Statistical Analyses of EEG data recorded to investigate cognitive differences between Individuals in a study context

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Declaration of Authorship

I hereby certify that the work presented here is, to the best of my knowledge and belief, original and the result of my own investigations, except as acknowledged, and has not been submitted, either in part or in whole, for a degree at this or any other university.

Neufeld

signature

Wolfsburg, 03.10.2020

city, date

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Abstract

The SIDDATA project is a multidisciplinary project aiming to develop a digital data-driven assistant to help students to achieve their academic goals. Based on EEG data recorded in a previous master thesis, it was investigated whether the well-studied phenomena alpha blockade can be observed in this dataset and whether there are differences in brain oscillations between the beginning and the end of an experiment. Therefore, a 2x2 within-subject analysis using a 2-way repeated measures ANOVA combined with Threshold-Free Cluster Enhancement to seek out clusters of significant differences between an eyes-open and eyes-closed condition on one hand and the beginning and the end of the experiment on the other hand was performed. The alpha blockade occurred in all subjects tested across a large amount of electrodes. Moreover, four out of six subjects showed a difference in brain oscillations between the beginning and the end of the experiment. The frequency band which most often showed a difference in brain oscillations between the beginning and the end of the experiment was the alpha band. As a first step towards helping students to achieve their academic goals as a part of the SIDDATA project, this thesis showed that an increased alpha activity might be an indicator of fatigue and decreased attention.

1.) Introduction

1.1) The SIDDATA Project

SIDDATA is a multidisciplinary project that is aiming to investigate how a digital data-driven assistant could be developed to support students to achieve their set academic goals based on their learning behaviors and data previously recorded from universities. This interdisciplinary project uses different approaches from Cognitive Science, Education Research, Business Information systems and Software Development. It is the role of the Neurobiopsychology lab which is a part of the Institute of Cognitive Science to measure attention in regard to processes of self monitoring and self organization. As an example of usage, the assistant in the future possibly will give feedback to a student indicating whether she is attentive based on electrophysiological data.

In a previous master project, Ökyü Bulca and Tahany Hmaid designed and implemented a test battery for the SIDDATA project aiming at characterizing study traits linked to academic success of the students based on both electrophysiological and behavioral measurements (Bulca, 2020; Hmaid, 2020). This thesis will utilize the electroencephalogram (EEG) measurements recorded by Ökyü Bulca and Tahany Hmaid in order to perform further spectral analyses on these recorded data and perform statistical tests with the aim to find differences between conditions in individual subjects. In particular, it will be investigated for these subjects whether there exists a difference in brain activity between different conditions under which EEG measurements were recorded.

1.2) Power Spectral Density

Spectral analysis is a method used to quantify an EEG signal. The power spectral density (power spectrum) is conceptualized as the distribution of power across frequency bands (Dressler et al., 2004).

In order to estimate the power spectral density of a signal at different frequencies, Welch's method is an approach often used in order to smoothen the power spectrum. In order to estimate the power spectral density, this method transforms the signal from a function of time to a function of frequency. In particular, first the signal is split up into segments of a specified length. In the next step, a window is applied to these segments (e.g. Hamming Window). Subsequently, a periodogram is calculated by using the fast fourier transform. As a last step, the squared magnitude of the result is computed. Finally, the individual periodograms are then averaged, such that the end result is an array of estimated power spectrum density per frequency bins (Cohen, 2019).

1.3) Alpha Blockade

One established phenomena which can be investigated using the power spectrum is the alpha blockade. The alpha blockade describes a change of power in the alpha frequency band upon eye closure/opening. To demonstrate this blockade, a person's brain activity is measured using EEG, while having the eyes opened or closed. The alpha activity is substantially reduced while the eyes of the subjects are open, i.e. the eye opening "blocks" the alpha activity (Krämer, 2005).

An example of how the alpha blockade can look like is shown in figure 1.

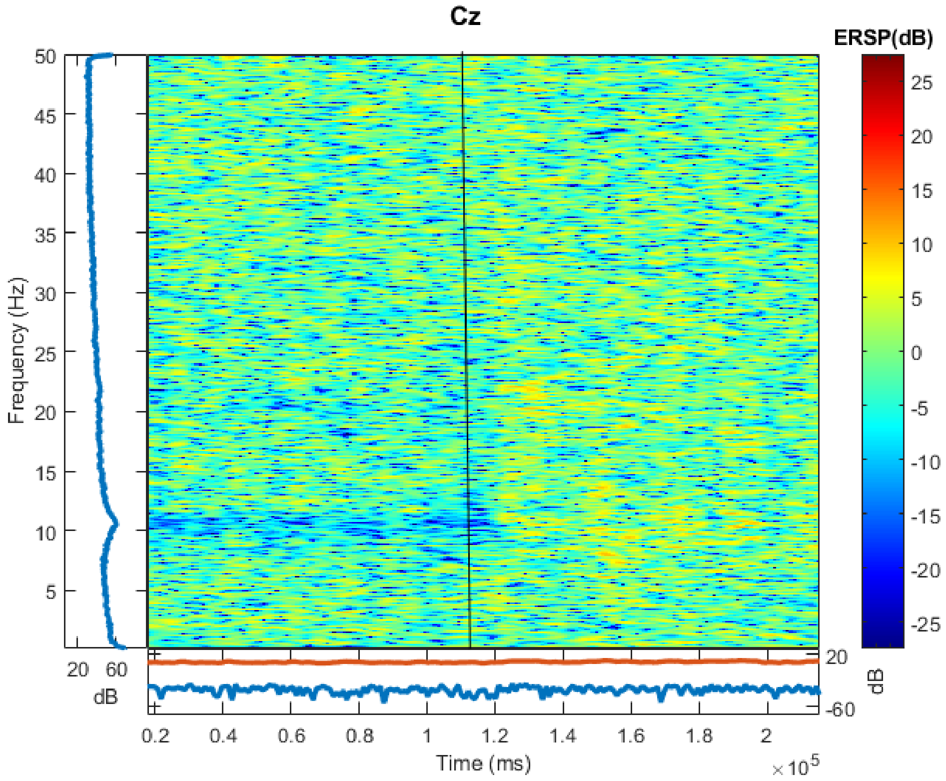

Figure 1: A visualization of the Alpha Blockade for electrode Cz in subject 2 in the beginning of the experiment. The figure plots time (ms) against frequency (Hz) and shows through the color bar the power at each time/frequency combination. The eyes-open condition was performed before the eyes-closed condition. In subject 2, the eyes-open condition had a duration of approximately 112 seconds and the eyes-closed condition had a duration of approximately 110 seconds. It is observable that around 10 Hz, the power is decreased in the eyes-open condition (0-112 seconds) compared to the eyes-closed condition (112-222 seconds).

To lay the groundwork for analysing oscillations in a recorded EEG dataset it was investigated whether this well-known phenomenon also occurs in this dataset.

1.4) Brain wave activity associated with Fatigue

A possible way to support students to achieve their academic goals would be to monitor when they are reaching a point of exhaustion and subsequently suggest them to take a break.

In order to quantify fatigue, EEG measurements can be considered as a reasonable approach. Craig et al. (2017) isolated 17 studies that have used EEG as a measure to capture the brain activity changes which occur when a person changes from an alert to an exhausted state. They summarized the 17 isolated studies as follows:

“Some conclusions from the 17 studies include: (a) Delta wave activity (examined in six studies)was found to increase significantly in four studies, decrease in one study, with no change in one study. The status of delta wave change associated with fatigue needs further examination. (b) Theta wave activity (examined in 16 studies) was found to increase signifi-cantly in 14 studies, with no change found in two studies. No studies found significant decreases in theta activity. Given these findings, it is likely that theta activity increases when a person fatigues; however, we do not know where in the cortex this occurs.(c) Alpha wave activity (examined in all 17 studies) was found to increase significantly in 15 studies and to decrease significantly in two studies. Alpha wave activity most likely increases when a person fatigues, although differences in activity between lower and upper alpha still require exploration, and regional differences need attention. (d) Beta wave activity change was examined in five studies, and it was found to increase significantly in two studies,decrease in one study, with no change found in two studies. The status of beta wave activity associated with fatigue remains unclear” (Craig et al., 2007, p. 574).

Since the experiment conducted by Ökyü Bulca and Tahany Hmaid had a duration of approximately 35 minutes and was cognitively demanding, it is expected that the subjects experienced mental fatigue and therefore it will be investigated whether changes in brain activity occurred at the end of the experiment compared to the beginning of the experiment.

1.5) Two-way repeated measures ANOVA

In order to compare differences of means between at least two groups (i.e. an eyes open and an eyes-closed condition), an Analysis of Variance (ANOVA) is commonly used. Differences of means between these groups are determined by comparing the amount of variation between groups with the amount of variation within groups. A repeated measures design is a research method that is often employed when multiple measurements are taken on the same subjects, but the time points or conditions between these measurements differ. Combining these both principles, a repeated measures analysis of variance (rANOVA) is employed. A two-way repeated measure ANOVA is often used when a dependent variable has been measured over two or more time points and two or more conditions. It is the main purpose to investigate the influence each of the factors (e.g. time and condition) has on the dependent variable (Lund Research Ltd, 2018).

1.6) Cluster Permutation Tests

In EEG analysis, due to the recording of many electrodes and many time/frequency points, it is often necessary to perform a statistical test on each of these (electrode/ time point / frequency point) combinations, which leads to a multiple comparison problem, as the probability of a false positive increased due to this combinatorial explosion. Corrections for multiple comparisons can provide nominal type 1 error rates, but increase the type 2 error rates, i.e. the probability of finding a true effect decreases (Sassenhagen and Draschkow, 2019).

It is possible to circumvent this problem by making use of the fact that neighboring electrodes and neighboring frequency/time points are not independent from each other via combining electrodes and frequency/time points that are close in space (neighboring electrodes) and the frequency/time domain (Ehinger, 2019).

Following this thought, the cluster size approach was introduced in order to include spatial information of the signal into statistical testing for significance. The idea of the cluster size approach is to calculate a test statistic (e.g. t-test), set an initial threshold on the data and calculate the number of neighboring samples (frequency points/time points) and electrodes which received a larger test score than this set threshold. Then, the null distribution is built by randomly relabeling the data under a large amount of permutations and recording the size of the maximal cluster under each of the permutation conditions. P-values for each cluster are then obtained by comparing the cluster size to the distribution built by the maximal cluster sizes which were obtained under each of the permutations (Mensen and Khatami, 2013; Ehinger, 2019).

Since the cluster size approach assigns more importance on the size of a cluster instead of the actual statistic scores each sample in the cluster obtained, the cluster mass approach was introduced as an attempt to improve on the cluster size approach. The cluster mass approach is based on the principle of first again calculating clusters above a certain threshold and then, for each of these clusters, adding up the values of the data points in the cluster instead of only the number of data points (Mensen and Khatami, 2013).

However, a major concern about the cluster size approach and the cluster mass approach is that to define a cluster, it is necessary to set an initial threshold value, which is somehow arbitrary. This threshold has to be set before data analysis in order to guarantee statistical validity. However, the choice of the threshold has a direct influence on the shape of the results. A too low threshold might lead to a single cluster formed over all time points / frequency bins, while a too large threshold might lead to no clusters being found at all (Mensen and Khatami, 2013; Ehinger, 2019).

