# Power Spectrum Analysis of EEG Signals During Mental Arithmetic Tasks Using MATLAB

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*Received September 16, 2024*
*Accepted August 01, 2025*
*Electronic access September 15, 2025*

This paper investigates the prefrontal cortex in the brain while one is performing a mental arithmetic task. It was conducted to provide more information and to encourage further research on how the brain functions. Because there have been varying beliefs relating to which parts of the brain are acti- vated during mental cognition, this research aims to provide further insight into this idea. Data was gathered from an EEG dataset and was analyzed using the pspectrum function in MATLAB. A power spectrum analysis was performed to determine which electrode channels activated the most. The hy- pothesis was that there will be more activity in the frontal lobe than other areas. The hypothesis was correct, showing that channels in the frontal lobe had a higher power of non-alpha waves, indicating that higher activity was present in the prefrontal cortex during the arithmetic task when compared to other areas of the brain. Since pre-frontal cortex activity has been known to be associated with or- ganizational skills, this research may provide insight into the organizational aspects of mathematical tasks. However, this analysis method, the power spectrum, was unable to achieve unanimous results across all subjects, therefore further research on different analysis methods may be beneficial.

**Keywords:** Power spectrum, EEG, prefrontal cortex, mental arithmetic, MATLAB

## Introduction

Mathematical problems like mental arithmetic tasks activate cognitive reasoning and calculation. Though we try to separate them, these activities are strongly intertwined. For example, number ordering skills and even ordering the months of the year greatly influenced arithmetic performance[1]. Neuro imaging technologies like Functional Magnetic Resonance Imaging (fMRI, which gives a visual image of the brain and its locations of activity[2]. Electroencephalography (EEG), which measures the brain's postsy- naptic potentials[3], and other BCI's detect signals and patterns in the brain that can be measured and analyzed.

The four frequency bands: delta (1.5-3.5 Hz), theta (3.5-7.5 Hz), alpha (7.5-13.5 Hz), and beta (13.5-19.5 Hz) are the most common bands used in EEG analysis. Theta and delta were found to have been related to brain activation during working memory tasks[4], but in the back regions of the brain they have been associated with visual spatial tasks[5]. Alpha waves have been compared to attention and the exclusion of unwanted information[6–8] and the fast waves (beta and gamma) can be correlated with information transfer between regions[9]. Previous research has also shown that the power of alpha waves increases in meditation depth, and in contrast it decreases with cognition. Further, in theta waves the power de- creases when meditation deepens, therefore they increase when one is experiencing disturbances[10].

Previous research focused on the occurrences of alpha waves and came to the conclusion that alpha activity tends to decrease during cognitive tasks[11]. Furthermore, there is a direct correlation between brain activity and beta waves, implying that the increase in beta waves are a result of brain jogging[12]. Additionally, several imaging studies have concluded that arithmetic tasks have a direct contribution to the activation of the frontal and parietal cortices[13], with semantic behavior associated with the pari- etal region[14,15] and the working memory being a main cognitive process present during the solving of mathematical processes[16], It was also shown that subjects with a damaged frontal region had problems working with multiple pieces of information but were consistent with more straightforward arithmetic questions[17]. As a result, it was indicated that the dorsolateral prefrontal cortex was activated in two-step mathematical problems and not in one-step problems. Several studies have reported that simple math- ematical calculations triggered the activation of the parietal regions[18,19] but the frontal region started to become more involved and active once more difficult steps were needed[18,20,21], which could be due to an increase in demand of the working memory[22]. It was also shown that the left prefrontal-parietal cortex was activated in order to maintain multiple pieces of information[22]. Because of the difference in findings on which areas of the brain are correlated with arithmetic, this research aims to establish a clear difference in the prefrontal and parietal cortices during arithmetic tasks.

 

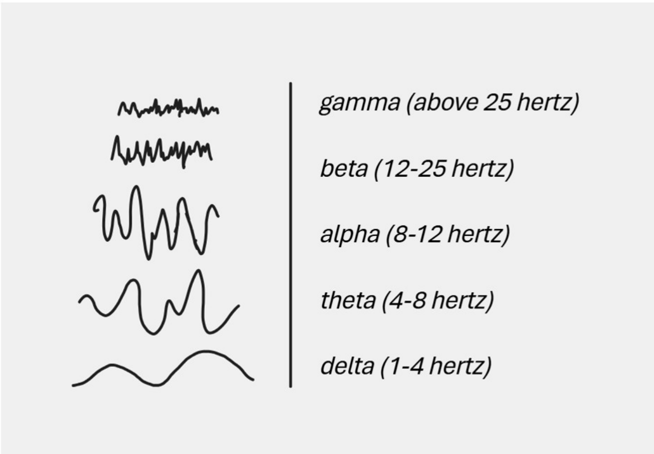


**Fig. 1** A rough drawing of the waves of the four main EEG bands

The purpose of this research is also to validate the reproducibility of similar studies that analyze the activation of different brain areas. We aim to use a different analysis method in order to provide an independent analysis of brain activity during mathematical tasks. MATLAB was used to analyze and visualize the power spectrum of the EEG signals before and during a mental arithmetic task.

