Analysing Brain response to vibrotactile stimuli

Abstract:

Vibrotactile stimuli have been shown to modulate cortical excitability and evoke event-related potentials in EEG recordings. In this study, we analyzed the effects of vibrotactile stimuli on cortical excitability and identified the cortical regions involved in processing vibrotactile information. EEG signals were recorded using a 128-channel EEG system while participants held vibrotactile that vibrated at random intervals. The raw EEG data were preprocessed using MNE-Python, and analysis was performed using epoch plots, evoked potentials, and time-frequency analysis. Our analysis revealed a significant increase in cortical excitability in the sensorimotor cortex, parietal, and frontal regions during the vibrotactile task compared to the baseline. The cortical excitability modulation was task-dependent, with different regions activated depending on the vibration frequency and intensity. Time-frequency analysis showed changes in power across different frequency bands over time, further supporting the task-dependent modulation of cortical excitability.

Introduction:

Vibrotactile stimuli have been shown to modulate cortical excitability and evoke event-related potentials in EEG recordings. Advanced data analysis techniques such as MNE-Python provide a comprehensive approach to investigating the neural mechanisms underlying vibrotactile stimulation. In this study, we employed MNE-Python to analyze the effects of vibrotactile stimuli on cortical excitability and to identify the cortical regions involved in processing vibrotactile information.

Methods:

128-channel EEG and 1-channel ECG recordings were obtained from 1 healthy subject. A participant was asked to hold a vibrotactile in each hand that vibrated at random intervals, and there were two stimuli in it. Event 1 corresponds to the regular stimulus, and event 2 corresponds to the sudden odd stimulus. EEG and ECG signals were preprocessed and analyzed using mne python.

Here are the steps followed to analyze data:

1. Load trigger and EEG data: The trigger and EEG data were loaded into MNE-Python. The trigger channel was used to mark the onset of the vibrotactile stimuli.Trigger data is interpolated to match the sampling frequency of EEG data.

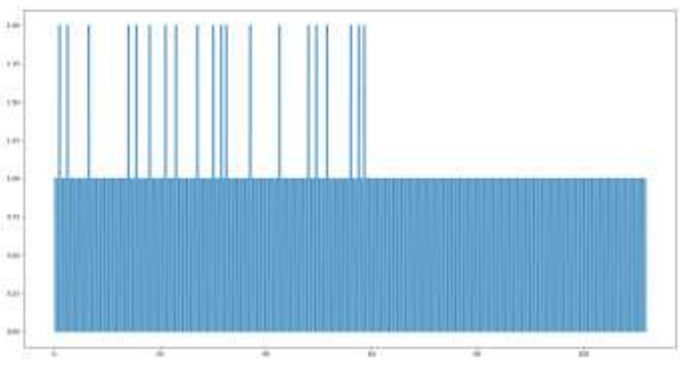


Fig 1: Trigger after interpolating to match sampling freq of EEG data

2. Concatenate stimulus data into EEG data: The stimulus data were concatenated with the EEG data. To analyze the activity of the brain corresponding to stimulus.
3. Set montage: The EEG montage was set to define the spatial locations of the electrodes on the scalp. A channel mapping is created and passed as info for creating the raw object in mne.

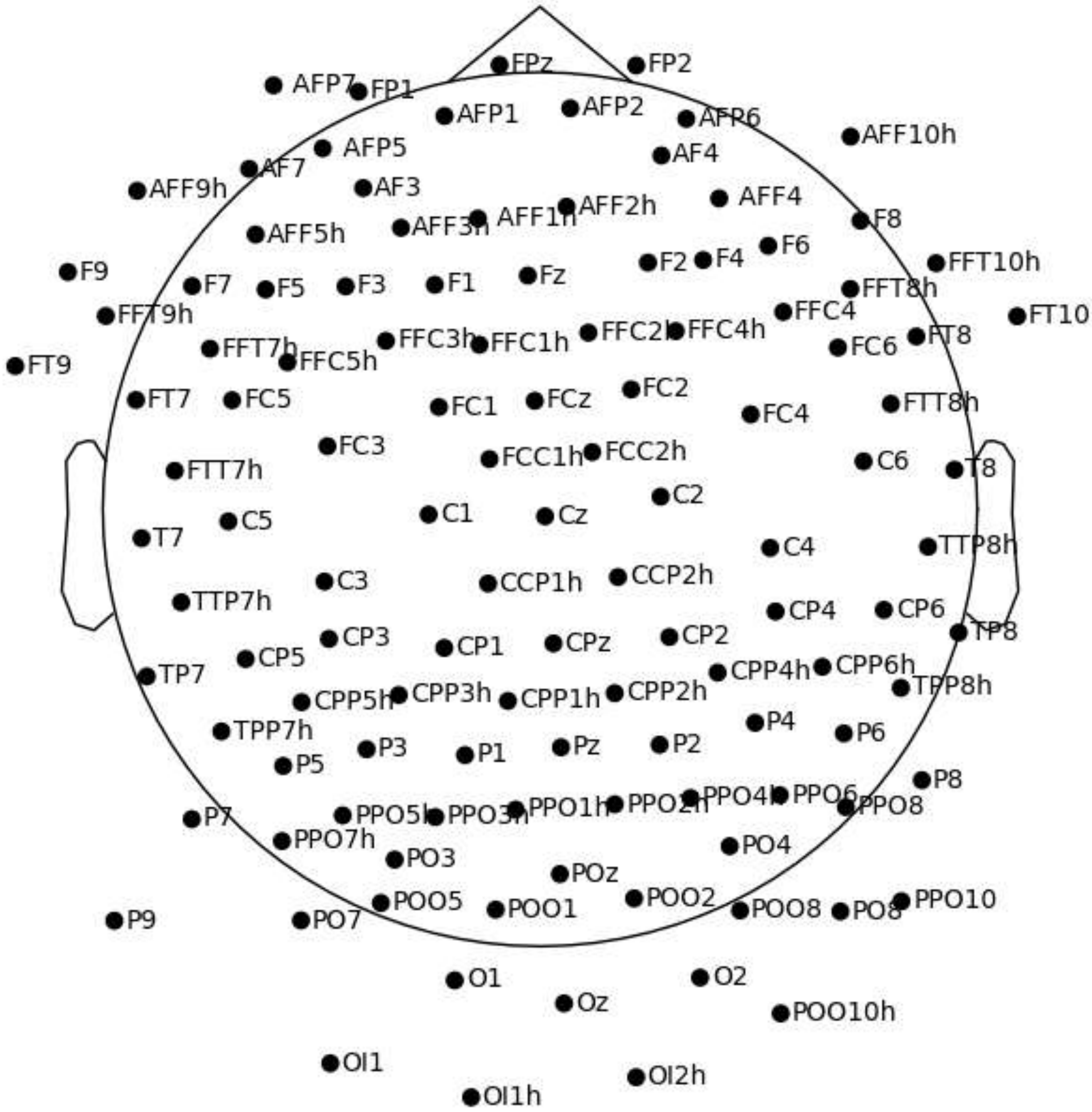


Fig2: Electrode positions in Scalp for EEG

4. Raw plots: Raw data was visualized using plots. Also set reference to average for further processing to get the better idea while comparing.

