used bandpass filtering to remove noise and isolate relevant frequency bands, which allowed us to focus on the specific brain rhythms like Delta, Theta, Alpha, Beta, and Gamma.

Then, we used Power Spectral Density (PSD) analysis with Welch's method, which estimated the signal power across frequencies by segmenting the data, applying a window function, and averaging the results. As this provided a clearer and more stable representation of neural activity across the brain regions.

After, we visualized both the time-domain and frequency-domain characteristics, as we compared the raw signal fluctuations and spectral power distributions. These techniques helped us identify differences in brain activity to understand how different regions process visual information.

Slide 6: Preprocessing & Filtering Results

Script:
"One of the most important steps in signal analysis is preprocessing. Raw ECoG data often contains noise which can obscure meaningful brain activity. To clean the signal, we applied a bandpass filter between 1 Hz and 100 Hz."

"The plot at the top shows the raw ECoG signal before filtering. You can see large fluctuations, which are not necessarily related to actual brain activity but rather external noise and drift. The plot below shows the filtered ECoG signal, where the oscillations appear much cleaner and more structured. By removing noise, we ensure that we're analyzing true neural activity."

"This preprocessing step is essential for performing Power Spectral Density (PSD) analysis, which allows us to accurately measure the frequency components of the signal without interference from noise."

Slide 7: Time-Domain Analysis

Script:
"Next, we visualized the time-domain signals. This plot shows the neural activity recorded from the three brain regions over a 10-second window.

- Observations:
    - Temporal lobe shows higher amplitude fluctuations. This indicates increased neural firing activity, which could be associated with sensory processing and cognitive engagement when the monkey's eyes are open.
    - In contrast, the cingulate cortex, known for its role in attention and decision-making, shows moderate activity, while the occipital lobe, responsible for visual processing, displays more rhythmic patterns with lower amplitude.
- By analyzing these differences, we can start to understand how neural activity is distributed across cortical regions and how different brain areas are engaged during specific behavioral states.

Slide 8: Frequency-Domain Analysis (PSD) - BRANDON

Script:
"To further investigate neural activity, we used the Power Spectral Density analysis. This method helps us identify the dominant frequency components of the signals. By applying power spectral density to our neural recordings, we were able to determine the dominant frequency bands associated with different brain regions, providing insight into their functional roles. Our analysis revealed that the occipital lobe exhibits strong activity within the alpha frequency band (8-12 Hz), indicating a state of relaxed wakefulness often associated with visual processing. This suggests that alpha oscillations play a crucial role in suppressing irrelevant visual input and facilitating efficient information processing. We observed increased power in the beta frequency band (12-30 Hz) within the temporal lobe, which aligns with its involvement in higher-order cognitive functions, such as memory formation, language processing, and auditory perception. Beta activity has been linked to active cognitive engagement and information retention. These

findings provide valuable confirmation of known neural mechanisms and highlight the effectiveness of PSD analysis in characterizing regional brain activity.”

Slide 9: Interpretation & Discussion

So from these results we can infer that the high alpha power in the occipital lobe suggests that this region is heavily engaged in visual processing, which makes sense given its role in interpreting visual input. This aligns with what we know from neuroscience that alpha waves are often linked to visual perception and attentional states.

And in the temporal lobe, we observed stronger beta activity, which corresponds with its involvement in cognitive functions such as memory, language, and auditory processing. This suggests that while the temporal lobe is not primarily responsible for vision, it still plays a role in higher-order processing of sensory information.

The cingulate cortex showed lower overall power, which indicated that it may not be as directly involved in primary sensory processing as the other regions.

But overall, these findings are consistent with established neuroscience research on brain region specialization and reinforce the idea that different areas of the brain contribute uniquely to sensory and cognitive functions."

