Sensorimotor Based Brain Computer Interface (April 2023)

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***Abstract*— Dr. Aysegul Gunduz provided Electroencephalography (EEG) data for two subjects who were asked to think about controlling the vertical movement of a cursor in the direction of a target. A Matlab program was developed to process the data utilizing Fast Fourier Transform (FFT) and obtaining r-squared values to determine appropriate frequency ranges in the EEG that are associated with the tasks that subjects complete. The brain activity is presented through a topo plot to highlight regions of the brain that exhibit the most activity when completing these tasks.**

***Index Terms*— Sensorimotor Rhythm (SMR), Brain Computer Interface (BCI), Fast Fourier Transform (FFT), r-squared**

I. Introduction

THE goal of this project was to develop a program in Matlab that would evaluate and highlight what regions of the brain are utilized when completing a one-dimensional sensorimotor rhythm (SMR) cursor control task. The data used to develop this program was collected at Wadsworth Center, Albany, NY and provided by Dr. Aysegul Gunduz. The data for the recordings were presented as 8 ".dat files" per subject with there being two subjects in total. Specifically, the data was collected utilizing BCI2000 software and an EEG cap which contained 64 channels at standard locations presented in Figure 1. The digitized sampling frequency was provided as 160 Hz. In addition, the letter associations for the EEG electrodes include: F for frontal, T for temporal, P for parietal, O for occipital, C for central.

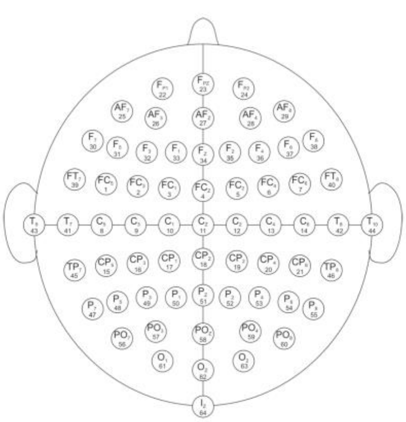

Figure 1: This diagram illustrates electrode locations and channel assignment numbers [1].

The task that the subjects completed caused modulation in their brain signals which would move a cursor up or down depending on the location of a target which was on the right-hand side of their screen and represented in Figure 2. Boxes 1-2 express how the user can control the cursor to go towards a target, box 3 shows that the target will display green if it is a successful hit, box 4 shows the blanks screen between trials, and box 5 shows a new trial starting in a different position. Note that the user only controls the up and down movement of the cursor, the horizontal direction movement is controlled by the program as they have approximately 4 seconds to complete the task.

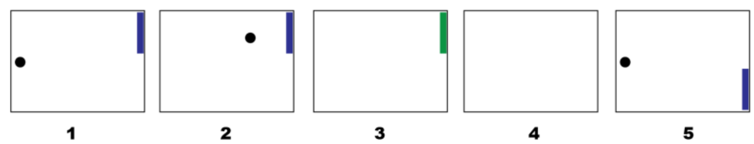

Figure 2: Task that was asked of subjects to complete utilizing brain modulation. (1) Represents start of a trial. (2) Shows the control of the cursor up towards the target. (3) Displays what a successful hit looks like. (4) Expresses the 1 second blank screen between trials. (5) Shows the start of a new trial [1].

When looking at this research, it is important to understand its significance and what it can be used for. To begin, SMR based BCI is a valuable method for collecting data for the purposes of trying to link brain activity to man-made devices [2]. This is valuable data that can be used for the millions of individuals who live with paralysis as this data could be used to create valuable neural prosthetics that can make their lives easier [3]. In order to make the data collected from EEG's useful for these purposes, a technique known as Fast Fourier Transform (FFT) is utilized to help obtain the power spectral density which is important for selecting desired EEG sample signals for analysis [4].

Furthermore, the activity of the brain is visualized by utilizing r-squared values which quantify the variation in brain activity between the two task conditions that the subjects complete [5].