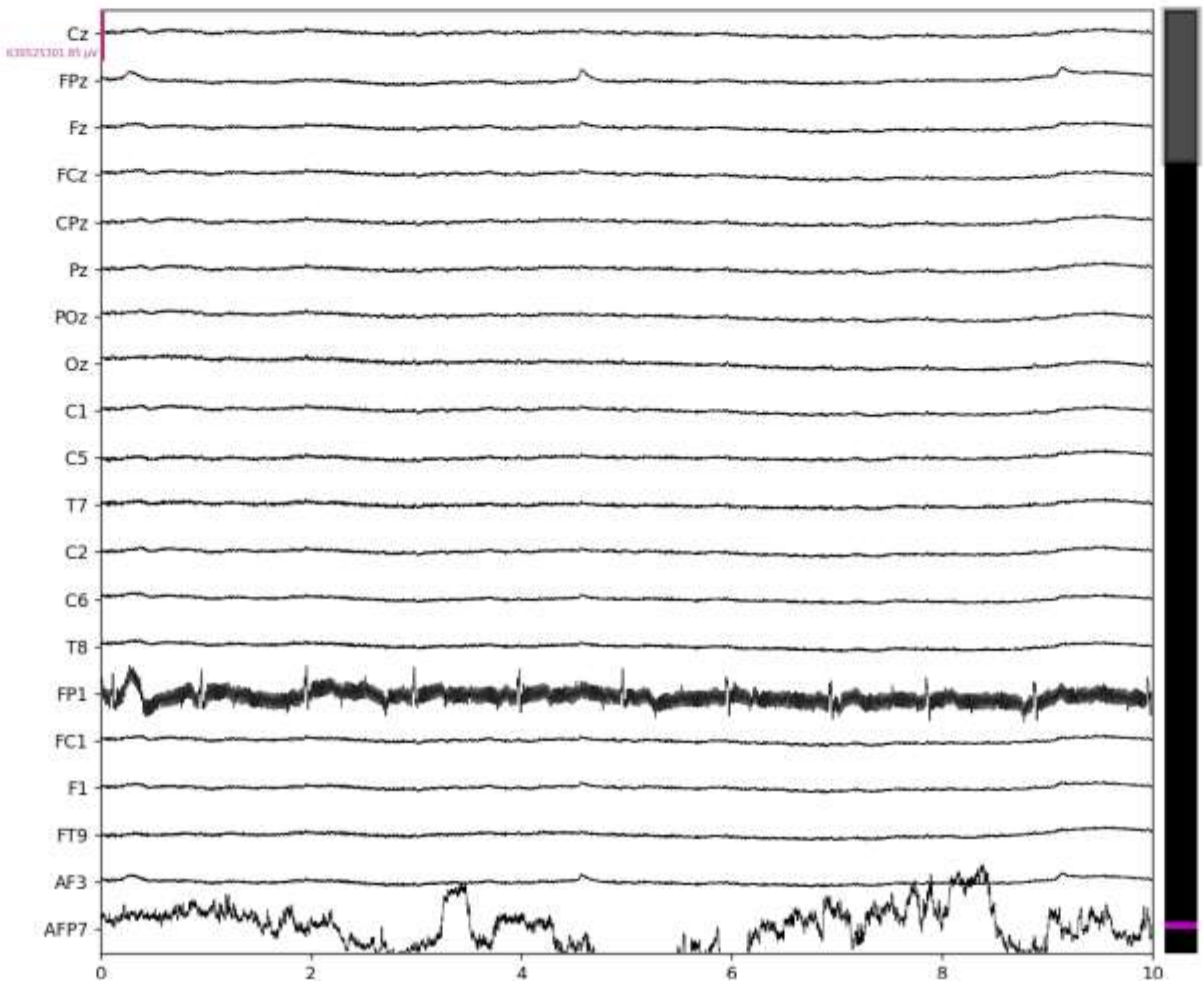


Fig 3: Raw Data

5. Filtering:
    a. A band-pass filter was applied (1-100Hz) to remove noise from the raw data.
    b. A notch filter with a 50Hz frequency was applied to remove 50Hz noise from raw data.