1.7) Threshold-Free Cluster Enhancement

In order to improve the shortcomings of cluster permutation tests, i.e. setting a somehow arbitrary initial threshold, Threshold-free cluster enhancement (TFCE) was proposed by Smith and Nichols (2009) as a statistical method to quantify differences between groups while taking control of the false-positive rate (Mensen and Khatami, 2013). This method makes it possible to compare the differences in the power spectral density between conditions over all electrodes and frequency bands while at the same time controlling for the multiple comparison problem by using the permutation approach (Czeszumski et al., 2019).

The TFCE approach reduces the impact of artifacts which are reflected by very large test statistic values (e.g. t-score), but lack the support of neighboring data points which would be expected from real signals. Moreover, TFCE takes control of the multiple-comparison problem due to the permutation analysis it employs as each data point is just compared to the data-driven null distribution and the number of comparisons decreases significantly (Mensen and Khatami, 2013).

Threshold-free cluster enhancement attempts to make different kinds of signals directly comparably by enhancing the value of weaker signals which lie in broad clusters to a level comparable to large values in peakier clusters. This is done by first quantifying the difference between two groups based on some test statistic (usually t-tests are employed), setting a set of thresholds on these calculated values and counting the number of neighboring frequency/time points and electrodes which are above these individual thresholds. This number of samples/electrodes above the threshold is then multiplied with the current set threshold. The final TFCE score for each frequency point /time point is then calculated as a summation of each score the point received at the different set thresholds (Mensen and Khatami, 2013; Ehinger, 2019).

Mathematically, this principle can be formulated as:

$$\mathrm{TFCE} = \int_h e(h)^E h^H dh$$

where ‘e’ represents the amount of neighboring frequency points which are above a specific threshold and ‘h’ represents the set threshold value. Since measures of the cluster extent and cluster height are not directly comparable, they are weighted by parameters (in the above formula denoted as ‘E’ and ‘H’). The default choice for these parameters are ⅔ for the weighting of cluster extent ‘E’ and 2 for the weighting of cluster height ‘H’ (Mensen and Khatami, 2013; Ehinger, 2019).

1.8) Statistical Analyses of EEG data recorded to investigate cognitive differences in a study context

In this bachelor thesis, a 2-way repeated measures ANOVA combined with TFCE was performed in order to investigate significant clusters reflecting differences in the dataset in respect to the main factor eye condition (Eyes-Open Beginning and Eyes-Open End vs EyesClosed-Beginning and EyesClosed-End), the factor time condition (Eyes-Open Beginning and Eyes-Closed Beginning vs Eyes-Open End and Eyes-Closed End) and the interaction of these factors within each subject.

1.8.1) Eye condition Hypotheses

For the factor eye condition, it is expected that the alpha blockade occurs, i.e. for all subjects there will be a significant decrease in alpha activity when the eyes are open compared to when they are closed.

1.8.2) Time condition Hypotheses

Gharagozlou et al. (2015) showed that for sleep deprived drivers in a virtual reality experiment, there was a significant increase in the alpha power between the first and final 10 minutes of driving, which suggested that changes in the alpha power could be a good indicator of drivers fatigue. For the factor time condition, it is expected that there will be an increase for subjects in alpha activity in the end of the experiment compared to the beginning of the experiment, in line with the results of Gharagozlou et al. (2015).

2.) Methods:

2.1) Experimental Procedure

As already indicated, the EEG data used in this bachelor thesis are based on the experiments conducted by Ökyü Bulca and Tahanyi Hmaid. In this section (2.1.1.-2.1.4), the subjects participating in their experiment, the test battery, the experiment itself and the data preprocessing will be described based on the master theses of Ökyü Bulca and Tahany Hmaid (Bulca, 2020; Hmaid, 2020).

2.1.1) Subjects

The experiment upon which this bachelor thesis is based on was conducted by Ökyü Bulca and Tahanyi Hmaid with eight subjects (5 males, 3 females). They had an average age of 23.75 years with a standard deviation of 4.4 years. All of these subjects were required to have a good understanding of the English language. Moreover, based on self-reports, all subjects were healthy and did not have any psychological or neurological conditions. Before participating in the experiment, the subjects were informed about the study in a written document. Subsequently, in order to participate in the study, a written informed consent form had to be signed by each subject. For participating, the subjects received money or course credits (Bulca, 2020; Hmaid, 2020).

2.1.2) A test battery developed to characterize study traits

In order to measure different aspects of cognitive ability such as working memory, cognitive flexibility and long-term memory, the experiment carried out by Ökyü Bulca and Tahany Hmaid consisted of three paradigms: A 2-back task, a Task Switching Paradigm and Old/New Recognition Task. During the 2-back task, the subjects were presented with words and had to classify words as targets or non-targets. A target was defined as a word that is identical to the word and all words which did not match the one two steps back were defined as non-targets. The Task Switching Paradigm required the subjects to classify numbers between 1 to 9 as smaller/larger than 5 or even/odd. A horizontal line appearing either below or above a fixation cross indicated which task the subjects had to perform as the next task. In the Old/New Recognition Task, the subjects had to decide whether a presented word was seen before ('old') or not seen before ('new'). The words from the N-back task were defined as the old words. Half of these words served as target-words in the N-back task, while the other served as non-targets. Moreover, in the beginning and the end of the experiment, the subjects had to perform an eyes-open and an eyes-closed condition which served the purpose to identify eye artifacts occurring in the data. (Bulca, 2020; Hmaid, 2020).

During the eyes-open condition, a cross appeared on the center of the screen on which participants had to fixate for 120 seconds. After this, a sound was played on a speaker and the participants were instructed to close their eyes for 120 seconds in order to complete the eyes-closed condition. This whole procedure was done at the beginning and the end of the experiment. The experiment had a total duration of approximately 35 minutes. (Bulca, 2020; Hmaid, 2020).

2.1.3) Experimental Setup and Procedure

To record the EEG data, an EEG cap with pre-attached electrodes was placed on the head of the subjects. For the recordings, an international 10-20 system (ANT Neuro, Netherlands) was used. The ASALAB software (ANT Neuro, Netherlands) was used for the EEG recording. The data was collected using 64 electrodes. The electrode impedances were decreased below 10 kΩ by adding a gel to the connection between the electrodes and the skull. The signals were acquired using average referencing The subjects were seated in a darkened room in front of a monitor with a size of 24'' at a distance of 80 cm with a sound box placed below the display. The experiment was coded in MATLAB (version 2016b) using the Psychophysics Toolbox. The subjects were instructed to keep as still as possible, to fixate on the middle of the screen during the experiment and to answer as accurately as possible. The answers were given on a standardized English keyboard (Bulca, 2020; Hmaid, 2020).

2.1.4) EEG data Preprocessing

EEG data was preprocessed in MATLAB (version 2016b, The Mathworks, Inc.) using the EEGLAB Toolbox (version 14.1.1). After the raw EEG data was loaded, an acausal high-pass filter with a frequency of 0.1 Hz was applied. The data were downsampled from 1024 Hz to 512 Hz after the recordings. The continuous EEG data was visually inspected for each subject and noisy channels as well as noisy parts which were caused by muscle movements, drifts or irregular spiking activity were manually removed. Following this, an Independent Component Analysis (ICA) was performed, the ICA weights were applied to the data and components reflecting eye or muscle artifacts, line noise, channel noise and noise from trains were further manually selected and deleted from the data (Bulca, 2020; Hmaid, 2020).

2.1.5) Epoching of the data

Based on triggers which were indicating the beginning and the end of the Eyes-Open/Eyes-Closed condition, the data was manually epoched and seperated into the four conditions, which are relevant for this bachelor thesis: The Eyes-open condition in the beginning of the experiment, the Eyes-closed condition in the beginning of the experiment, the Eyes-open condition in the end of the experiment and the Eyes-closed condition in the end of the experiment. The removal of artifacts led to epochs of different length as well as to the removal of triggers which were necessary to define the eyes-open/eyes-closed conditions.

For subject one the necessary triggers to select the different conditions were lost, thus it was decided not to analyze the data of subject one. The same was true for subject 3, but only for the end of the experiment. Therefore, subject 3 was also excluded from the analysis since it could not be analysed further with the chosen statistical methods.

2.1.6) Partitioning the dataset into smaller Intervals

After manually selecting the Eyes-open conditions and Eyes-closed conditions, the continuous dataset was splitted such that trials with a length of two seconds were generated. Due to the different length the conditions had because of the earlier noise removal, there was an unequal number of generated trials for the conditions. Additionally, trials with discontinuity while partitioning the dataset were removed from further analysis.

In the end, a different number of trials was obtained for each condition (Eyes-Open Beginning, Eyes-Closed Beginning, Eyes-Open End, Eyes-Closed End). However, the toolbox used for the two-way repeated measures ANOVA combined with TFCE required an equal number of trials for each of the groups because this would speed up the computations dramatically. Therefore, as many trials were used as the condition with the lowest amount of trials allowed.

For subject 6, the length of the eyes-open condition and the eyes-closed condition differed greatly, since a lot of data was removed of the eyes-closed condition, both in the beginning and the end of the experiment. Since no triggers were lost and therefore it was still possible to select the conditions, it was decided to analyze the data of subject 6.

2.2) Power Calculations and Statistical Analyses

2.2.1) Power Spectral Density

In order to calculate the power spectral density, EEGLABs spectopo function was used, which employs Welch’s method to estimate the power spectral density at each frequency bin ranging from 0 to 256 Hz. A window length of one second and a fast fourier transform (fft) length of one second was used. The windows did not overlap.

2.2.2) Two-Way Repeated Measures ANOVA using TFCE

The analysis in this bachelor thesis was performed within each subject, i.e. it was investigated whether there exist differences regarding the power spectrum between conditions within each subject.

For each subject, the power spectrum was calculated for the frequencies ranging from 0-30 Hz for all trials and all electrodes. The power spectrum was calculated for all the four conditions for each subject.

A two-way repeated measures ANOVA was performed to employ a statistical test which extracts differences between eye conditions (Eyes-Open/Eyes-Closed) as well as differences between time conditions (Beginning/End of the experiment) and an interaction of these factors.

Subsequently, an individual F-value for each frequency/channel pair for all of the factors eye condition (Eyes-Open/Eyes-Closed), time condition (Beginning/End of the experiment) and interaction (interaction of these factors) was calculated using the ANOVA approach.

Threshold-free Cluster Enhancement (Smith and Nichols, 2009; Mensen and Khatami, 2013) was used for further analysis. To perform the analysis, the toolbox ept_TFCE-matlab was utilized (Mensen, 2015).

TFCE was performed on the frequencies ranging from 0-30 Hz and all electrodes simultaneously to compare the eyes-open and the eyes-closed condition in the beginning of the experiment in order to investigate whether there are significant clusters in the alpha frequency band showing the alpha blockade (hypothesis-driven analysis) and in addition to this to investigate whether there are significant clusters of electrodes showing significance at other frequency bands (exploratory analysis). Using the TFCE approach, an individual TFCE-value was calculated for each of the frequency/electrode pairs. The parameters $E = 0.66$ and $H = 1$ were used to calculate the TFCE-values.

For the factor time condition, the same procedure was followed to investigate whether there are power differences for any frequency band between the beginning and the end of the experiment and for the interaction of the factors eye condition and time condition.

In order to obtain p-values for each frequency/electrode pair, 5000 permutations were used and each of these data points was randomly assigned to a condition in order to build a null hypothesis. Following this permutation approach, an individual p-value was calculated for each frequency bin by comparing the individual TFCE-value of each frequency/electrode pair to the empirical null distribution of F-values which was built by the permutations.

This procedure was repeated for all electrodes and for all factors: The eye factor, the time factor and the interaction factor.