### Power Spectrum and MATLAB

A power spectrum analysis is an important application of signal processing. Power spectrum density analysis quantifies how the intensity of a time-varying signal is distributed across the frequency domain. MATLAB was used to perform the power spectrum density analysis. A power spectral density analysis has been used to analyze various brain activities, espiecally in epilepsy and seizures[23]. How- ever, one has to be cognizant about the leakage effects of this analysis, where peaks with higher powers tend to leak into a neighboring peak with lower power[24]. The multitaper method was introduced as a solution to prevent leakage[25]. This study used the average power across the complete activity to minimize leakage effects.

## Results

Figure 2 is an example of the pspectrum plots for channels 1 to 7 on subject 1. In the graph in Figure 2, the left side represents the EEG waves *before* the task and the right represents activity *during* the task. Every channel was analyzed. The y-axis is the frequency in Hz, while the x-axis is the time in minutes. The colorbar on the right is power in decibels, with yellow being a higher power and blue being a lower power.

Data from 36 subjects was analyzed. The number of subjects that showed increased activity during the mental arithment task for each channel is shown in Table 1.

It can be seen that the channels associated with the prefrontal cortex (Fp1, Fp2, F7, F8) showed higher activity during the mathematical task, meaning that the subjects had the most activity in the prefrontal cortex rather than the parietal. Details about the electrode placement can be found in Methods.

In the example graph below, the left side represents the EEG waves before the task and the right represents activity during the task. Every channel was analyzed. The y-axis is the frequency in hertz, while the x-axis is the time in minutes. The colorbar on the right is power in decibels, with yellow being a higher power and blue being a lower power.

## Discussion

Looking at the gathered results, only 4 channels (Fp1, Fp2, F7, F8) were found to have significant activ- ity during mathematical tasks: Fp1 - 19 out of 36 subjects (52.7%) showed higher activity, Fp2 - 18 out of 36 subjects (50%) showed higher activity, F7 - 17 out of 36 subjects (47.2%) showed higher activity, and F8 - 19 out of 36 subjects (52.7%) showed higher activity.

Our results as to which channels are related to mental arithmetic both support previous research and presents a different idea from other research done in the field. Others observed that there is a develop- mental shift in brain activation from the pre-frontal lobe to the left-parietal with age[26], as children grow from ages 8 to 19[27]. When performing mental arithmetic tasks, our subjects, aged 16-26, showed more activity on the pre-frontal lobe symmetrical for both left and right sides.

Previous research indicates that the frontal cortex subserves domain-general processes of problem solv- ing, such as the structuring of multiple solution steps, whereas parietal cortex supports number-specific early encoding processes that vary as a function of problem size[28]. Our research supports this because the type of subtraction task used (4 digits minus 2 digits) requires some extent of organizational, non-straightforward thinking. To elaborate, one may need to decide and plan how to approach the subtraction problem. One may decide to subtract the tens digit first and units' digit later, while someone else may decide to subtract it in the reverse order. Or divide the number up in different ways to achieve the subtraction. For example, 2634 - 52 = 2600+34-(50+2) = 2550 + 32 = 2582.

However, not every subject had an increase in prefrontal cortex activity during the task — only around half of them did. It was considered that some subjects may be experiencing the shift from the prefrontal cortex to parietal, but after relooking at the ages of the subjects in which the 5 channels (Fp1, Fp2, F7, F8, Fz) had experienced 'higher' activity, even subjects of ages above 19 showed high prefrontal cortex activity and some subjects of ages less than 19 showed less activity in that area. It is possible that the subjects weren't putting much effort into the