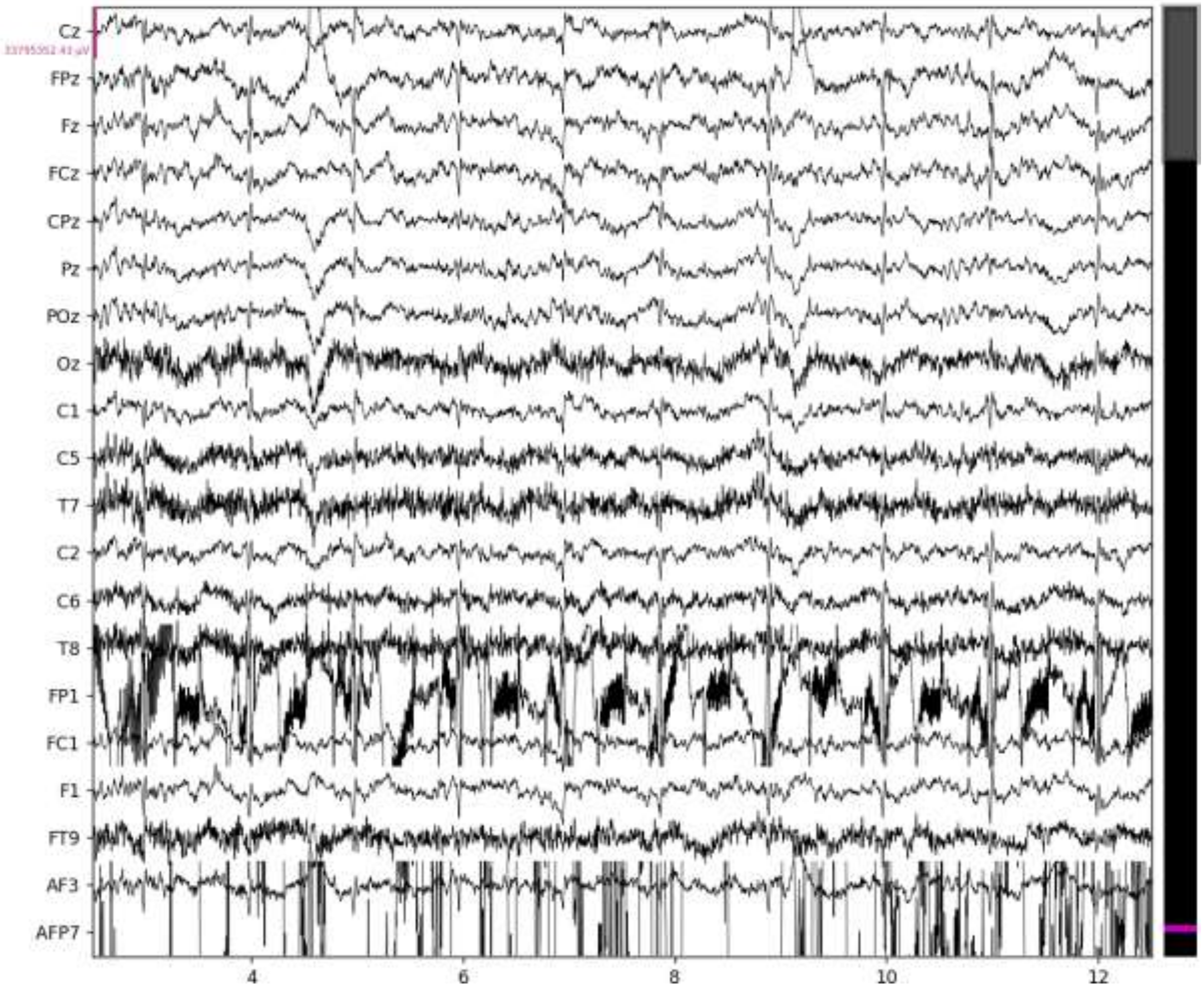
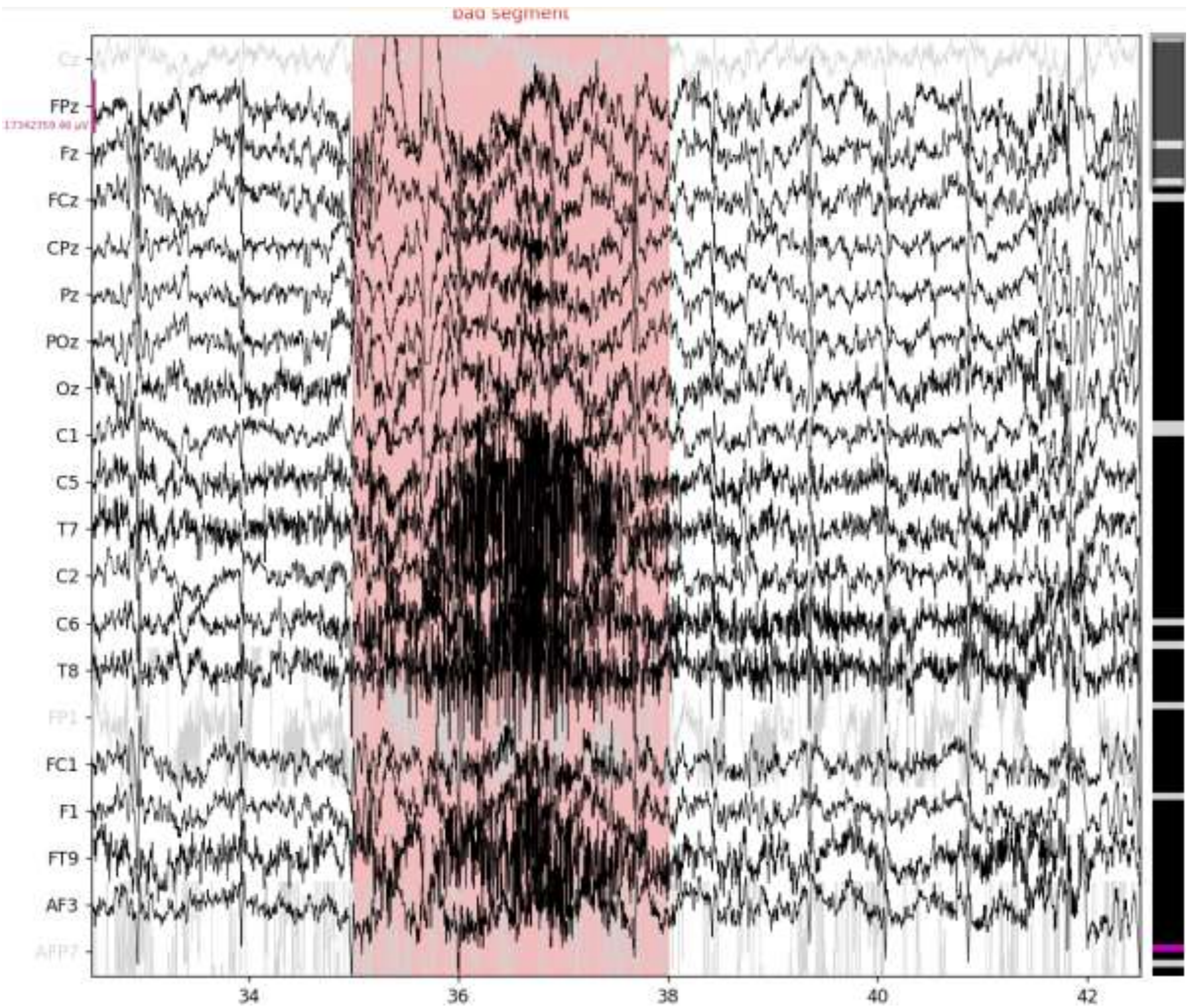
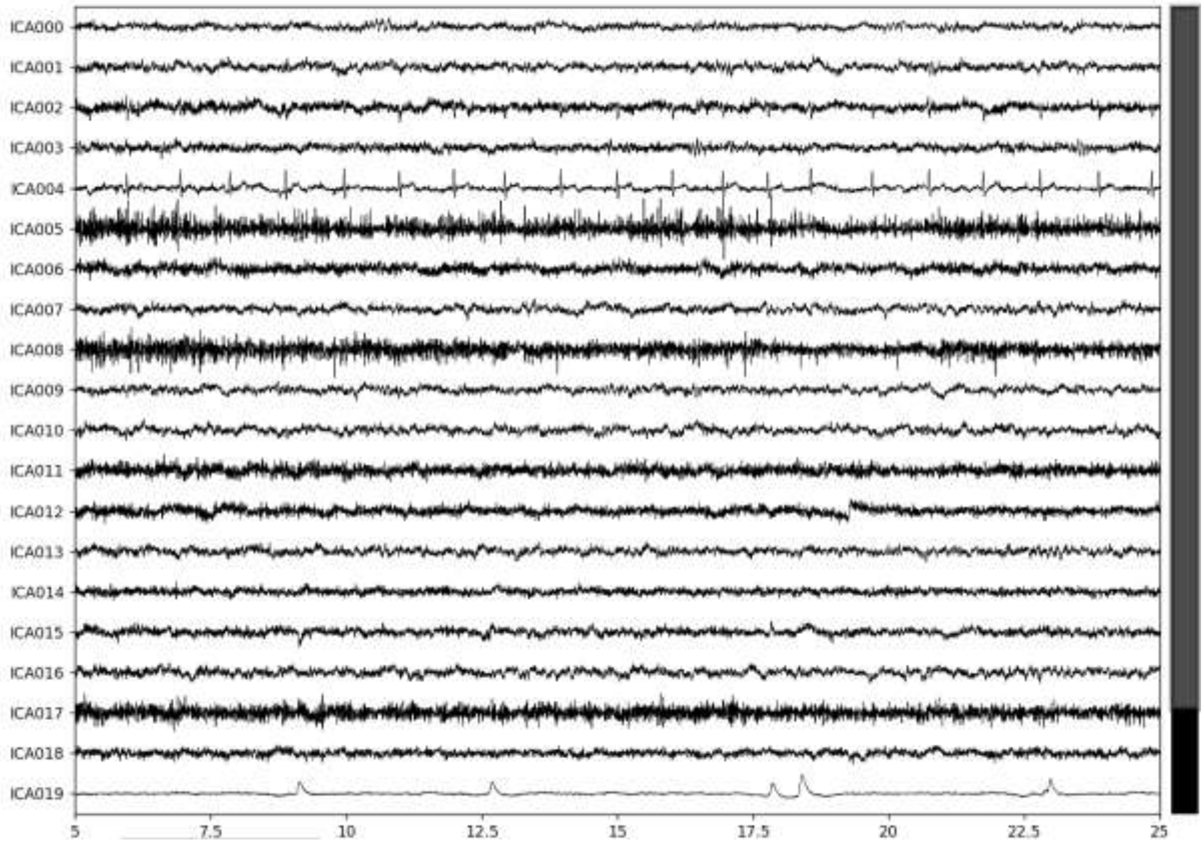


Fig 4: Filtered Data

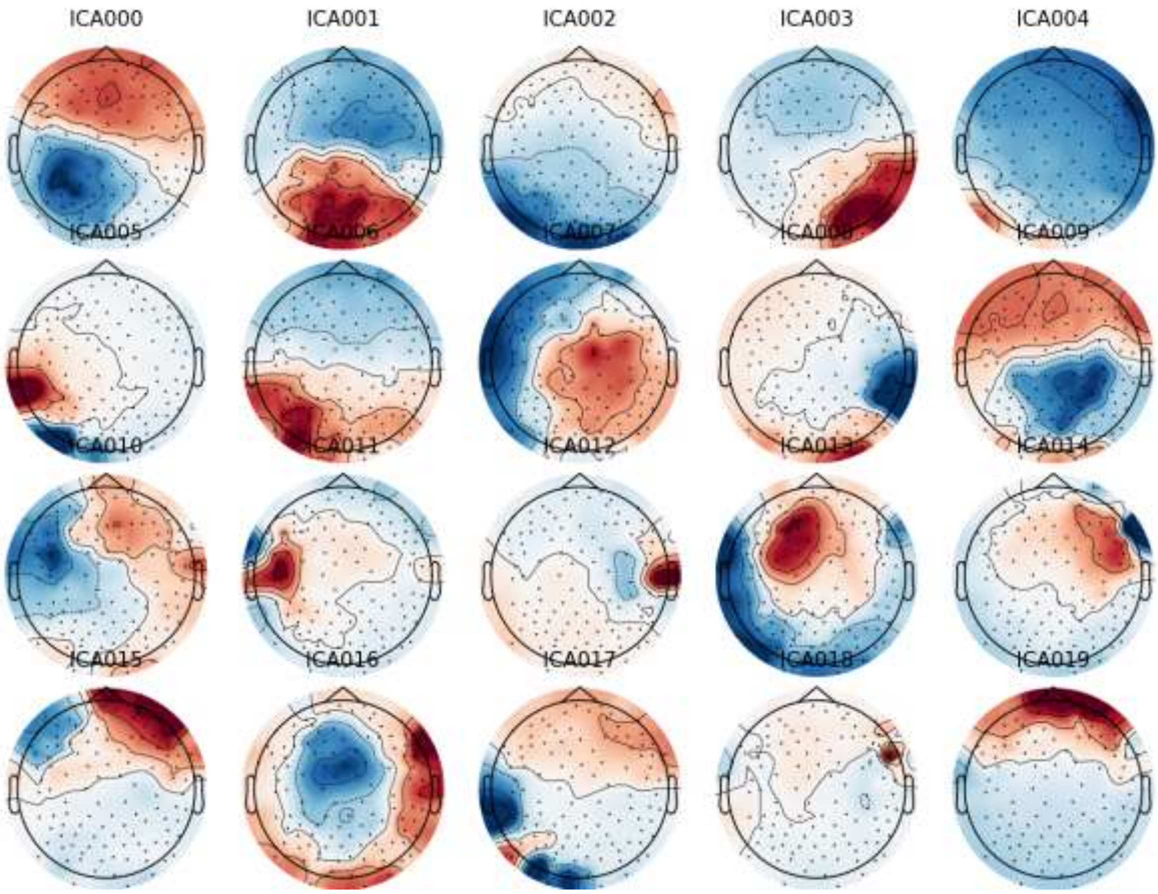
6. Marking bad channels and segments: Bad channels and segments were marked to remove bad data for analysis. Bad channels were marked by looking at the plot using interactive plots. Bad segments were marked using annotations.