In the end, a matrix of p-values of dimension 3 (eye factor, time factor, interaction) x 31 (all frequencies) x 64 (electrodes) was obtained.

The interpretation of p-values which were calculated based on TFCE values and the null distribution built by the permutation does not support the interpretation of individual time/frequency points as significant, as significance could be reached due to two different reasons: Either there is a real significant difference between conditions for a particular frequency or the particular frequency is just close to frequency bins which show a real significant difference between conditions. (Sassenhagen and Draschkow, 2019).

Therefore, a cluster was defined as at least two neighboring frequency points which both reached significance, i.e. a p-value of < 0.05.

Since the alpha blockade typically occurs in the occipital lobe (Krämer, 2005), significant clusters which formed in the alpha frequency range for the electrodes O1, OZ and O2 were reported. To furthermore compare them to clusters for electrodes at different lobes, significant electrodes of the electrodes PZ, CZ and FZ were reported.

For each of these individual electrodes, the cluster size (in the figure 5 this would be 8-12 Hz), the median difference which occurred between the conditions at the frequencies in the cluster and the minimum and maximum difference which occurred in a significant cluster were reported.

Moreover, to get a broader visualization of at which frequencies differences between conditions (EyesOpen-EyesClosed, Beginning-End) occur, butterfly plots and topographical plots integrating the differences between conditions and the significant electrodes at each frequency are shown using a EEG visualization toolbox called “EEGVIS toolbox” written by Benedikt Ehinger (Ehinger, 2018). Therefore, the difference curves for each subject and each individual electrode was calculated across frequencies by averaging over conditions and subtracting these averages from each other.

For example, when calculating the difference between the eyes-open and eyes-closed condition for a subject, it was calculated an average for the eyes-open condition by averaging over the eyes-open condition in the beginning and the end of the experiment. The same was done for the eyes-closed condition and finally, to obtain the difference curve, the eyes-closed condition was subtracted from the eyes-open condition.

3.) Results

In the results section, the partitioning results, the calculated differences between conditions, the calculated F-values, the calculated TFCE-values and the calculated P-values for the factor “eye condition” of subject two will be given and discussed in detail. Furthermore, it will be discussed for six selected electrodes (O1,O2,OZ,P1,PZ,P2) at which frequencies clusters of significant results have formed, which was previously defined as neighboring frequency points receiving p-values < 0.05. All other subjects are discussed in less detail, but the same figures for all the other subjects can be found in the appendix.

3.1) Subject 2

3.1.1) Partitioning Results

In order to illustrate the proceeding of partitioning, the table 1 shows the latency, the generated trials, the deleted trials and the final number of trials of each of the conditions in the beginning and the end of the experiment exemplary for subject two. For instance, the eyes-open condition in the beginning of the experiment had a duration of 112.256 seconds, which resulted in 56 intervals with a length of two seconds for this subject. Since seven trials were deleted due to data discontinuity, the eyes-open condition in the beginning of the experiment finally had 49 trials. Following the same procedure, the eyes-closed condition in the beginning of the experiment ended up with 47 intervals, the eyes-open condition in the end of the experiment with 50 intervals and the eyes-closed condition in the end of the experiment with 47 intervals. Since the toolbox which was used as a tool for statistical analysis required all conditions to have an equal amount of trials, 47 trials were used for each of the groups. The number of trials for the subjects ranged from 40 to 60 for all subjects, except for subject six who had 14 trials in the eyes-closed condition in the beginning and 6 trials in the eyes-closed condition in the end. Similar tables for all subjects can be found in the appendix (table 5 - table 10).

Beginning

Condition	**Latency**	**Generated trials**	**Deleted trials**	**Final trials**
Eyes-open	112.256 seconds	56	7	49
Eyes-closed	110.51 seconds	55	8	47

End

Condition	**Latency**	**Generated trials**	**Deleted trials**	**Final trials**
Eyes-open	103.199 seconds	51	1	50
Eyes-closed	105.4 seconds	52	5	47

Table 1: This table shows the latency, the number of generated trials and the final number of trials for each condition for subject two.

3.1.2) Differences between the conditions “Eyes-Open” and “Eyes-Closed”

As a first step of the statistical analysis, the difference in power spectral density between conditions had to be calculated for all electrodes within a subject. Figure 2 illustrates the results which were obtained for subject two for the factor eye condition, i.e. it was compared the eyes-open condition in the beginning and end of the experiment to the eyes-closed condition in the beginning and end of the experiment. After subtracting the eyes-closed condition from the eyes-open condition, it is observable that a large difference between the conditions in the alpha band was obtained for many of the 64 recorded electrodes. In the alpha band, the difference curves for all electrodes except for electrode FT7 at 9 Hz with a difference of 0.4 dB (larger activity in the eyes-open condition compared to the eyes-closed condition), were negative for subject two. The maximum difference was found in electrode PO5 at 10 Hz with a difference of -13.5 dB.

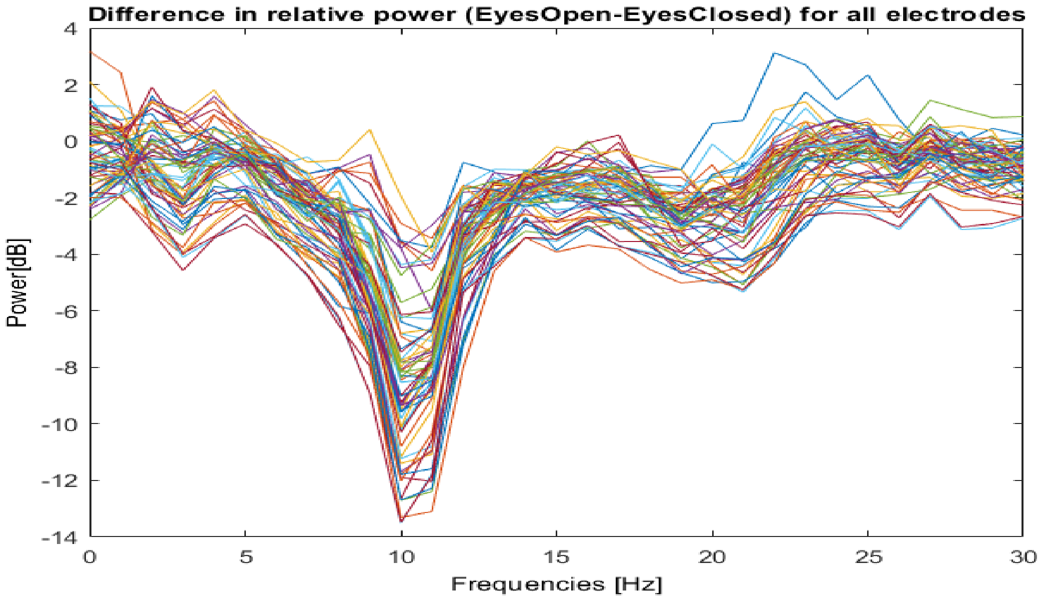

Figure 2: This figure illustrates the difference curve (EyesOpen-EyesClosed) for all electrodes for subject two. The figure plots frequencies (X-Axis) against difference in relative power (Y-Axis). It was obtained by averaging over the EyesOpen Conditions in the beginning and the end of the experiment and subtracting from it the average of the Eyes-Closed Condition in the beginning and end of the experiment for each electrode. It is visually observable that the largest difference for most electrodes occurs at around 8-12 Hz.

3.1.3) F-values

Based on the calculated differences, F-values were calculated for each individual electrode/frequency with the help of a two-way repeated measures ANOVA. As illustrated in figure 3, many electrodes reached very large F-values in the alpha band. Since F-values are defined to be non-negative, these F-values were positive, although the difference was negative after subtracting the eyes-closed condition from the eyes-open condition, as illustrated in figure 2. A maximum F-value of 508.58 was found at 10 Hz at electrode PO6.

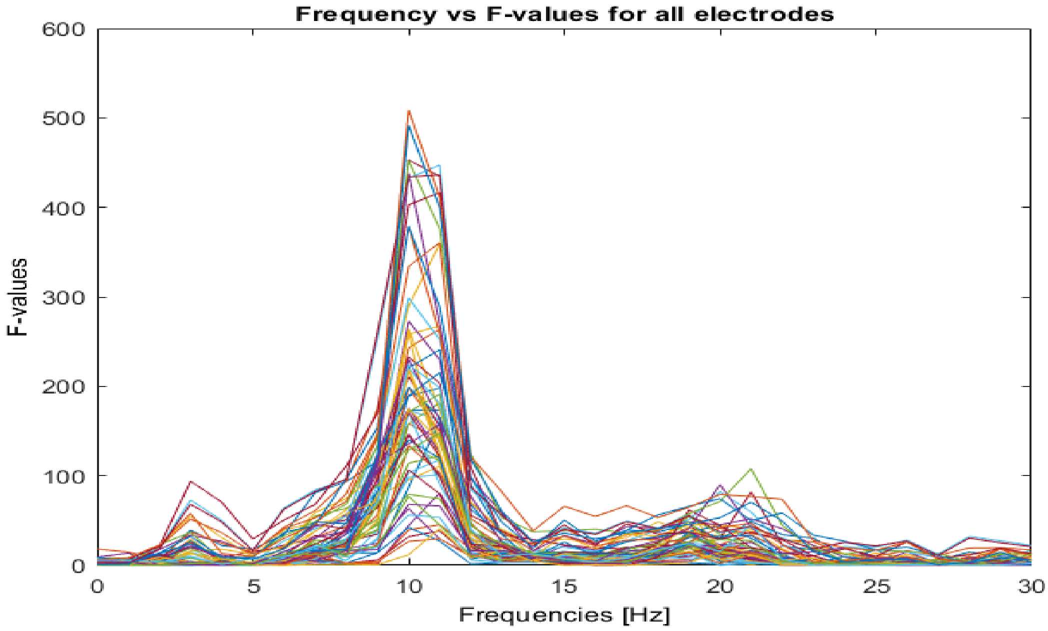

Figure 3: This figure illustrates the calculated F-values for subject two for different frequencies for all electrodes for the factor "eye condition" (Eyes-Open/Eyes-Closed). On the X-Axis, one can see the Frequencies from 0-30 Hz, on the Y-Axis, one can see the F-values for each of these frequencies. It is observable that the largest F-values occur in the alpha band.

3.1.4) TFCE-values

After the F-values were calculated as a test statistic for each individual electrode/frequency pair, these values were enhanced or suppressed which resulted based on the TFCE principle and subsequently resulted in individual TFCE-values for each electrode/frequency pair. In figure 4, it can be seen that electrodes generally reached very high TFCE-values in the alpha band, which was caused by the large differences which were observed at these frequency bins and subsequently the large test statistic scores (F-values), which were illustrated in figure 2 and 3. The maximum TFCE-value was found at electrode PO6 at 10 Hz.