Slide 10: Conclusion & Future Work

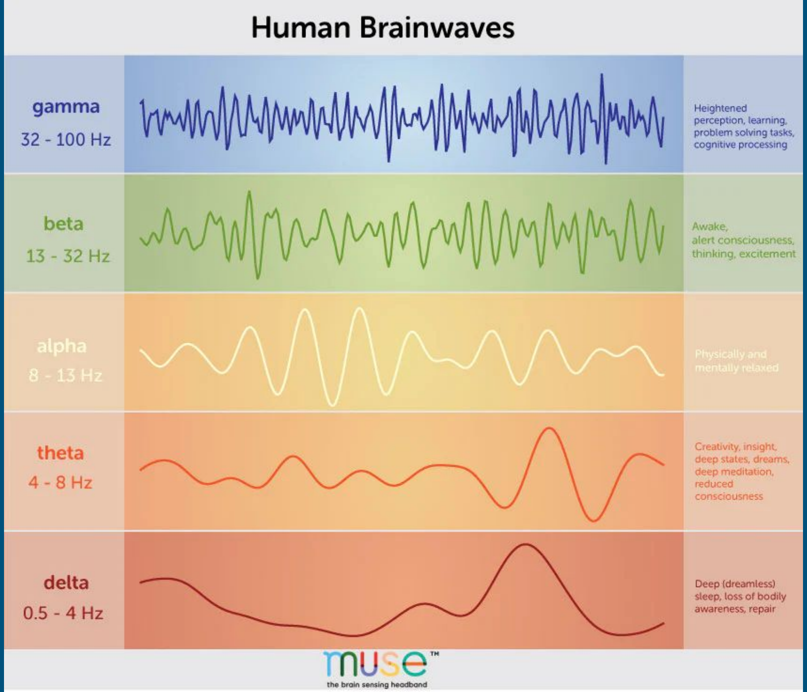
Script:
"In conclusion, we successfully applied signal processing techniques to analyze ECoG data. We were also able to find that different brain regions exhibit distinct frequency characteristics, with the occipital lobe showing strong alpha activity and the temporal lobe showing beta activity. For future work, we plan to compare these results with the eyes-closed condition and perform statistical tests to validate our findings.

Spectral Analysis of Resting-State ECoG in Monkeys Across Different Consciousness States

By: Drew Chaudhari, Brandon Huynh, Andrew Lu, Justin Chen

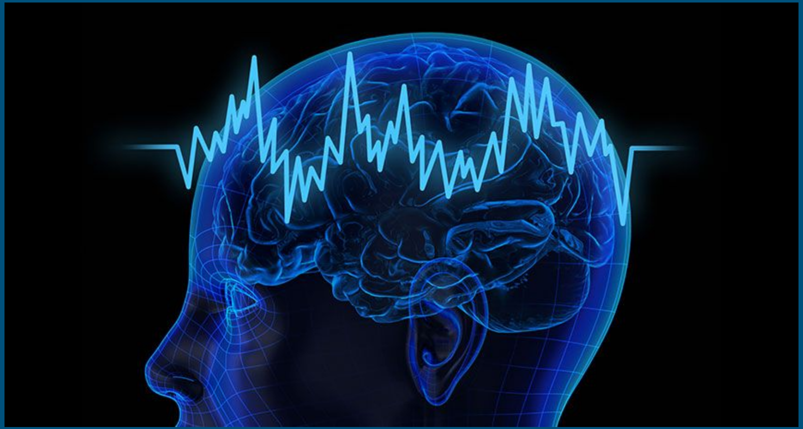
Introduction & Motivation

- **Why study ECoG signals?**
  - ECoG provides **high temporal and spatial resolution** for studying brain activity.
  - Helps understand neural oscillations in different brain regions.
- **Why is signal processing important?**
  - Raw neural data is noisy; signal processing techniques help extract meaningful patterns.
- **Why Ecog over EEG?**
  - Higher spatial resolution → Captures local brain activity better.
  - Higher temporal resolution → Detects fast neural changes.
  - Less noise → More accurate signal processing.



Research Question

- How do brain signals differ across different brain regions when the monkey's eyes are open?
- What frequency bands dominate neural activity in different brain areas?

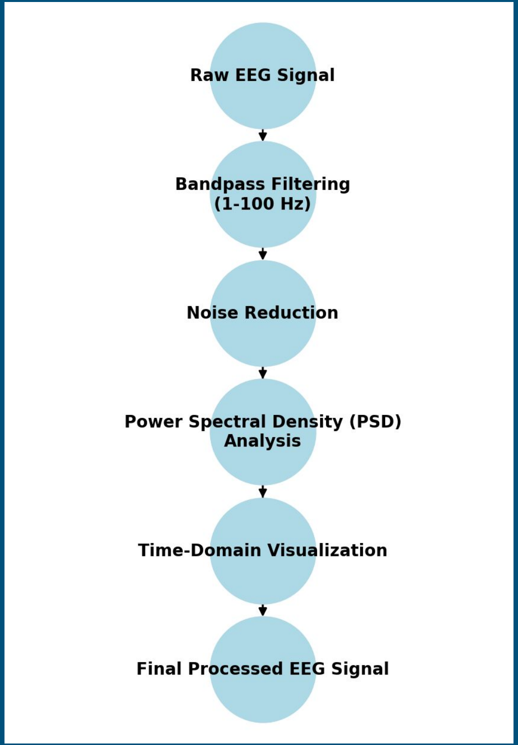


Dataset Description

- **Dataset Name**
  - *ECoG_monkey.mat*
- **Monkey Species**
  - Macaca fuscata (Japanese macaque)
  - Macaca mulatta (Rhesus macaque)
- **Signal Type**
  - ECoG recordings from a monkey's brain.
- **Brain Regions Recorded**
  - Cingulate
  - Occipital
  - Temporal
- **Sampling Rate**
  - 1000 Hz
- **Number of Electrodes**
  - Three