Although the task of having a subject control the movement of a cursor up and down may seem insignificant, it is an important steppingstone for mapping functions onto the brain which can then be utilized to develop neural prosthetics.

II. Methods For SMR-Based BCI Mapping

The first step in this project was to compile all the data for a subject utilizing a "load_data" function and then extract the data

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from the structs provided that would be needed for analysis of trials.

After loading in the trials from the subjects, it could be observed that they did not complete all the trials with 100% accuracy. Therefore, in order to have useful data to analyze the trials that were incorrect should be removed from the data.

```
for i=1:big-1
    if states.TargetCode(i)~=0 && states.TargetCode(i+1)~=states.TargetCode(i)
        if states.TargetCode(i)==states.ResultCode(i)
            correct=correct+1;
        else
            states.TargetCode((i-920):1:i)=0;
        end
        count=count+1;
    end
end
```

(1)

(1) Shows the method used to determine which trials were inaccurate and remove them from the data. Specifically, the if statements look at the values of the "TargetCode" and "ResultCode" at the end of a trial. If the values at the end did not match, that would represent an incorrect/failed trial and would then replace all the values for that trial with 0.

After the data was filtered, it was placed into a matrix that consisted of 64 rows for each electrode used in collecting the EEGs and columns representing each time sample withing the 160 Hz sampling frequency, and this was done for each trial. In addition, it was separated into two separate matrices which represented the two movements that an individual would have to complete, which was up or down.

Within these matrices FFT would be completed for each channel in a trial. The 160-point FFT would be completed using 400ms time windows that would be repeated every 50ms. These FFT's would then be summed and averaged to get the desired FFT to be analyzed.

Following the completion of the FFT's, the r-squared values were calculated between the two target positions using the function "calc_rsqu" and plotted to determine the frequency range that presents the largest r-squared value difference.

This frequency range, along with the average of the r-squared values, is then utilized to plot an activity map that allows for visualization of what channels appear to be most active in a subject while performing a task.

III. Results

When processing the data for analysis one of the first elements to be monitored was the subject's accuracy when completing the tasks. From code *(1)* in the methods section, this was monitored utilizing counters which monitored the total number of trials (count) and the total number of correct trials (correct). For subject 1, the total number of trials was 143 and the total correct trials was 133 which resulted in 93% accuracy. For subject 2, the total number of trials was the same, but the total number of correct trials was 126 which resulted in an accuracy of 88.1%.

Following the processing of data, completing FFT's, and calculating the r-squared, this data was plotted for Subject 1 and 2 in Figure 3 with 0.4 being the max r-squared value for the color bar.

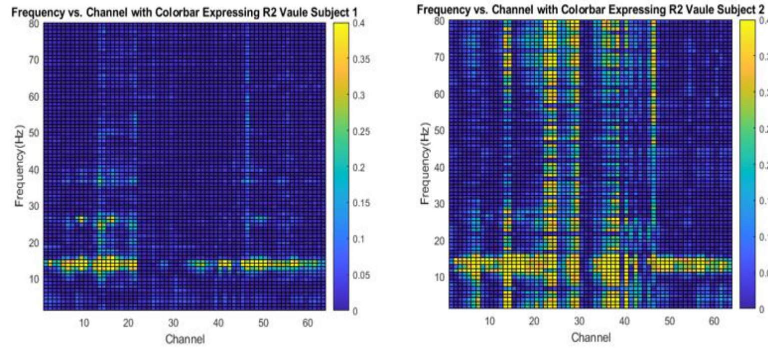

Figure 3: Graphs depicting Frequency vs. Channel plot with a color bar showing the respective R2 value for each cell. The left plot represents the values for Subject 1 and the right represents the values for Subject 2.

From Figure 3, it can be noted that the activity in subject 1 was significantly smaller with there only being a band of higher r-squared values between 11-15 Hz for the majority of channels. Subject 2's activity r-squared values appeared to be fairly high for the majority of the frequency values, and more present in specific channels. The r-squared values themselves represent the variation between the activity for a subject's cursor control for the two target positions. Therefore, subject 1's more distinguishable frequency band most likely represents the frequency that would be associated with the completion of the task and was utilized for the topo plot.