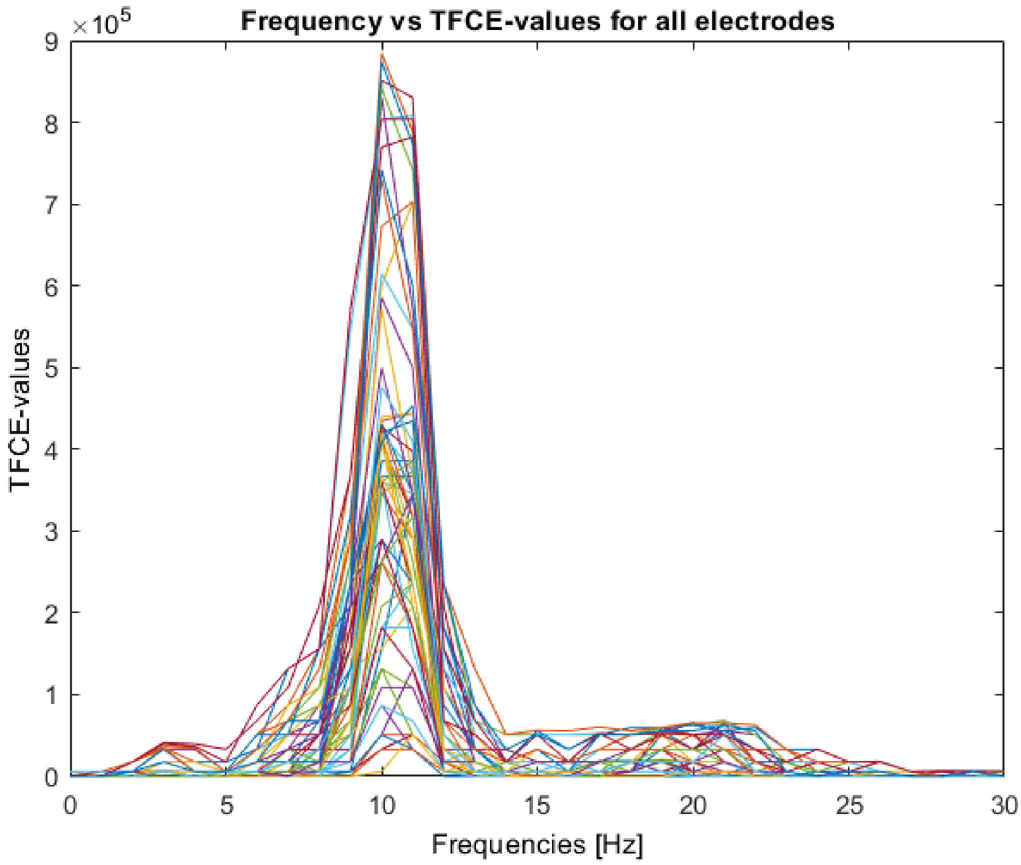

Figure 4: This figure shows the calculated TFCE-values for subject two at different frequencies for all electrodes for the factor “eye condition” (Eyes-Open/Eyes-Closed). On the X-Axis, one can see the Frequencies from 0-30 Hz, on the Y-Axis, one can see the TFCE-values for each of these frequencies. Comparable to the F-values, the largest TFCE-values for most electrodes occur in the alpha band

3.1.5) TFCE Results Visualization

Factor Eye Condition: Eyes-Open/Eyes-closed

The TFCE results indicate clusters of significant results for each factor and each condition based on the previous calculations of difference values, F-values and TFCE-values. As illustrated in figure 6, for subject 2 a lot of electrodes were showing significant differences between the eyes-open condition and the eyes-closed condition across all frequencies. Almost all of these electrodes having a significant difference between conditions show an effect which indicates that the power for the eyes-open condition is smaller than for the eyes-closed condition.

In the delta band at 0-2 Hz, there are only a few significant electrodes which are distributed over the whole head in small clusters of significant electrodes (i.e in the parietal-occipital lobe, namely the neighboring electrodes PO4 and PO6), but more electrodes showed a significant difference at 2-4 Hz in the higher delta band. In the theta band (4-8 Hz), there are some electrodes showing a significant difference between conditions in parietal and occipital regions at 4-6 Hz and many electrodes showing a significant difference between conditions from 6-8 Hz. The difference between the eyes-open and the eyes-closed conditions is the strongest in the alpha band and particularly strong at around 10-11 Hz, with a maximum difference between conditions of more than 13 dB occurring at the electrodes PO5 (10 Hz) with -13.5 dB, PO6 (10 Hz and 11 Hz) with -13.3 dB at 10 Hz and -13.09 dB at 11 Hz and PO7 (10 Hz) with -13.47 dB. In the low beta band, ranging from 12-22 Hz, electrodes distributed over the whole head show a significant difference between conditions. After 22 Hz, i.e. in the high beta band, mainly parietal and occipital electrodes remain to have a significant difference.

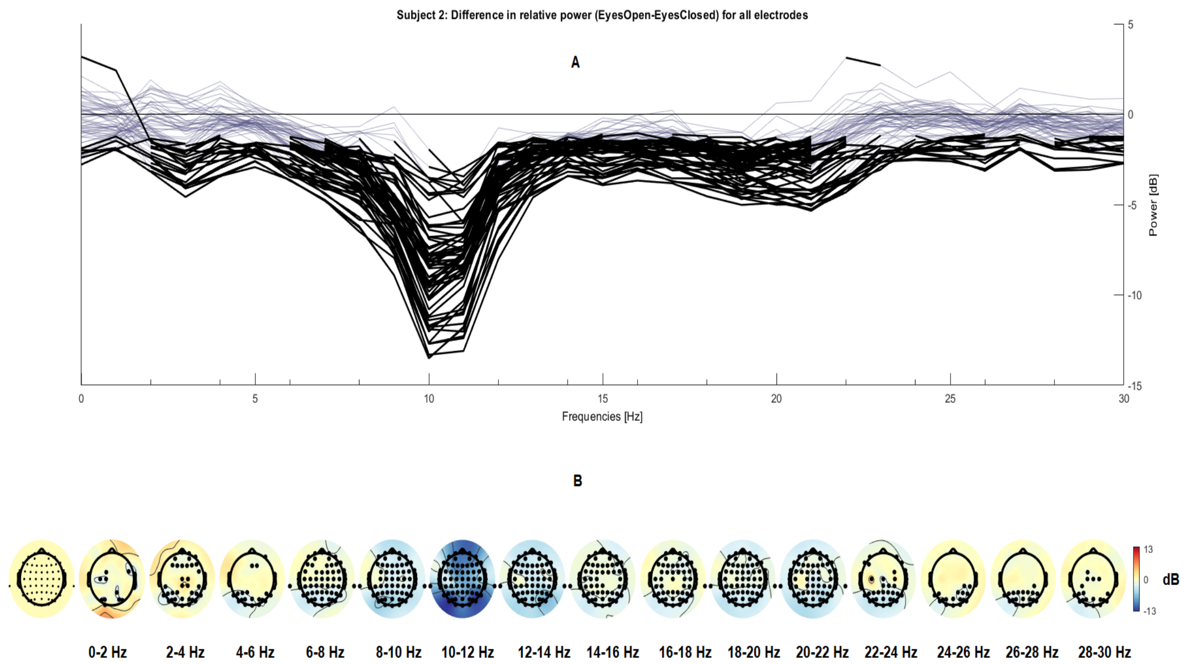

Figure 5: The figure illustrates the results of the TFCE analysis in subject two for the factor eye condition and consists of two parts. Part A illustrates the difference curve for each electrode after subtracting the eyes-closed from the eyes-open condition. The X-Axis represents the frequencies from 0-30 Hz, the Y-Axis shows the difference between the conditions in power given in dB. The bold lines indicate significant electrodes at a particular frequency. Part B shows topographical plots which show the difference in power averaged over 2 Hz. The significant electrodes are indicated by black dots.

For all the electrodes selected for further inspection, a significant cluster including the alpha band reflecting a difference between conditions has formed. For the electrodes of the occipital lobe, very broad clusters can be observed, ranging almost over the whole frequency spectrum (O1: 2-30 Hz, O2: 2-24 Hz, OZ: 3-30 Hz), while the electrodes FZ, CZ and PZ show clusters of significant frequency bins which are more closely centered around the alpha band (FZ: 8-12 Hz, CZ: 7-13 Hz, PZ: 6-13 Hz)The minimum difference observed in the alpha band cluster is comparably small in occipital electrodes (O1: -1.54 dB, O2: -1.39 dB, OZ: -1.28 dB) compared to the electrodes FZ (-2.89 dB), CZ (-2.25 dB) and PZ (-2.39 dB), while the maximum difference is larger in the occipital electrodes (O1: -9.53 dB, O2: -11.69 dB, OZ -10.15 dB) compared to the frontal (FZ: -9.82 dB), central (CZ: -8.44 dB) and parietal electrodes (-8.37 dB) which were further investigated.

Considering these individual electrodes, the minimum difference between conditions which belong to the significant cluster tends to be on the edge of the clusters for all electrodes, while the maximum difference is found at 10 Hz (see table 2).

Electrode	**Cluster range**	**Median difference**	**Minimum difference in Cluster (Frequency)**	**Maximum difference in Cluster (Frequency)**
O1	2-30 Hz	-2.91 dB	- 1.5 dB (2 Hz)	- 12.02 (10 Hz)
O2	2-24 Hz	- 3.32 dB	- 1.39 dB (24 Hz)	- 11.69 dB (10 Hz)
OZ	3-30 Hz	- 2.69 dB	- 1.28 dB (27 Hz)	- 10.15 dB (10 Hz)
FZ	8-12 Hz	- 5.96 dB	- 2.89 dB (8 Hz)	- 9.82 dB (10 Hz)
CZ	7 -13 Hz	- 3.72 dB	- 2.25 dB (7 Hz)	- 8.44 dB (10 Hz)
PZ	6-13 Hz	- 4.14 dB	- 2.39 dB (6 Hz)	- 8.37 dB (10 Hz)

Table 2: For each selected electrode, the cluster range shows the frequency clusters which have formed for this particular electrode, the median difference which occurs at this cluster, the minimum difference which occurs at this cluster, at which frequency this minimum difference can be observed, the maximum difference which occurs at this cluster and again at which frequency this difference can be observed.

Factor Time condition: Beginning/End

Comparing the beginning and the end of the experiment there were almost no significant differences found for any electrodes for the factor time condition (see figure 6). However, some electrodes in frontal central (FC2, FC6), frontal temporal (FT7, FT8), temporal (T7, T8), parietal (P5, P7) showed a significant difference between 0-2 Hz, indicating that these low frequencies belonging to the delta band had an increased power in the end of the experiment compared to the beginning of the experiment. The maximum difference in the delta band occurred at 0 Hz for electrode T8 (-5.21 dB). Moreover, at 26-30 Hz, i.e. the high beta band, electrode M2 showed a significantly larger activity in the beginning of the experiment compared to the end of the experiment with a maximum positive difference value of 3.23 dB at 28 Hz.