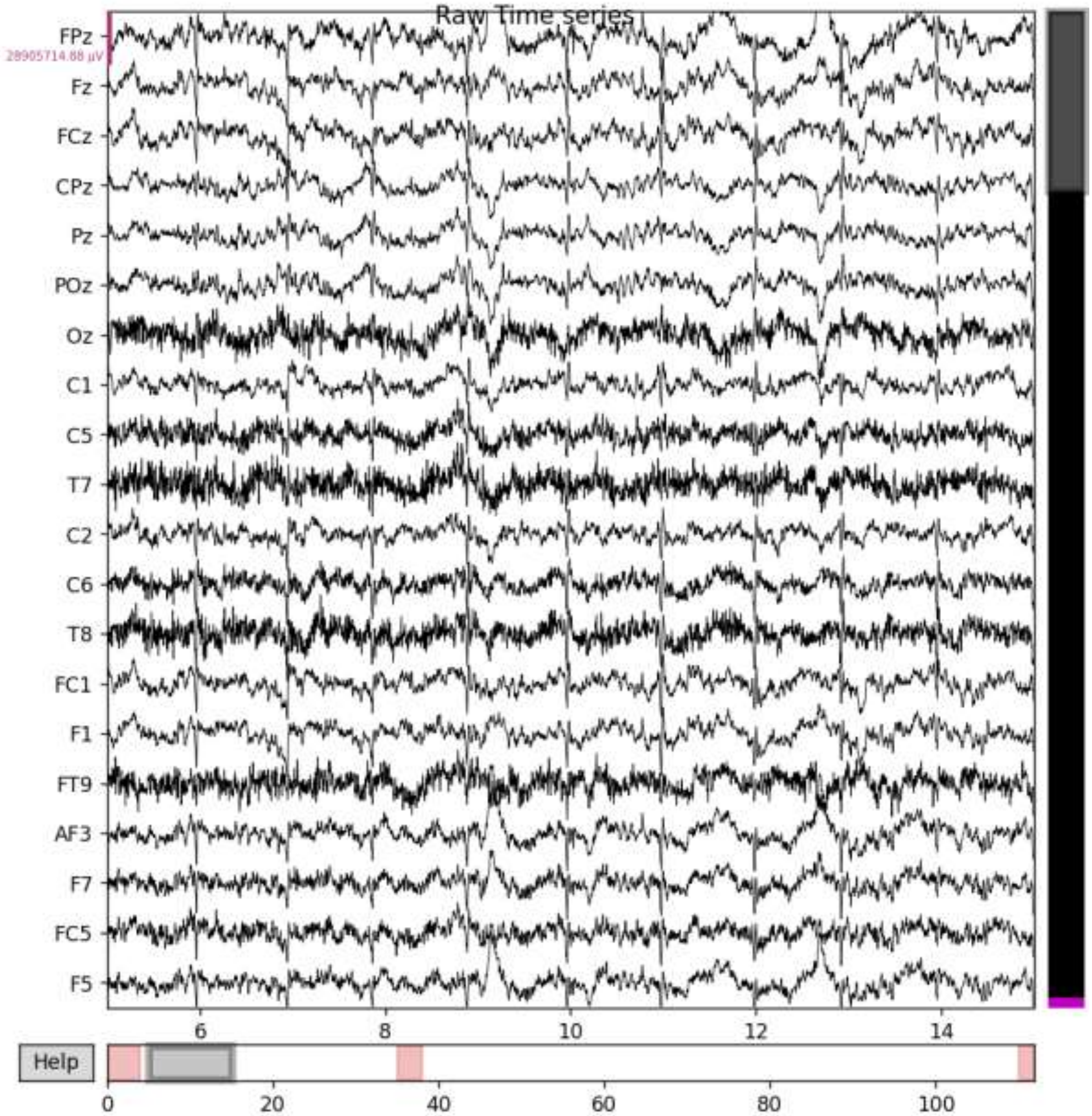


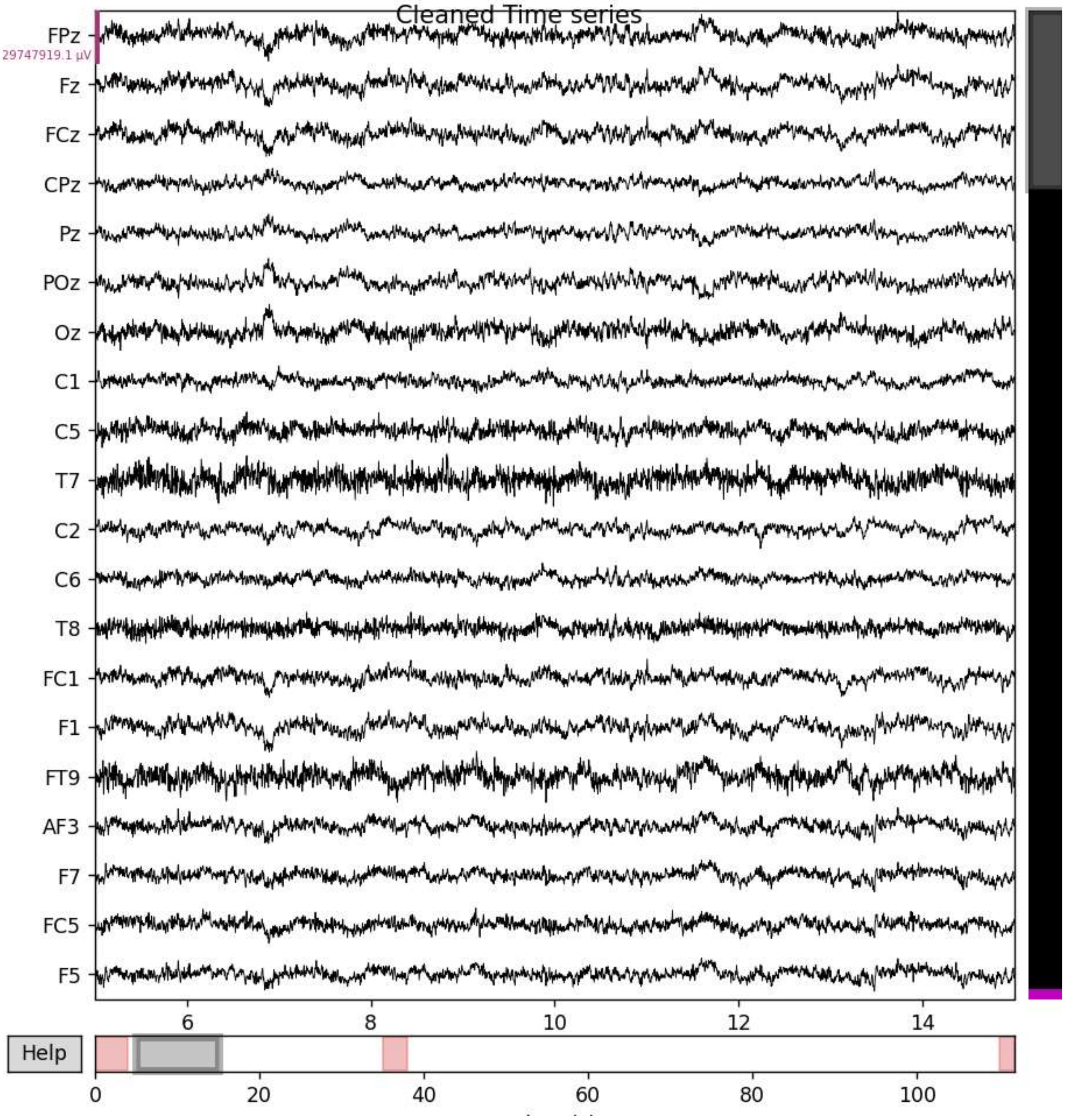
7. Preprocessing:
    a. Independent component analysis (ICA): ICA was performed on the filtered and annotated data, and 20 components were selected for decomposition. Bad components were identified by visual inspection and removed.
    b. Artifact Rejection and Reconstructing Clean data: Bad ICA components were removed from the filtered and annotated data, and the clean data was then reconstructed.