Signal Processing Techniques

- **Bandpass Filtering**
  - Removes unwanted noise and isolates the relevant frequency bands.
- **Power Spectral Density (PSD)**
  - Identifies dominant frequency components using Welch's method.
- **Time Domain Visualization**
  - Examines raw and filtered neural activity over time.



Preprocessing & Filtering Results

Bandpass Filtering (1-100 Hz)

- **Before Filtering:** Raw signals contain noise and low-frequency drift.
- **After Filtering:** Cleaned signals highlight meaningful neural oscillations.

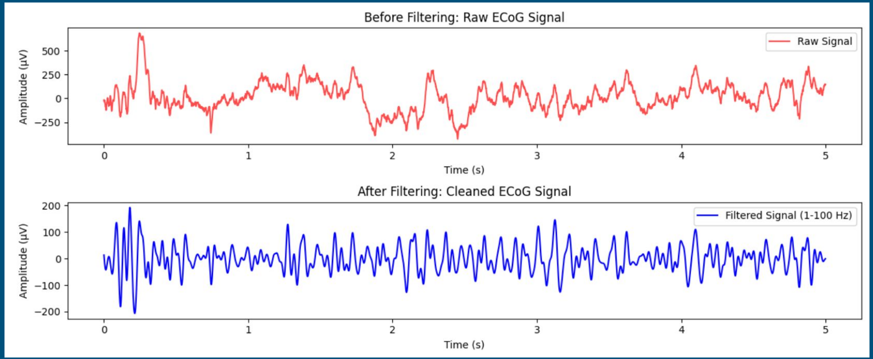
Design

Passband: 1-100 Hz (Removes drift & muscle noise).

Filter Type: Butterworth bandpass filter (smooth response).

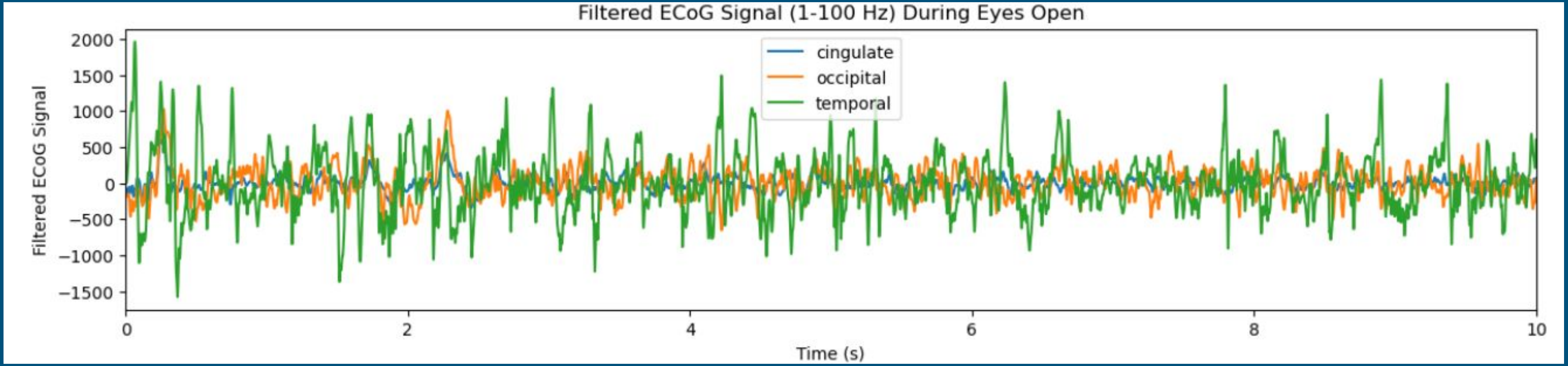
Filter Order: 4th order (balances sharpness vs. stability).

Implementation: Used Scipy's butter() and filtfilt() for zero-phase filtering.