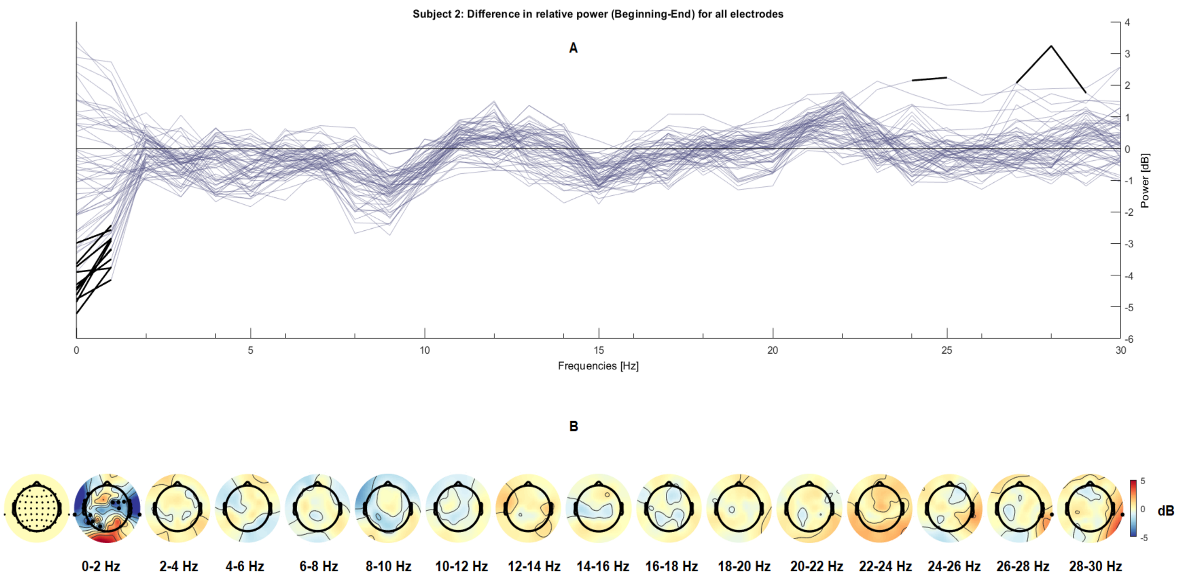

Figure 6: The figure illustrates the results of the TFCE analysis in subject two for the factor time condition and consists of two parts.Part A illustrates the difference curve for each electrode after subtracting the end from the beginning condition. On the X-Axis you can see the frequencies from 0-30 Hz, on the Y-Axis you can see the difference between the conditions in power in dB. The bold lines indicate significant electrodes at a particular frequency. Part B shows topographical plots which show the

difference in power averaged over 2 Hz and the significant electrodes in each of these 2 Hz frequency ranges, which are represented as dots.

3.2) Subject 4

Factor Eye Condition: Eyes-Open/Eyes-closed

The results for the factor eye condition are, in general, very comparable to the results of subject 2, except for the observation that for subject four at 0-2 Hz a cluster of significant electrodes has formed in the delta band (0-2 Hz) in the left temporal lobe. Since the results for the other frequency bands are very similar to subject two, as again a significant difference between conditions for many electrodes over a broad frequency range are found, they are not further discussed. Moreover, also the further inspected electrodes (O1, O2, OZ, FZ, CZ and PZ) showed similar patterns as subject two: For occipital electrodes, very broad clusters of significant neighboring frequency bins have formed, ranging from 2-30 Hz for the electrodes O1, O2 and OZ, while the electrodes FZ, CZ and PZ showed a cluster of significant neighboring frequency bins closer around the alpha band (FZ: 6-12 Hz, CZ: 2-12 Hz, PZ: 5-13 Hz). However, subject four differed from subject two regarding the factor time condition and the interaction effects. Therefore, these factors will be discussed in more detail. However, the butterfly plot and a table showing the results of the further inspected electrodes are given in the appendix (Figure 14, Table 11).

Factor Time Condition: Beginning/End

In contrast to the factor eye conditions, subject four differed from subject two regarding the factor time conditions, as subject two only showed differences between the beginning and the end of the experiment in the delta band, while subject four had differences between the beginning and the end of the experiment for all frequency bands. Almost all of the significant differences found showed an increase in power at the end of the experiment compared to the beginning of the experiment. The only electrode which formed a cluster of significant frequency points indicating that the power spectrum at the beginning of the experiment was larger compared to the end of the experiment was electrode AF3 in the delta band at 0-1 Hz. Other than that, a lot of electrodes (parietal, occipital, central and frontal electrodes) showed a significant difference reflecting an increase in power at the end of the experiment with a maximum difference of -9.31 dB at electrode P5 (0 Hz). At 4-6 Hz, which is defined as the low theta band, clusters of electrodes showing a significant difference have formed in the temporal lobe. At 8-13 Hz (alpha band), almost all electrodes distributed over the head show a significant difference between conditions and a maximum difference between conditions is reached at 8 Hz in electrode C3 (-4.85 dB). In the beta band, differences for a lot of electrodes ranging over the whole head were found at 16-20 Hz and 22-26 Hz. Ranging from 26-30 Hz, a cluster of electrodes in the left temporal lobe has formed.

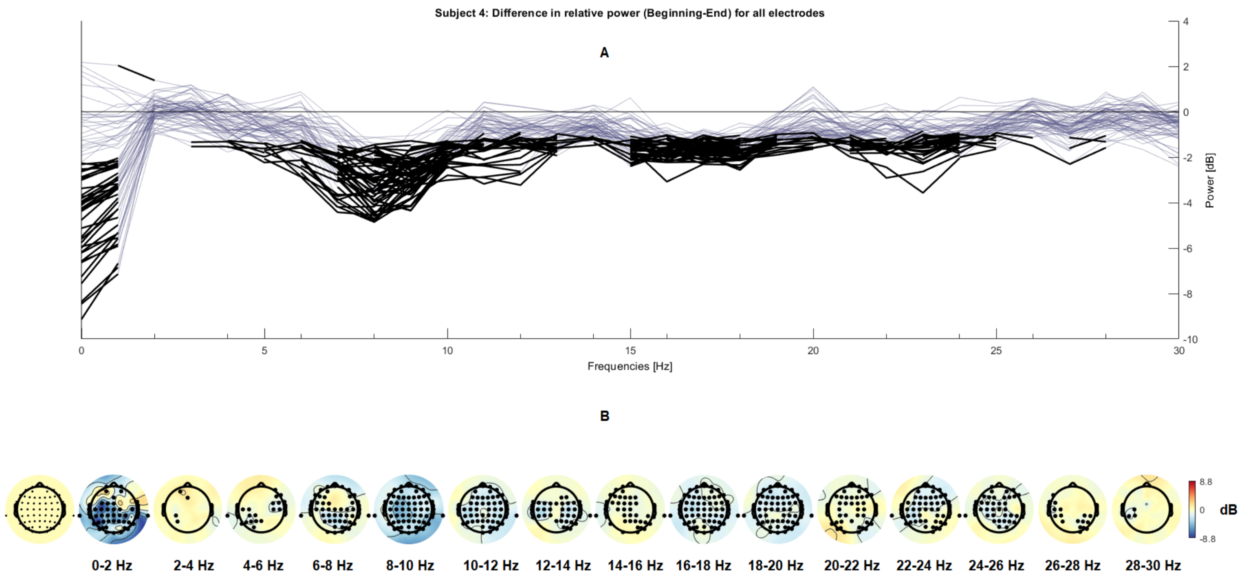

Figure 7 : The figure illustrates the results of the TFCE analysis in subject four for the factor time condition.

Interaction Effect:

For electrode FZ, an interaction effect in the alpha band most compatible with an effect ranging from 9-11 Hz was noted. For the electrode CZ, the analysis revealed a significant cluster for the interaction effect ranging from 10-15 Hz (alpha band to beta band) and 19-20 Hz (beta band). For electrode PZ, three significant clusters at 8-9 Hz (alpha band), from 11-13 Hz (alpha band) and from 20-23 Hz (beta band) occurred. For the electrode O1, a significant cluster from 20-21 Hz (beta band) has formed. For the electrode O2, two clusters reflecting interaction effects from 8-10 Hz (alpha band) and from 22-23 Hz (beta band) were found. For the electrode OZ, the analysis revealed two clusters ranging from 9-10 Hz (alpha band) and from 19-23 Hz (beta band).

3.3) Subject 5

Factor Eye condition: Eyes-open/Eyes-closed

As illustrated in figure 8, for subject 5, in the delta band at 2-4 Hz, there are only the electrodes PO4 and PO6 which showed a significant difference between conditions at this frequency band, showing an increased delta activity at the eyes-closed condition. In the theta band, a few electrodes, located in parietal and temporal brain regions, showed a decrease in the theta power in the eyes-open condition compared to the eyes-closed condition at 4-8 Hz. Moreover, a high fraction of the 64 recorded electrodes were significant in the alpha band forming clusters between 8-13 Hz distributed over the whole head. It is observable that the largest effect occurs in the alpha band (10-12 Hz) in figure 8. The largest difference between conditions was reaching more than -13 dB after subtracting the eyes-closed from the eyes-open condition. More precisely, the electrodes P6 (-13.59 dB), P8 (-13.11 dB), PO7 (-13.21 dB) and PO8 (-13.84 dB) all reached a difference of more than -13 dB between conditions at 10 Hz. In the theta band, at 12-14 Hz many electrodes show an effect and are distributed over the whole head. The electrodes P6, P8, PO4, PO6 and PO8 form a cluster of electrodes which show an effect from 14-16 Hz. In the theta band, the frequency band for which the most electrodes show a significant difference between conditions is at 20-22 Hz.

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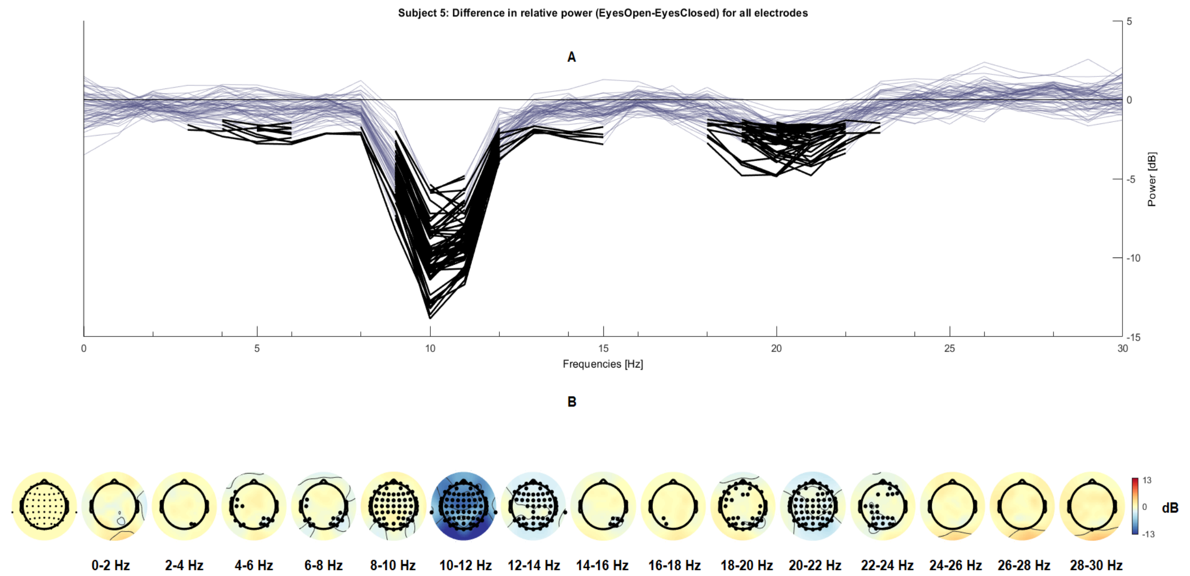

Figure 8: The figure illustrates the results of the TFCE analysis in subject five for the factor eye condition.

Table 3 shows that for the electrodes O1, O2, OZ, FZ, CZ and PZ, a cluster of significant neighboring frequencies reflecting significant differences have built in the alpha band. In contrast to subject 2 and 4, the clusters of neighboring significant frequency points for the occipital electrodes are centered close around the alpha band (O1: 9-12 Hz, O2: 9-12 Hz, OZ: 9-12 Hz) instead of ranging over the whole frequency range, as it was the case for subjects 2 and 4.