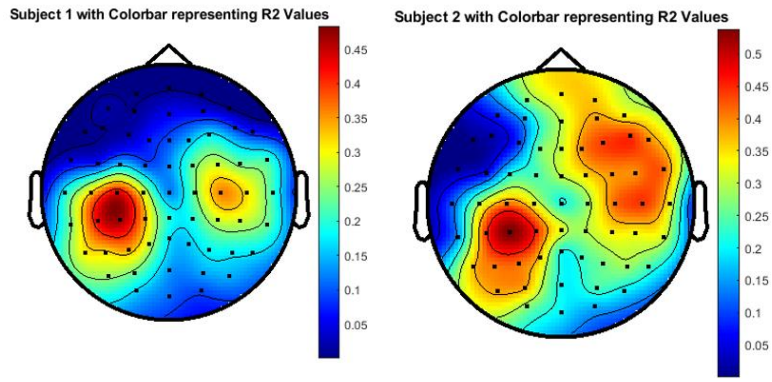

Figure 4: Topo Plots for Subject 1 (left) and Subject 2 (right) for the frequency range of 11-15Hz. The color bar represents the averaged r-squared values.

With the r-squared values being averaged across the frequency range of 11-15 Hz, the topo plots in Figure 4 were generated. From subject 1's plot, it appears that the tasks for this research resulted in the most significant activity occurring in: C5, C3, C1, CP5, CP3, and CP1 electrodes for the left hemisphere. For the right hemisphere the C4 electrode appeared to receive the most activity.

For subject 2, the range of significant activity appears to be significantly larger, especially for the right hemisphere. The right hemisphere has significant activity in: AF4, F2, F4, F6, F8, FC4, FC6, FC8, C4, and C6 electrodes. The left hemisphere had the most activity occurring within electrodes: CP5, CP3, CP1, P5, P3, and P1.

IV. Discussion

From the results, there is a clear difference in EEG activity between subject 1 and 2. Specifically, from Figure 4, the right hemisphere of subject 2 was 2-3 times as active as subject 1. This makes it difficult to distinguish what region of the right hemisphere associates with the completion of the tasks that were given to the subjects. This large variation across the hemisphere most likely correlates to subject 2 only having an accuracy of 88.1% compared to the 93% accuracy of subject 1. As a result of this information, it could be concluded that individuals with broader activity could find it more challenging to utilize SMR-based BCI since their information is more difficult to process and analyze.

When determining these conclusions, it is also important to highlight why certain parameters were selected for the analysis of this data. Specifically, the 0.4 r-squared value for Figure 3 and the Frequency range of 11-15 Hz.

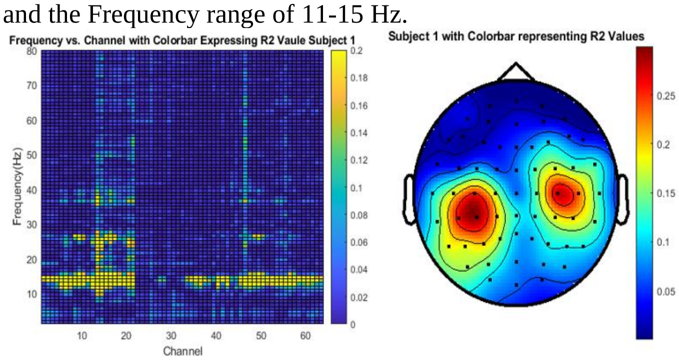

Figure 5: R-squared plot (left) and topo plot (right) for Subject 1 with a max r-squared value of 0.2 and frequency range of 9-17 Hz.