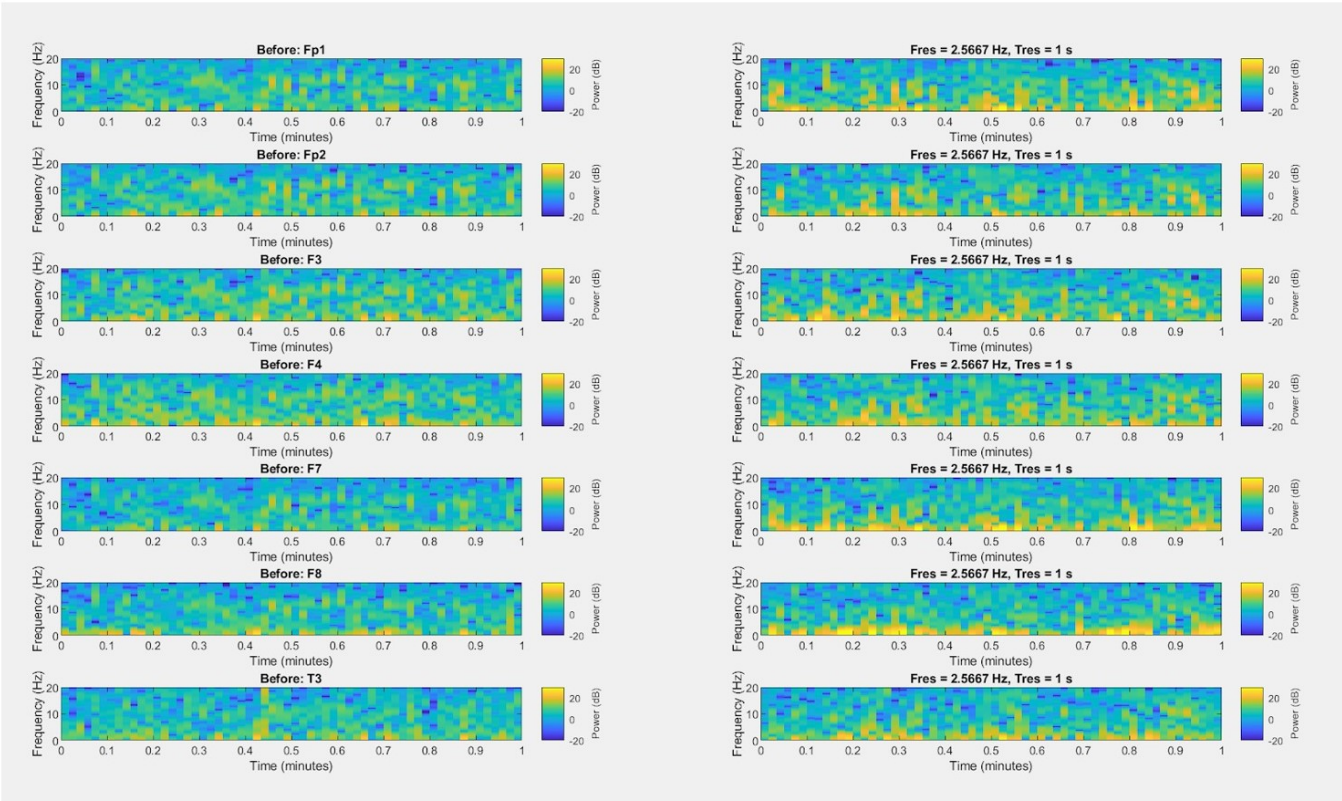


**Fig. 2** Spectrogram plot

**Table 1** EEG Channel Subject Distribution

| Ch 1–4 | # subj. | Ch 5–8 | # subj. | Ch 9–12 | # subj. | Ch 13–16 | # subj. | Ch 17–20 | # subj. |
|---|---|---|---|---|---|---|---|---|---|
| Fp1 | 19 | F7 | 17 | C3 | 6 | P3 | 4 | Fz | 11 |
| Fp2 | 18 | F8 | 19 | C4 | 5 | P4 | 5 | Cz | 3 |
| F3 | 10 | T3 | 4 | T5 | 9 | O1 | 5 | Pz | 5 |
| F4 | 10 | T4 | 11 | T6 | 9 | O2 | 6 | | |

task, or there is an issue with the analysis method, meaning that it was unable to capture detailed differences during the task.

## Materials and Methods

### EEG dataset

EEGs are recordings of mental activity of the brain via non-invasive electrodes on the surface of the scalp. Several electrodes are placed in different parts of the scalp, allowing specific electrodes to gather signals from specific parts of the brain. The gathered EEG waves are then analyzed for their frequency and power content.

The EEG data was gathered from Physionet Databases[29]. The data was recorded monopolarly using the Neurocom EEG 23-channel system, and the frontal, parietal, temporal, and occipital regions were accounted for with the use of 21 channels. A filter with a 30Hz cut-off frequency and a power line notch filter of 50Hz were also used to filter out frequencies greater than 30 Hz, and power noise of 50Hz. The Independent Component Analysis (ICA) was used to eliminate artifacts during preprocessing, such as eyes, muscle, and cardiac pulsation.