Electrode	**Cluster range**	**Median difference**	**Minimum difference in Cluster (Frequency)**	**Maximum difference in Cluster (Frequency)**
O1	9-12 Hz	- 9.19 dB	- 3.45 dB (12 Hz)	- 12.72 dB (10 Hz)
O2	9-12 Hz	- 8.36 dB	- 3.7 dB (12 Hz)	- 12.36 dB (10 Hz)
OZ	9-12 Hz	- 7.56 dB	- 3.38 dB (12 Hz)	- 10.44 dB (10 Hz)
FZ	9-12 Hz	- 6.77 dB	- 2.16 dB (12 Hz)	- 9.96 dB (10 Hz)
CZ	9-12 Hz	- 7.22 dB	- 2.06 dB (12	- 11.32 dB (10

			Hz)	Hz)
PZ	10-12 Hz	- 5.35 dB	- 2.11 dB (12 dB)	- 7.24 dB (11 dB

Table 3: The table shows the cluster range, median difference, minimum difference (frequency) and maximum difference (frequency) for subject five in the eyes condition.

<u>Factor Time condition: Beginning/End</u>

In subject 5 for the factor time condition, there aren't any significant differences found across frequencies and electrodes except for the electrode F6 which showed a difference between conditions at 0-2 Hz in the delta band and the electrode CP1 at 0-4 Hz, in the delta band too. Both these electrodes showed a larger beta activity in the beginning of the experiment than in the end of the experiment (see figure 9).

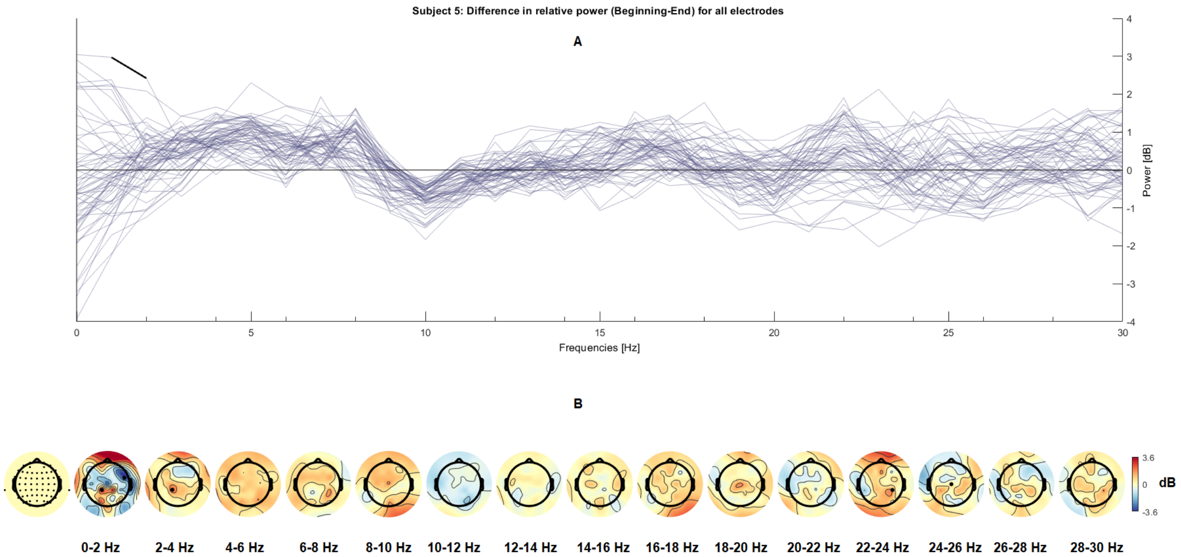

Figure 9: The figure illustrates the results of the TFCE analysis in subject five for the factor time condition.

3.4) Subject 6

<u>Factor Eye Condition: Eyes-Open/Eyes-closed</u>

In the lower delta band at 0-2 Hz, the electrode FT8 was the only electrode which showed a difference between conditions, in particular from 0-1 Hz. Additionally, electrodes in parietal-occipital brain regions reached significance from 2-4 Hz (PO4, PO5, PO6, PO7) and 4-6 Hz (i.e. PO5, PO6, PO7). The highest number of electrodes showing a significant difference in the theta band was found at 6-8 Hz, primarily occurring in parietal, temporal and central electrodes (see figure 10) and reached a maximum difference of -7.48 dB at 6 Hz in electrode T8. Moreover, a difference between conditions for the largest amount of electrodes comparing all frequency bands was found in the alpha band and reached more than -11 dB found at 9 Hz at the electrodes FC2 (-11.29 dB), P7 (-11.85 dB), P8 (-11.39 dB), P5 (-11.05 dB), PO7 (-11.11 dB) and PO8 (-11.05 dB). In contrast to subjects 2,4 and 5, the analysis revealed that subject 6 did not show any significant difference for any electrode in the beta band between the eyes-open and the eyes-closed condition, as it can be seen in figure 10.

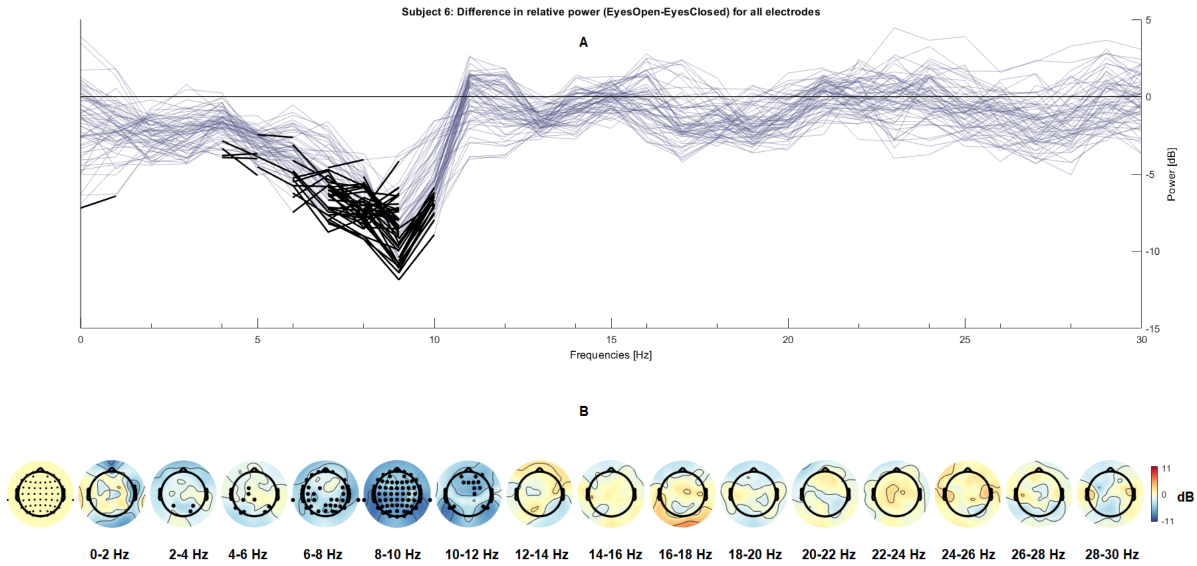

Figure 10: The figure illustrates the results of the TFCE analysis in subject six for the factor eye condition.

Similarly to subject 5, the electrodes O2, FZ, CZ and PZ did not form a cluster of significant frequency bins which spanned over the whole investigated frequency range, i.e. they did not show an effect for each individual frequency bin ranging from the delta to the beta band. However, a difference to the other subjects can be seen, as the electrodes O1 and OZ did not show any effect in the alpha band (see table 4).

Electrode	**Cluster range**	**Median**	**Minimum**	**Maximum**

		difference	difference in Cluster (Frequency)	difference in Cluster (Frequency)
O1	No cluster	/	/	/
O2	8-9 Hz	- 8.73 dB	- 7.45 dB (8 Hz)	- 10.02 dB (9 Hz)
OZ	No cluster	/	/	/
FZ	9-10 Hz	- 8.51 dB	- 6.4 dB (10 Hz)	- 10.62 dB (9 Hz)
CZ	8-9 Hz	- 8.21 dB	- 6.73 dB (8 Hz)	- 9.7 dB (9 Hz)
PZ	6-9 Hz	- 7.31 dB	- 4.8 dB (6 Hz)	- 7.79 dB (8 Hz)

Table 4: The table shows the cluster range, median difference, minimum difference (frequency) and maximum difference (frequency) for subject six in the eyes condition.

Factor Time Condition: Beginning/End

There were found no significant differences between the beginning and the end of the experiment for any frequency (see appendix for Figure 15 showing the butterfly plot and topoplot for subject 6).

3.5) Subject 7

Factor Eye condition: Eyes-open/Eyes-closed

The performed analysis revealed significant differences between conditions in the delta band primarily in frontal and central electrodes which indicate that the power density was smaller for the eyes-open condition compared to the eyes-closed condition. However, at 2-8 HZ, i.e. ranging from the high delta band to the theta band, the direction of the effect changes, as electrodes in frontal and central brain regions show a significant increase in the eyes-open condition compared to the eyes-closed condition. In the alpha band at 8-13 Hz the power for the eyes-open condition is smaller than in the eyes-closed condition, which can primarily be observed in central, temporal and parietal-occipital electrodes. The maximum difference between conditions in the alpha band occurs at 10 Hz in electrode PO6 (-3.72 dB). In the low beta band at 12-18 Hz, parietal and occipital electrodes show a difference between conditions (a decrease of beta activity in the eyes-open condition compared to the eyes-closed condition). A lot of electrodes distributed over the whole head reached significance at 18-22 Hz indicating a decreased power for the eyes-closed condition compared to the eyes-open condition as well. Moreover, the maximum difference between conditions of -4.69 dB was found at 19 Hz for electrode P6.

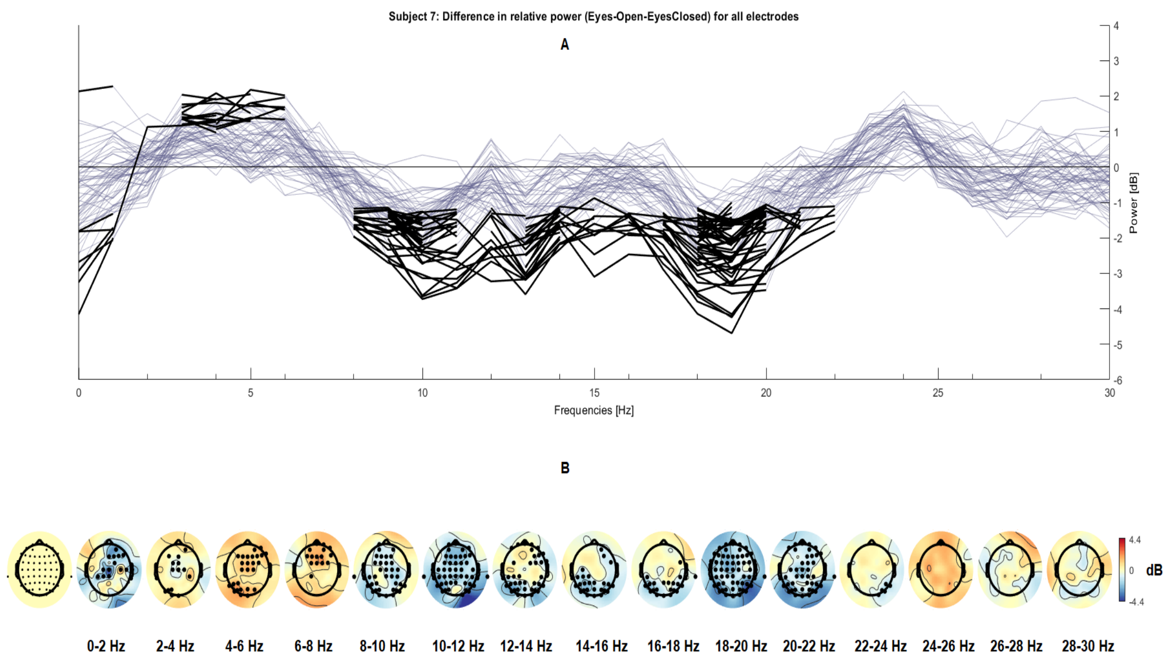

Figure 11: The figure illustrates the results of the TFCE analysis in subject seven for the factor eye condition.