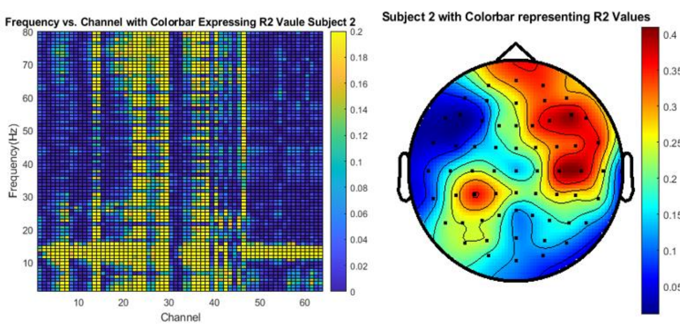

Figure 6: R-squared plot (left) and topo plot (right) for Subject 2 with a max r-squared value of 0.2 and frequency range of 9-17 Hz.

First, since the values for r-squared range from 0 to 1, the lower value of 0.2 was used for the color bar in Figures 5 & 6 to evaluate a frequency range. For the topo plot in Figure 5, the 0.2 appeared to be effective in selecting a proper frequency range of 9-17 Hz as there appeared to be 2 distinct regions of high brain activity for the tasks in subject 1. However, subject 2 appeared to have a significantly greater variability with more yellow regions in the r-squared plot making distinguishing a select frequency range challenging. In addition, approximately half of the EEG electrodes express activity in the subject's brain when using subject 1's frequency range (Figure 6). Therefore, the 0.2 r-squared value had too low of a tolerance for the frequencies in this analysis.

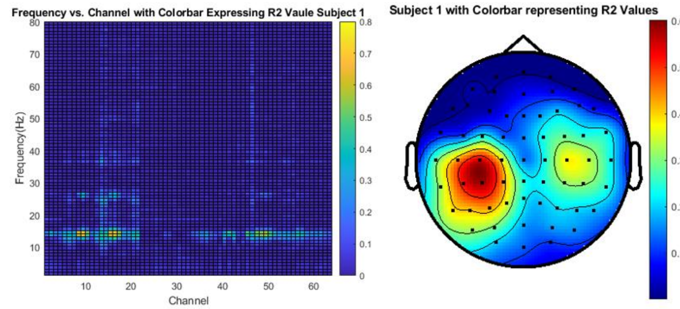

Figure 7: R-squared plot (left) and topo plot (right) for Subject 1 with a max r-squared value of 0.8 and frequency range of 13-15 Hz.

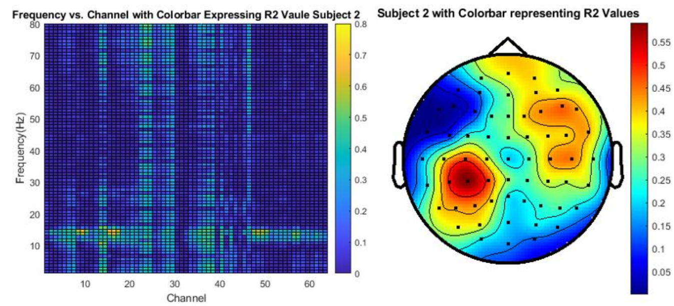

Figure 8: R-squared plot (left) and topo plot (right) for Subject 2 with a max r-squared value of 0.8 and frequency range of 13-15 Hz.

When looking at the higher r-squared value of 0.8, the tolerance appeared to be too high and very faintly presented a frequency band which in subject 1 was determined to be 13-15 Hz (Figure 7). This reflected in less activity being present in the topo plot for subject 1 and for subject 2. This would be more valuable when only assessing subject 2, but the necessity to compare the frequency ranges appropriate for each respective topo plot a middle value of 0.4 was determined to be most effective and are presented in Figure 3 & 4.

Ultimately, the use of SMR-based BCI is most effective when there are distinct regions of brain activity upon completion of a task. With more complex motor tasks, this could make the implementation of neural prosthetics more difficult and more efficient ways of organizing or separating data may need to be utilized to accomplish this.

References

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