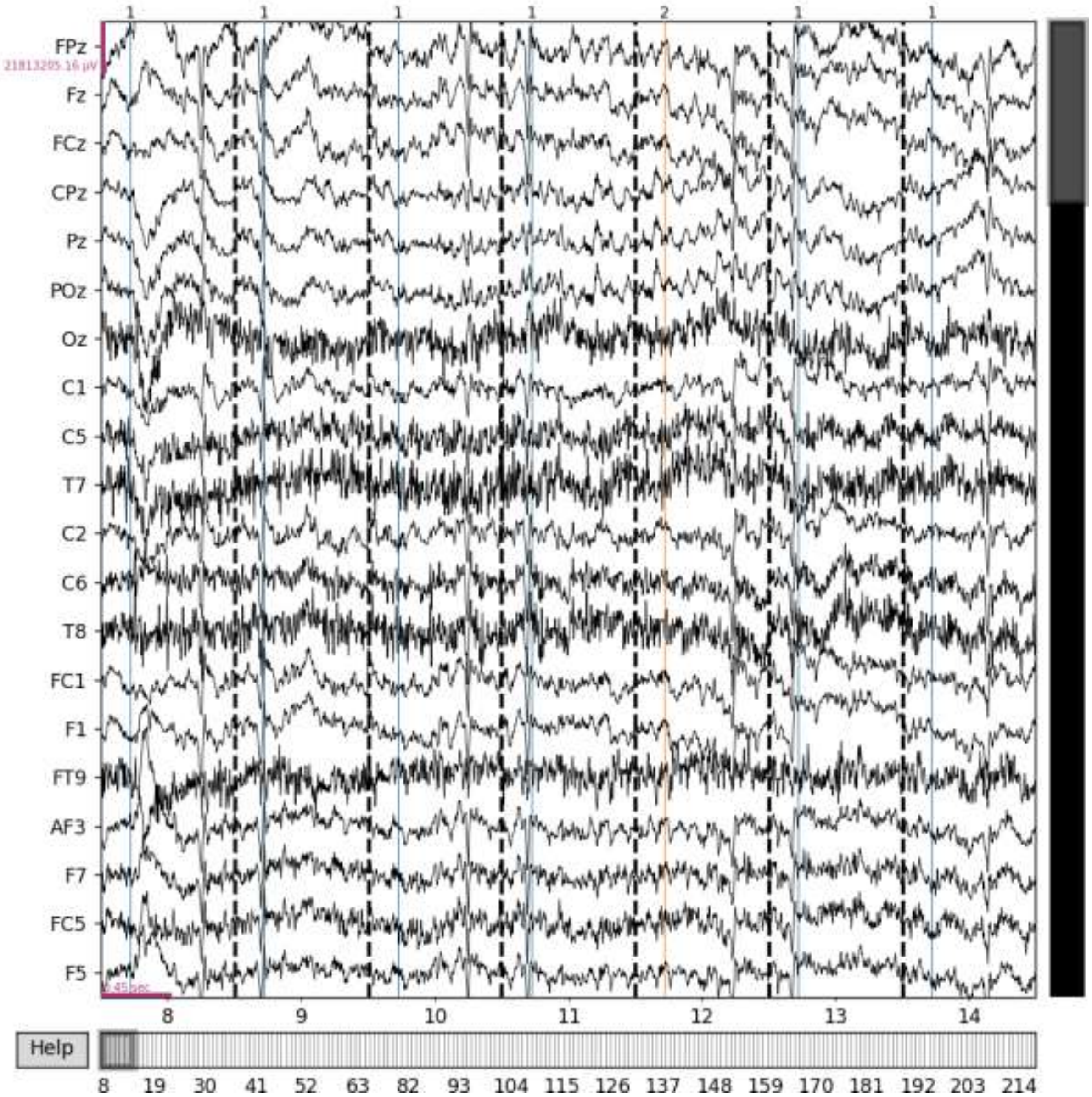
ICA components




Raw Time series
FPz
28905714.88 µV
Fz
FCz
CPz
Pz
POz
Oz
C1
C5
T7
C2
C6
T8
FC1
F1
FT9
AF3
F7
FC5
F5
6
8
10
12
14
Help
0
20
40
60
80
100

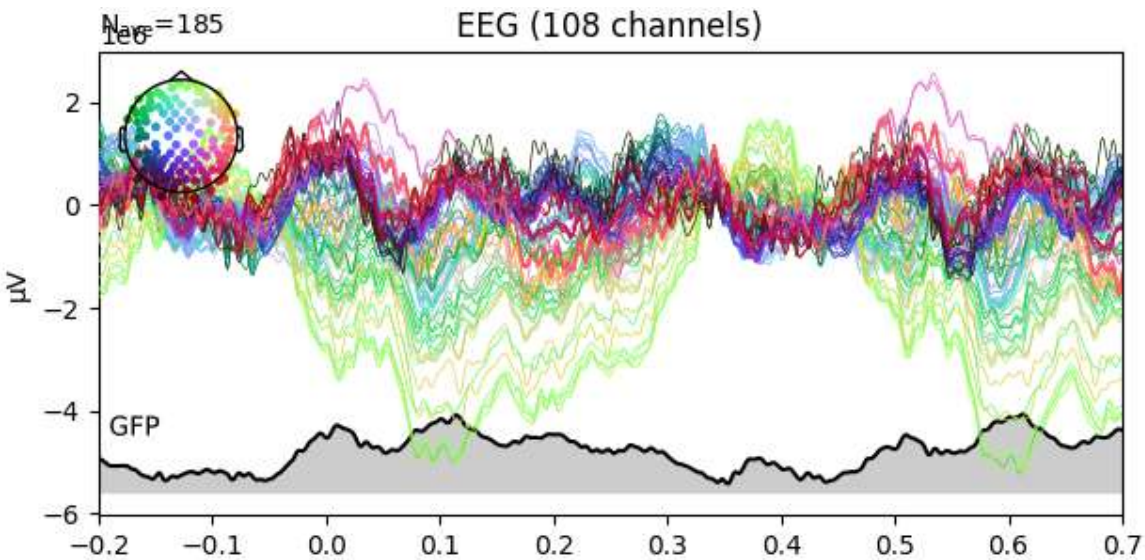


8. Analysis:
    a. The clean data was epoch-ed according to the stimulus onset.
    b. A baseline of -200ms to -50ms was selected and subtracted from the data.
    c. Epoch plots were created to visualize the effects of the vibrotactile stimuli on cortical excitability.
    d. The average for both potentials was calculated and plotted to visualize the Event-Related Potential.