Comparable to subject 5 and 6, the electrodes O1, O2, FZ, CZ and PZ formed a cluster in the alpha band, which did not range over a broad frequency range. The table 12 (appendix) shows more detailed information about these electrodes.

<u>Factor Time condition: Beginning/End</u>

For the main factor time, in the delta band a difference between the conditions beginning and end of the experiment reflecting an increase of power in the beta band at the end of the experiment compared to the beginning of the experiment was found for electrodes CPZ and P6. In addition to this, the maximum difference between conditions of more than -4.8 dB was reached which was found at 0 Hz for electrode P6 (-5.32 dB). In the alpha band, at 10-12 Hz, electrodes distributed over the whole head showed a significant difference between conditions maximum difference between conditions of -4.38 dB at 11 Hz (electrode CP3). In the beta band, a cluster of significant neighboring electrodes was found at 12-14 Hz in the central and left temporal lobe and at 20-24 Hz in the temporal lobe, also showing an increase in power at the end of the experiment.

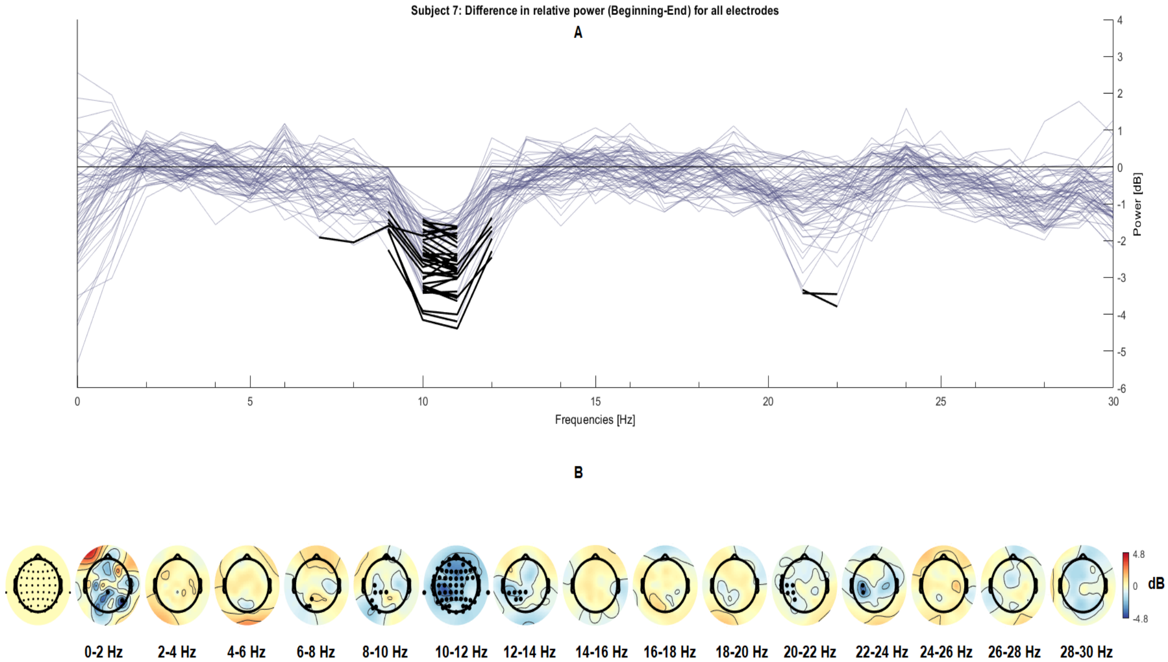

Figure 12: The figure illustrates the results of the TFCE analysis in subject seven for the factor time condition.

3.6) Subject 8

Factor Eye Condition: Eyes-open/Eyes-closed

A decrease of power was found at 2-4 Hz for the electrode POZ and for the electrode PO4. At 4-6 Hz in the low theta band, the electrodes P1 and P3 showed a significant decrease of theta activity in the beginning of the experiment compared to the end of the experiment In the high theta band from 6-8 Hz significant differences are occurring in a lot of electrodes distributed over the whole lobe. The same effect was found for the alpha band which showed a decrease in alpha activity in the eyes-open condition compared to the eyes-closed condition with the largest difference between conditions occurring at 8-10 Hz. The maximal difference in the alpha band occurred at 10 Hz for the electrode PO5 (-4.17 dB). Interestingly, for the beta band, different directions of effects occurred: Both, a decrease of beta activity in the eyes-open condition between 16-18 Hz (primarily in frontal regions) and 24-30 Hz (frontal and parietal/occipital regions) and an increase of beta activity for the eyes-open condition at 12-16 Hz and 18-22 Hz (temporal, occipital and parietal regions) was found (see figure 13). Moreover, the largest difference between conditions occurred at electrode PO6 at 26 Hz (4.93 dB) and 27 Hz (4.98 dB) which showed a larger beta activity at these frequencies in the eyes-open condition.

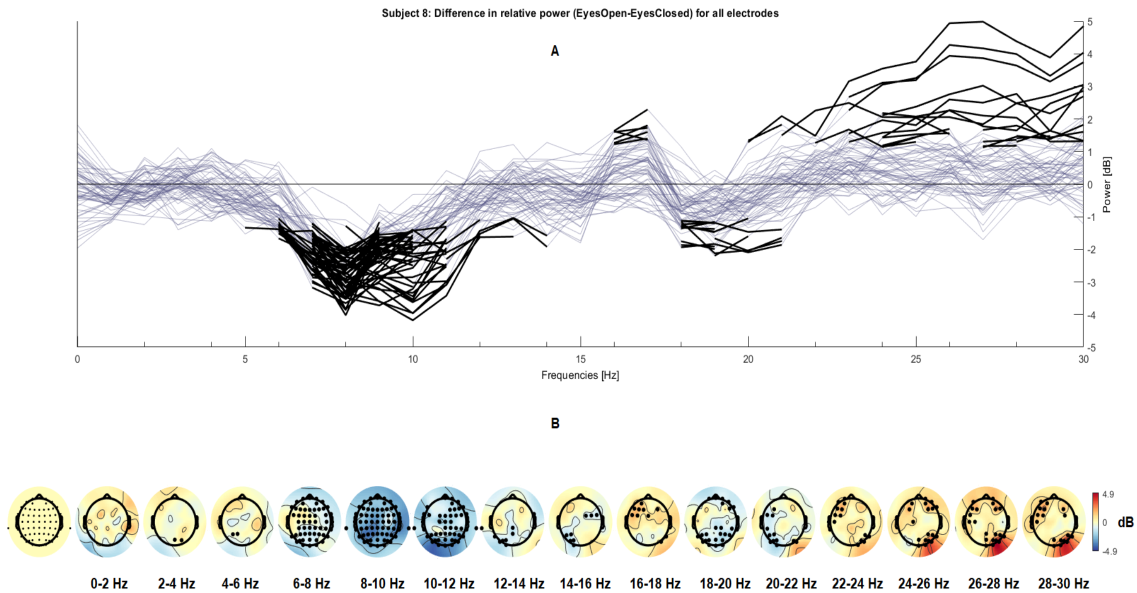

Figure 13: The figure illustrates the results of the TFCE analysis in subject eight for the factor eye condition.

<u>Factor Time Condition: Beginning/End</u>

For the factor time, an increase in delta power was found for the electrode F4 ranging from 0-1 Hz, which also showed the maximum difference between conditions (4.18 dB), showing a larger activity at the beginning compared to the end. For the alpha band, a significantly larger activity at the end of the experiment primarily for electrodes at the frontal, central and temporal lobe occurred. The maximum difference in the alpha band occurred at 11 Hz for electrode C4 (-3.72 dB). Additionally, the analysis revealed differences in the beta band ranging over a broad frequency range. The maximum difference between conditions in the beta band occurred at 28 Hz for the electrode PO7 (-3.8 dB).

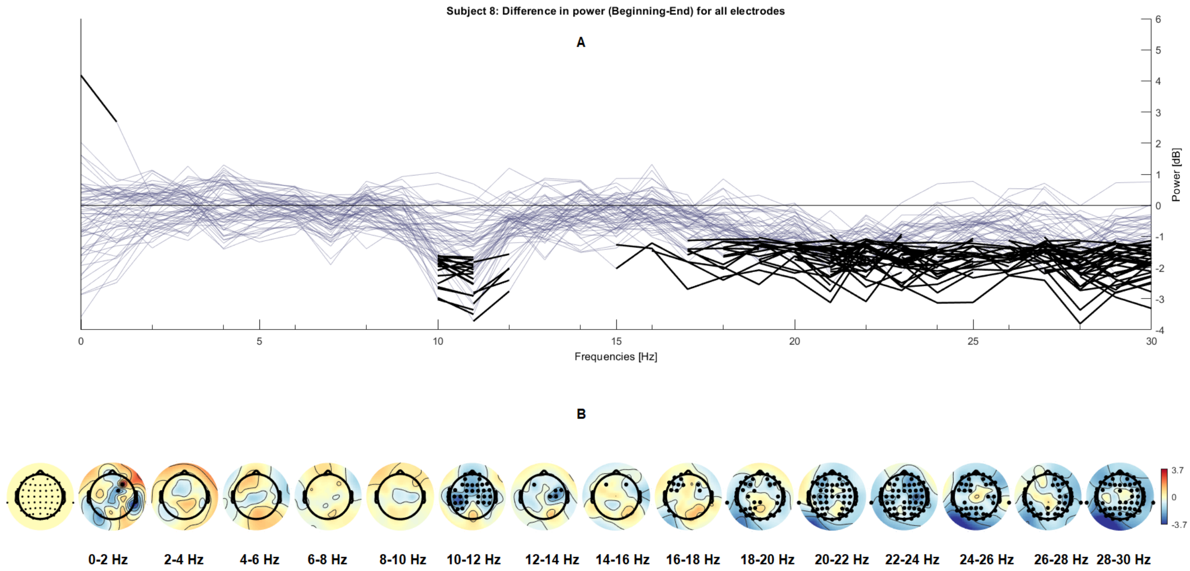

Figure 14: The figure illustrates the results of the TFCE analysis in subject eight for the factor time condition.

4.) Discussion

In this bachelor thesis, a recorded EEG dataset was examined using a two-way repeated measures ANOVA combined with Threshold-Free Cluster Enhancement including permutation analysis. As the main factors, the eye condition with the levels eyes-open and eyes-closed and the time condition with the levels beginning and end of the experiment were analyzed. Moreover, the interaction of these factors were investigated.