The arithmetic task was a subtraction task, where 36 subjects were required to subtract a two-digit number (such as 23) from a four-digit number (such as 3174).

Every participant solved the exact same mathematical problems. They were given 4 minutes to com- plete the task, and the number of problems solved in 4 minutes was recorded. However, upon receiving the dataset, it was seen that during the subtraction task, 3 minutes were recorded and before the task 1 minute was recorded. The participants were only accepted if they have a good vision, color vision, no mental or cognitive impairment, or any verbal disabilities.

The subjects are split into two groups:

- Group "G", who performed a **Good** quality count (The mean number of operations per 4 minutes was 21, standard deviation was 7.4).
- Group "B" performed a **Bad** quality count (The mean number of operations in 4 minutes was 7, standard deviation was 3.6).

### EEG Analysis

The EEG data was downloaded from Physionet Databases, from the "EEG During Mental Arithmetic Tasks" dataset in the European data format (EDF). The EEG data was recorded using electrodes and placing them in specific places around the brain to ensure coverage of the scalp. This is called the international 10/20 scheme (see Figure 3). The subjects were recorded two times: *before* and during a subtraction task. All subjects were recorded for one minute before the task, and 3 minutes during the task. Because data timings were inconsistent, we decided to compare the first minute for both recordings. Data was recorded with a sampling rate of 500 samples per second.

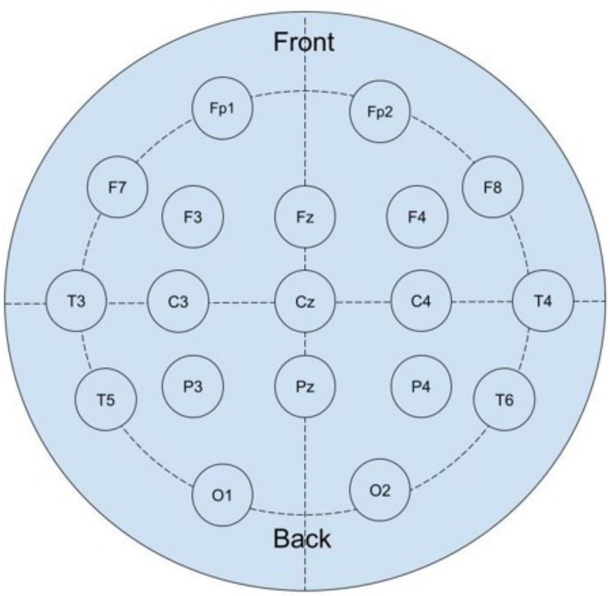


**Fig. 3** The international 10/20 electrode placement scheme

EEG analysis was performed using the pspectrum function in MATLAB. The parameters provided to the pspectrum function are detailed below.

```
pspectrum(data, sampling_rate, "spectrogram",
    'FrequencyLimits', [0,20], ...
    'OverlapPercent', 0, ...
    'MinThreshold', -20, ...
    'TimeResolution', 1)
```

- **data**: EEG data
- **sampling_rate**: 500Hz
- **FrequencyLimits**: The range of frequencies analyzed
- **MinThreshold**: Power over -20 dB is graphed
- **OverlapPercent**: No overlap was used to prevent leakage
- **TimeResolution**: Indicates the duration of segments over which the short-time power spectra is computed

The average power in the first minute was calculated using the `pspectrum()` and `bandpower()` MATLAB functions:

```
[p, f] = pspectrum(data, sampling_rate,
'power');
bandpower(p, f, [0,20], 'power')
```

After obtaining the average power, `if` statements were used to determine which graph—either the *before* graph or the *during* graph—had higher power. Results were organized in a spreadsheet.

A 10% error margin was considered for the analysis. That is, if the *before* and *during* values were within 10% of each other, they were considered equivalent and not meaningful.

MATLAB code and analysis data used in this research can be found at this[30] GitHub location.

## Conclusion

It was determined from this research that mental arithmetic is directly correlated to the frontal lobe activity. This supports research that indicates how working memory as well as other brain activators stimulate the prefrontal cortex. To expand on this research, studies can be made to thoroughly examine the parts of the brain that deal with specific aspects of mental cognition and investigate the difference in brain waves between word problems and arithmetic problems. Additionally, the analysis can be performed on different frequency bands to find any dependency of EEG signals across the different frequency bands when complex mental mathematical operations are performed.

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