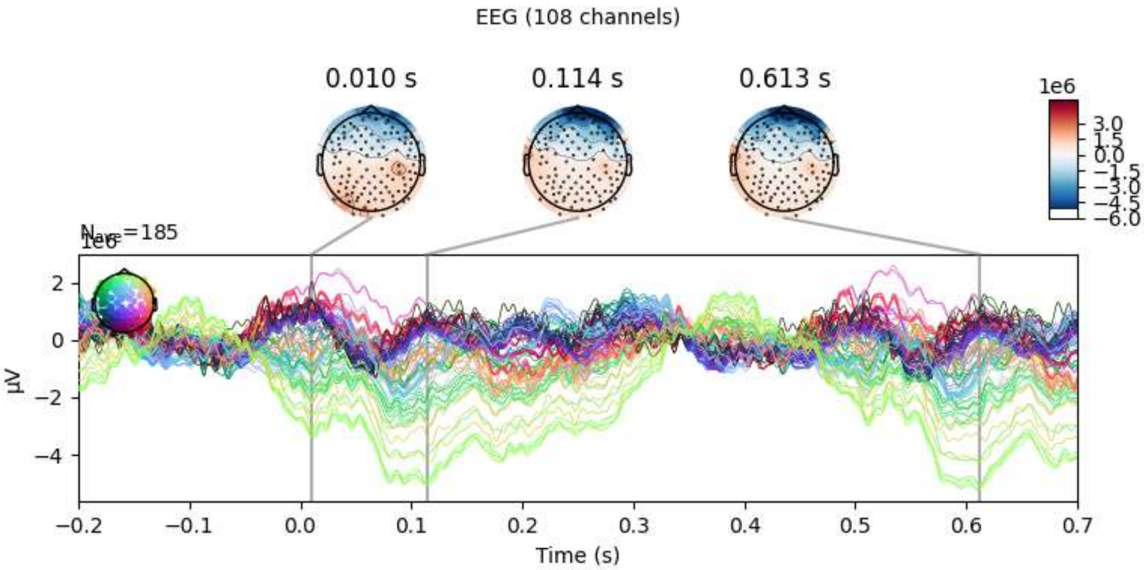


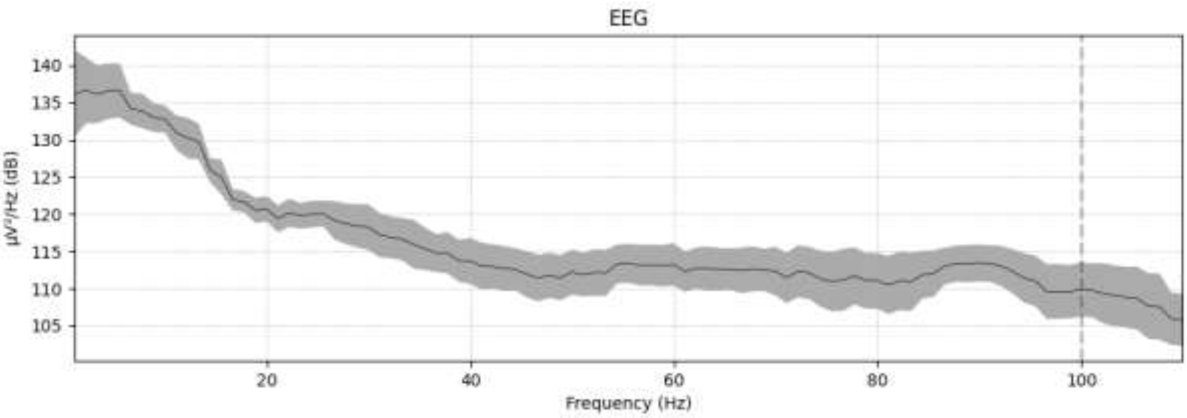
FPz
Fz
FCz
CPz
Pz
POz
Oz
C1
C5
T7
C2
C6
T8
FC1
F1
FT9
AF3
F7
FC5
F5
8
9
10
11
12
13
14
Help
8 19 30 41 52 63 82 93 104 115 126 137 148 159 170 181 192 203 214

Event 1:

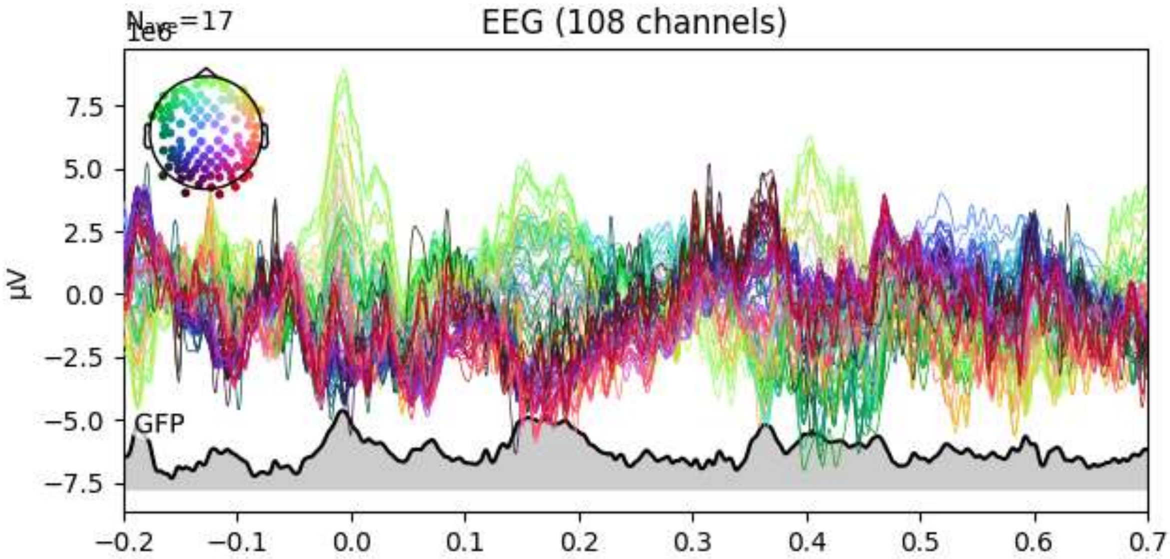


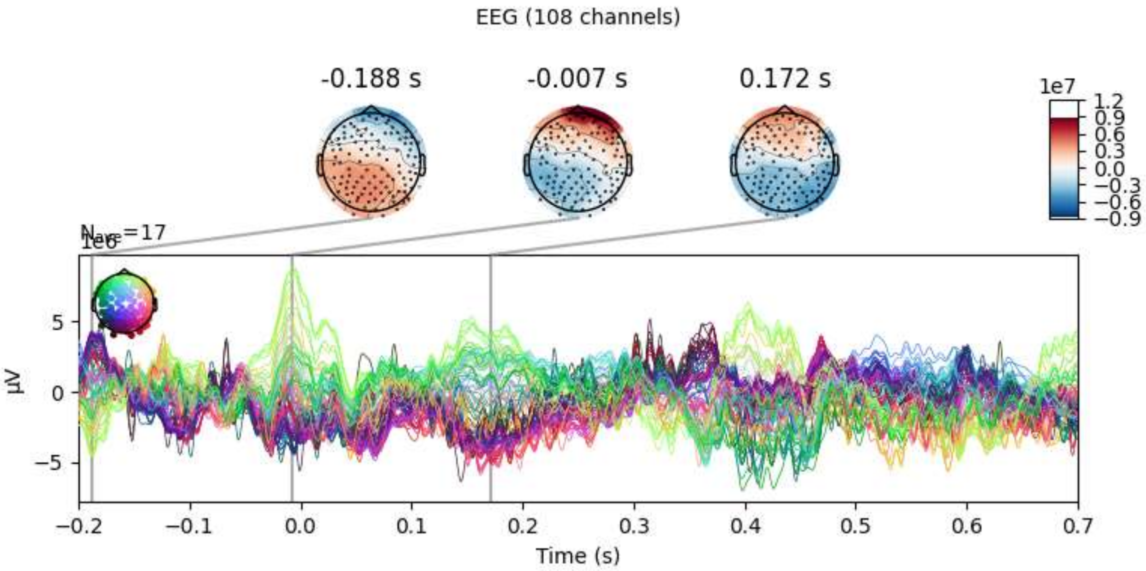
N_{ave}=185
1e6
EEG (108 channels)
µV
GFP
2
0
−2
−4
−6
−0.2 −0.1 0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7

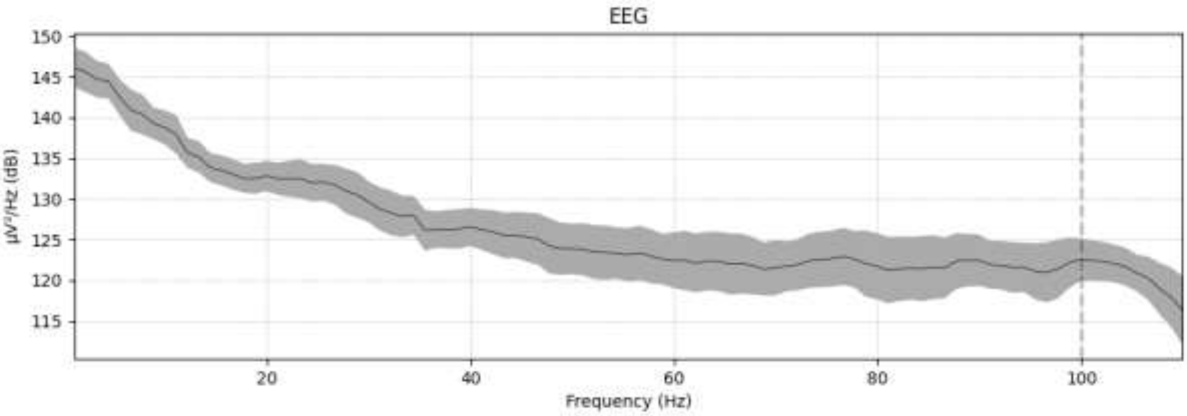

EEG (108 channels)
0.010 s
0.114 s
0.613 s
1e6
3.0
1.5
0.0
−1.5
−3.0
−4.5
−6.0
N_ave=185
1e6
2
0
−2
−4
µV
−0.2
−0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time (s)