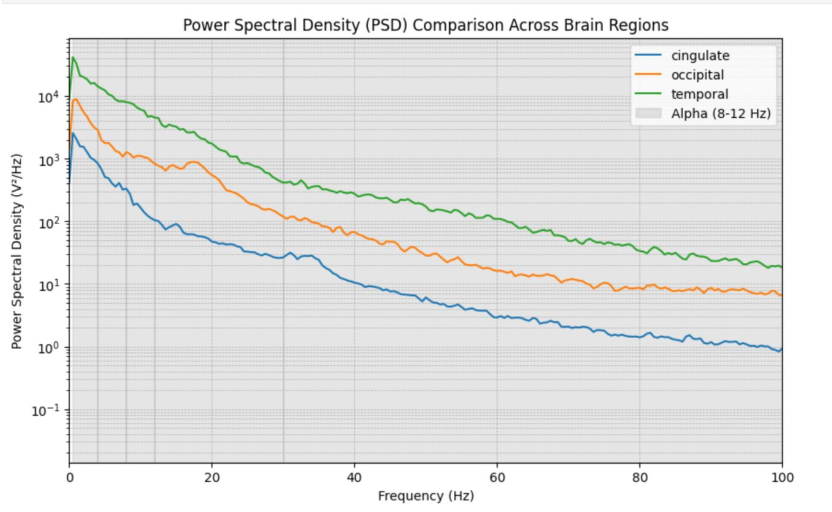
Comparisons between different regions of the brain

- Temporal lobe shows higher amplitude fluctuations
- Cingulate signals show more stability



Power Spectral Density Analysis (PSD)

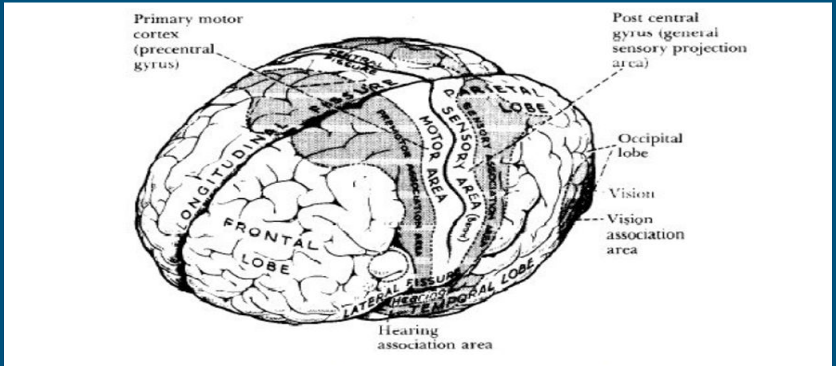
- **Occipital Lobe**
  - *Exhibits high power in the alpha range (8-12 Hz)*
- **Temporal Lobe**
  - Shows increase activity in the beta range (12-30 Hz)
- **Cingulate Cortex**
  - Has lower power overall



Interpretation and Discussion

What can we infer from these findings?

- **Alpha Activity**
  - The alpha activity in the occipital lobe aligns with visual processing.
- **Beta Activity**
  - The beta activity in the temporal lobe demonstrates the involvement in cognitive processing.
- **Cingulate Cortex**
  - Indicates reduced direct sensory processing.

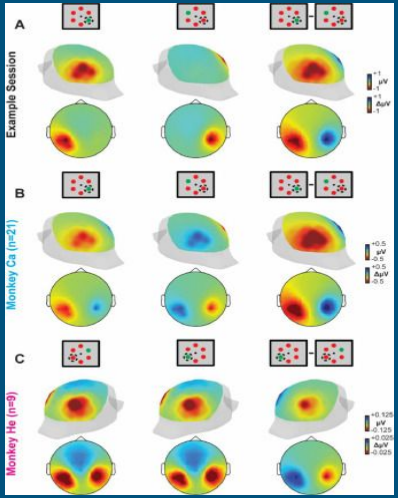


Conclusion

- Successfully filtered, analyzed, and visualized ECoG signals
- Identified dominant frequency bands across brain regions
    - Occipital - > Alpha (8-12 Hz)
    - Temporal - > Beta (12-30 Hz)
    - Cingulate - > Lower Power

Future Work:

- Compare eyes open vs. eyes closed conditions
- Perform statistical analysis to confirm regional differences
- Investigate Event-Related Potentials (ERP) in response to stimuli



References

Yanagawa, T., Chao, Z. C., Hasegawa, N., & Fujii, N. (2013). Large-Scale Information Flow in Conscious and Unconscious States: an ECoG Study in Monkeys. *PLoS ONE*, *8*(11), e80845. https://doi.org/10.1371/journal.pone.0080845