EEG
140
135
130
125
120
115
110
105
µV²/Hz (dB)
20
40
60
80
100
Frequency (Hz)

Event 2:

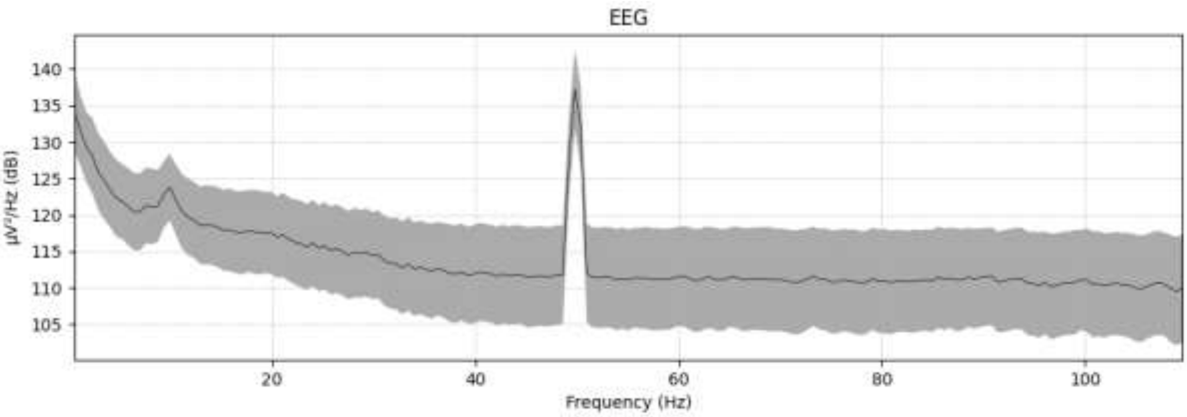

N_ave=17
1e6
EEG (108 channels)
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
µV
GFP
−0.2
−0.1
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

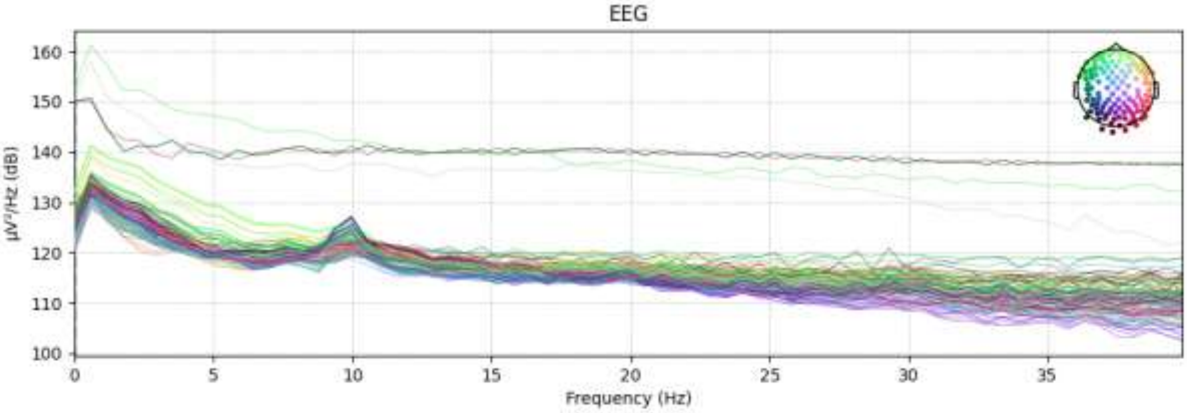




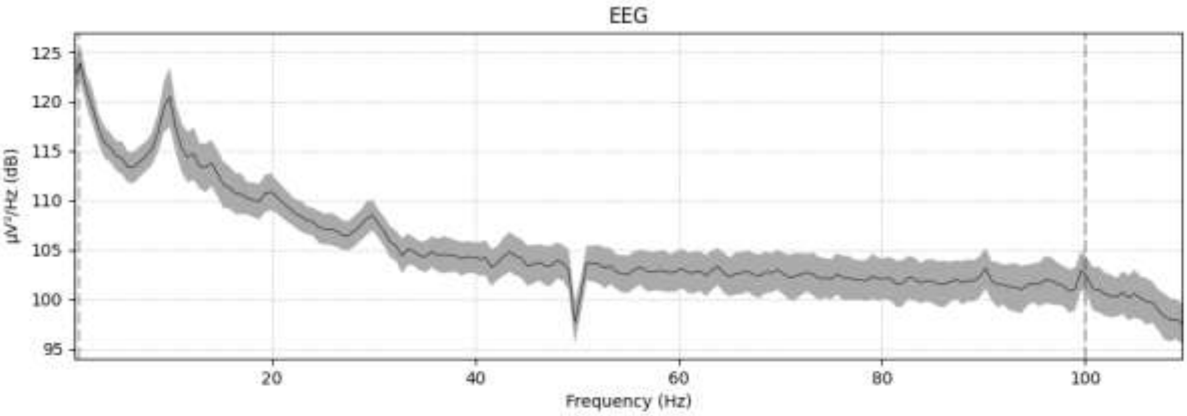
9. Time-frequency analysis: Time-frequency analysis was performed to investigate the changes in power across different frequency bands over time.
   For most of the other plots the power spectra plots are plotted along with eeg signals.

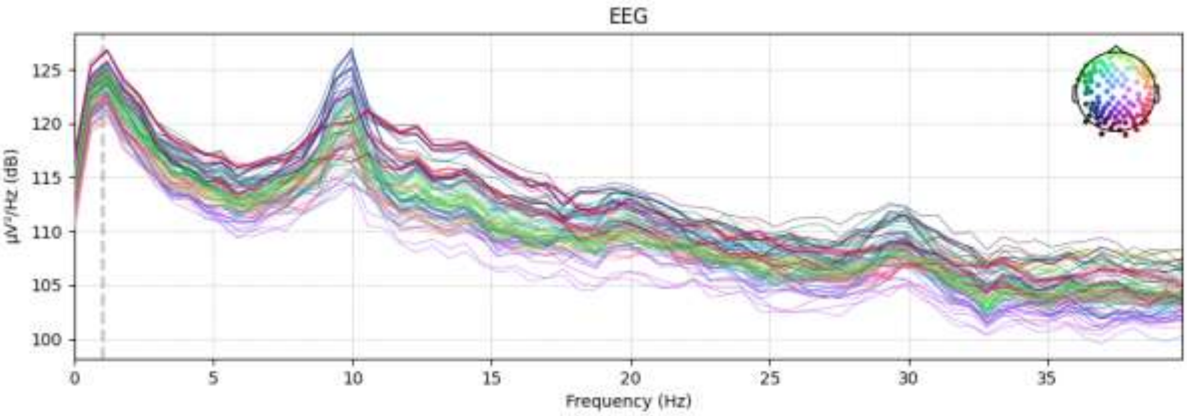
   Raw EEG



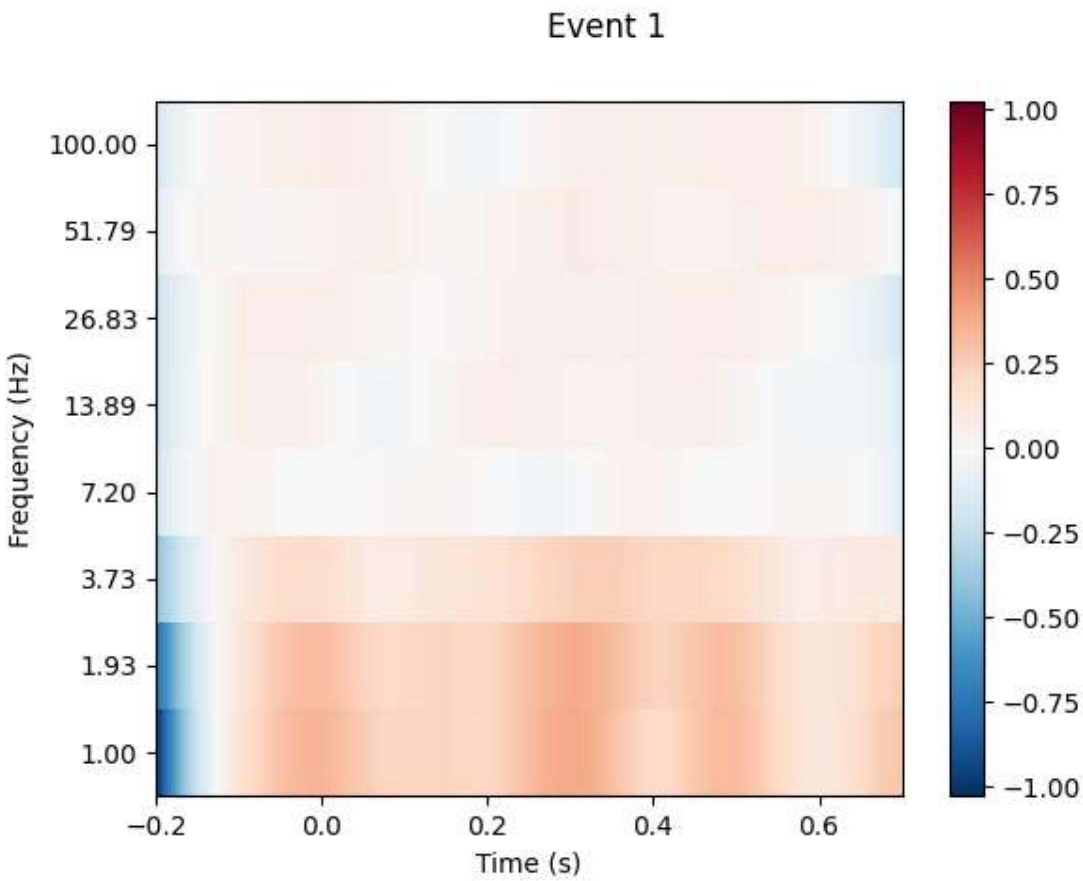


Cleaned EEG

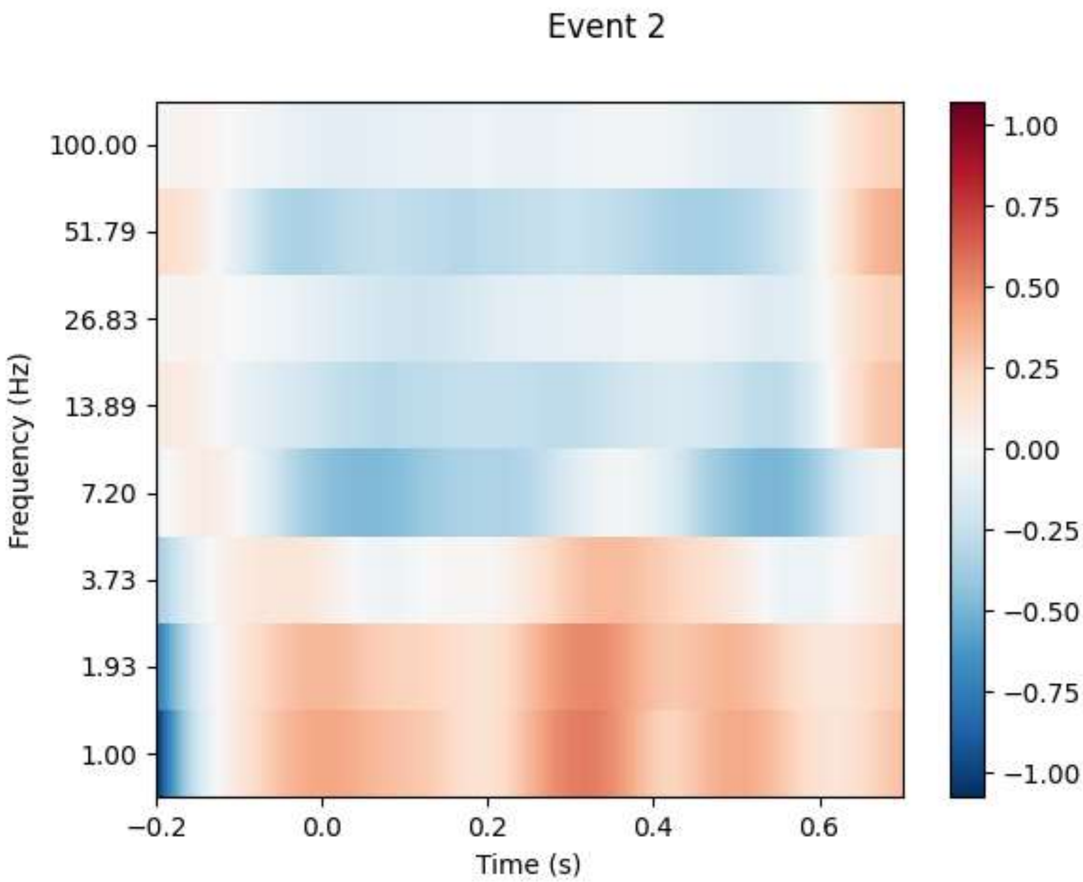




Stimulus Event 1 TFR



Stimulus Event 2 TFR



Results:

Our analysis revealed a significant increase in cortical excitability in the sensorimotor cortex, parietal, and frontal regions during the vibrotactile task compared to the baseline. The cortical excitability modulation was task-dependent, with different regions activated depending on the vibration frequency and intensity. Time-frequency analysis showed changes in power across different frequency bands over time, further supporting the task-dependent modulation of cortical excitability. We can see the higher power around 10Hz frequency this suggest the alpha oscillations are happening whenever there is stimuli. Also, the Power spectra follows the 1/f scale. The variation is power is quite huge for the raw data but it’s narrower for cleaned data. Also, from the event 1 and 2 plot we can infer that more activity is happening in case of event 1 which is normal stimuli. In the TFR of event 1 the power is relatively more than that in case of event 2, which shows we have more cortical activity happening when there is a regular stimulus compared to when there is sudden change in stimulus. 1/f nature is also visible in time frequency plots.

Conclusion:

The detailed steps in analyzing the EEG data using MNE-Python allowed for a comprehensive analysis of the effects of vibrotactile stimuli on cortical excitability. Using MNE-Python enabled us to perform ICA and time-frequency analysis, providing insights into the neural mechanisms underlying vibrotactile stimulation. Overall, our results contribute to a better understanding of the effects of vibrotactile stimuli on cortical excitability and provide a basis for future studies on the topic.

Discussion:

Our results indicate that vibrotactile stimuli modulate cortical excitability task-dependent, with different cortical regions activated depending on the vibration frequency and intensity. The observed increase in cortical excitability during the task is likely due to enhanced neural synchronization and increased processing of sensory information. The time-frequency analysis showed changes in power across different frequency bands over time, indicating that the cortical regions involved in processing vibrotactile information are dynamically modulated during the task.

The use of MNE-Python allowed for a comprehensive EEG data analysis and provided insights into the neural mechanisms underlying vibrotactile stimulation. The ICA analysis allowed for the removal of artifacts from the EEG data, improving the accuracy of our results. The epoch plots and evoked potentials showed task-dependent changes in cortical excitability, while the time-frequency analysis revealed changes in power across different frequency bands over time. These findings suggest that vibrotactile stimulation's neural mechanisms are complex and involve multiple cortical regions and frequency bands.

Overall, our results contribute to a better understanding of the neural mechanisms underlying vibrotactile stimulation and its effects on brain activity. Future studies could use a similar approach to investigate the effects of vibrotactile stimulation on individuals with neurological disorders, such as stroke or Parkinson's disease, to better understand the potential clinical applications of vibrotactile stimulation.