The analysis performed in this bachelor thesis showed that a well-studied phenomena, the alpha blockade, can be proven for all subjects based on the EEG recordings of eyes-open and eyes-closed conditions which both lasted two minutes and was repeated in the beginning. As expected, for all subjects, significant clusters reflecting differences in the alpha activity have formed in the alpha band. The alpha blockade occurred across electrodes for all subjects. Besides the alpha band, differences for the eyes-open vs eyes-closed condition were found in other frequency bands as well. This might be explained by the fact that TFCE was used as a statistical method and very significant and strong differences might have “pushed” very small differences in other frequency bands to significance, as the neighboring relation used for TFCE was defined as neighboring frequency points.

Jung et al. (1997) showed that changes in the EEG power spectral density accompany changes in the alertness state of subjects. Gharagozlou et al. (2015) showed that for sleep deprived drivers in a virtual reality experiment, there was a significant increase in the alpha power between the initial and final 10 minutes of driving, which suggested that changes in the alpha power could be used to detect drivers fatigue. Since the subjects in the experiment conducted by Ökyü Bulca and Tahanyi Hmaid had to perform exhausting cognitive tasks and therefore mental fatigue was expected, similar results were hypothesized before the experiment for the factor time condition. In line with this expectation, the frequency band for which a difference between the beginning and the end of the experiment occurred for the highest number of subjects was the alpha band indicating that we seem to indeed be able to measure fatigue in some subjects.

The executed analysis showed differences between the beginning and the end of the experiment. The initial expectation,namely that the alpha activity increases at the end of the experiment, was confirmed for a subset of the subjects. Three subjects (subject 4,7 and 8) showed an increase in alpha activity at the end of the experiment. A possible explanation why subject 2, 5 and 6 did not show any difference in alpha activity between the beginning and the end of the experiment might be the fact that the duration of the experiment (35 minutes) was too short to exhaust the subjects significantly. Future work in the SIDDATA project could possibly investigate whether there is a change in alpha activity in the brain of the subjects after a longer duration of studying. This could be achieved by including more cognitive tasks to the test battery which would further exhaust the students and examine which frequency bands show a difference between the beginning and the end of the experiment.

Craig et al. (2012) summarised previous research investigating the relationship between mental fatigue and electrophysiological measurements. They showed that studies also found a relationship between mental fatigue and different frequency bands than the alpha band. In line with this summary, two subjects (subject 2, subject 4) showed an increase in delta activity at the beginning of the experiment, one subject (subject 4) showed an increase in theta activity at the end of the experiment, three subjects (subject 4,7 and 8) showed an increase in alpha activity at the end of the experiment and two subjects (subjects 4 and 8) showed an increase in beta activity at the end of the experiment. Given these results, the SIDDATA project should not only examine possible differences in alpha activity before and after students perform cognitive demanding tasks, but also investigate different frequency bands.

In order to determine mental fatigue, different measurements can be applied. These different methods can be described as subjective, psychological, performance and physiological methods (Gharagozlou et al., 2015). For the SIDDATA project, it would be an interesting approach to combine EEG measurements with subjective methods to measure if students are attentive while studying or not. Previously employed subjects methods by researchers are standard questionnaires such as F-vas or the Karolinska sleepiness scale (Gharagozlou et al., 2015). Following this approach, brain waves could be compared between a time frame in which students feel attentive against a time frame for which students do not feel attentive in order to identify brain wave changes which occurred for the students when they felt less attentive. However, this approach assumes that students can accurately determine when they are attentive or not. Therefore, it would be another promising approach to use more performance-based objective measurement (i.e. a decrease in performance in the N-back task) in order to investigate which changes in brain waves occur when the performance decreases. In this bachelor thesis, it was done a first step to identify brain wave activity changes which occurred after using the test battery by showing that there was an increase in alpha activity in three of the six students after a prolonged time of performing cognitive demanding tasks.The analysis performed in this thesis was restricted to a very small number of subjects, but as a first suggestion in line with previous research suggests increased alpha activity in the EEG data as a method to detect fatigue in students. However, future work in the SIDDATA project would need to confirm these results with a higher number of subjects to identify the different types of brain oscillations which are linked to a mental fatigue of the students. Once these brain oscillations have been identified with a higher number of subjects, they could be used to predict decreased attention when a student is not fully aware of losing concentration while monitoring the process of studying. As a first step, once there is a statistically relevant difference in alpha activity, the learning assistant could suggest the students to take a break. Moreover, a timespan of attention for each individual student could be determined based on brain oscillations in order to design an individual study plan for each student. Overall, a first promising step into using EEG as a live tracker of attention was made.

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Appendix

Partitioning Results

Subject 3

Beginning

Condition	**Latency**	**Generated trials**	**Deleted trials**	**Final trials**
Eyes-open	113.113 seconds	56	7	49
Eyes-closed	114.84 seconds	57	4	53

Table 5: This table shows the latency, the number of generated trials and the final number of trials for the beginning condition for subject three.

End

Data were lost.

Subject 4

Beginning

Condition	**Latency**	**Generated trials**	**Deleted trials**	**Final trials**
Eyes-open	114.83 seconds	57	7	50
Eyes-closed	116.13 seconds	58	4	54

End

Condition	**Latency**	**Generated trials**	**Deleted trials**	**Final trials**
Eyes-open	118.4 seconds	59	1	58
Eyes-closed	108.301 seconds	54	1	53

Table 6: This table shows the latency, the number of generated trials and the final number of trials for the beginning condition for subject four.

Subject 5

Beginning

Condition	Latency	Generated trials	Deleted trials	Final trials
Eyes-open	119.1 seconds	59	8	51
Eyes-closed	118.561 seconds	59	6	53

End

Condition	Latency	Generated trials	Deleted trials	Final trials
Eyes-open	118.6 seconds	59	7	52
Eyes-closed	104.699 seconds	52	7	45

Table 7: This table shows the latency, the number of generated trials and the final number of trials for the beginning condition for subject five.

Subject 6

Beginning

Condition	Latency	Generated trials	Deleted trials	Final trials
Eyes-open	118.768 seconds	59	3	56
Eyes-closed	68.67 seconds	34	20	14

End

Condition	Latency	Generated trials	Deleted trials	Final trials
Eyes-open	117.1 seconds	58	4	54
Eyes-closed	62.799 seconds	31	23	8

Table 8: This table shows the latency, the number of generated trials and the final number of trials for the beginning condition for subject six.

Subject 7

Beginning

Condition	**Latency**	**Generated trials**	**Deleted trials**	**Final trials**
Eyes-open	116.031 seconds	58	7	50
Eyes-closed	114.359 seconds	57	13	40

End

Condition	**Latency**	**Generated trials**	**Deleted trials**	**Final trials**
Eyes-open	115.201 seconds	58	13	45
Eyes-closed	107.898 seconds	57	15	42

Table 9: This table shows the latency, the number of generated trials and the final number of trials for the beginning condition for subject seven.

Subject 8

Condition	**Latency**	**Generated trials**	**Deleted trials**	**Final trials**
Eyes-open	117.959 seconds	58	3	55
Eyes-closed	120.020 seconds	60	0	60

End

Condition	**Latency**	**Generated trials**	**Deleted trials**	**Final trials**
Eyes-open	119.699	59	3	56

	seconds			
Eyes-closed	105.781 seconds	52	9	43

Table 10: This table shows the latency, the number of generated trials and the final number of trials for the beginning condition for subject eight.

TFCE Visualizations

Subject 4

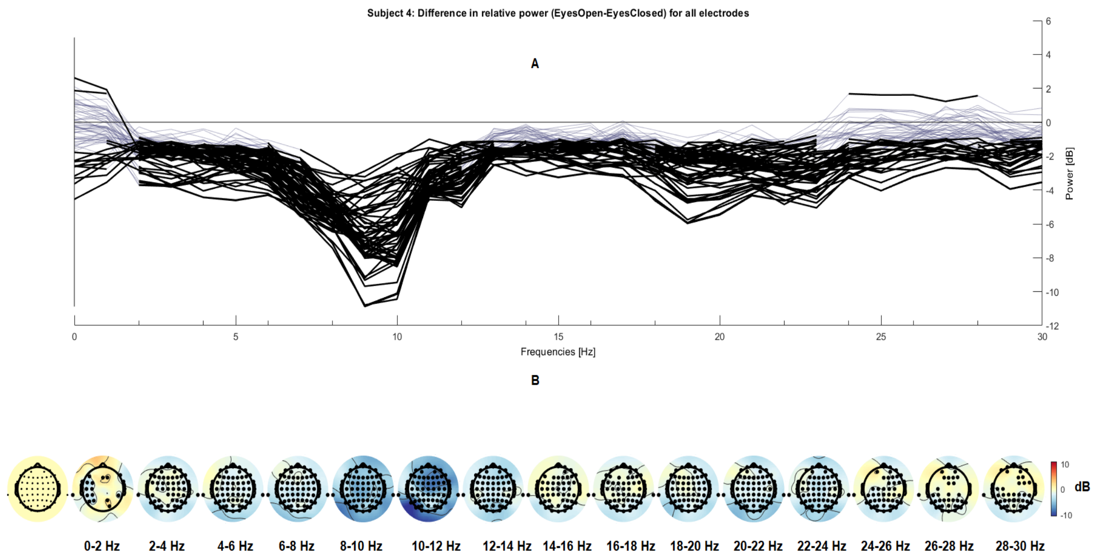

Figure 14: The figure illustrates the results of the TFCE analysis in subject four for the factor eye condition.

Subject 6

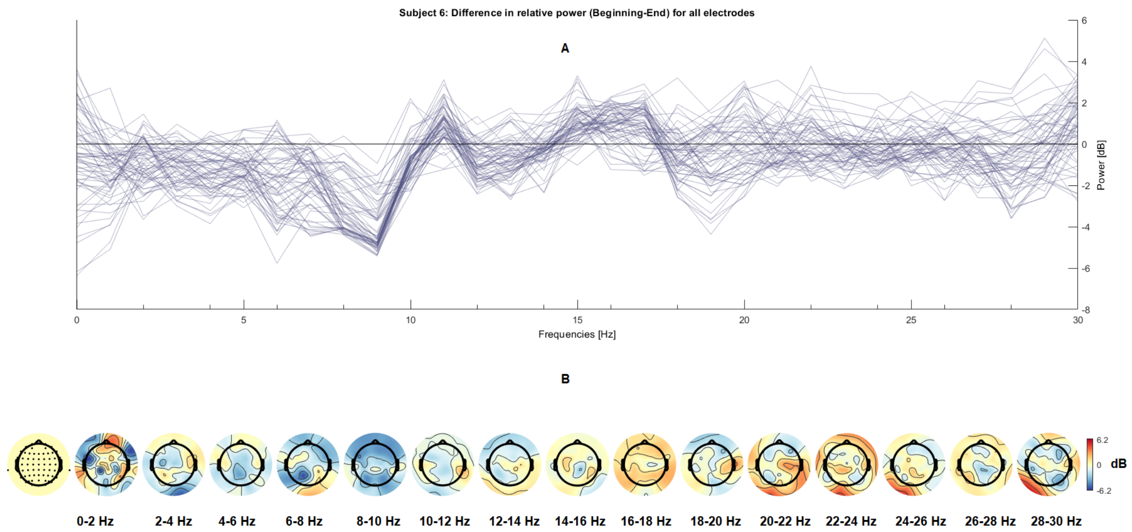

Figure 15: The figure illustrates the results of the TFCE analysis in subject six for the factor time condition.

Tables for further inspected electrodes

Subject 4

Electrode	Cluster range	Median difference	Minimum difference in Cluster (Frequency)	Maximum difference in Cluster (Frequency)
O1	2-30 Hz	-3.32 dB	-1.68 dB (27 Hz)	- 9.11 dB (9 Hz)
O2	2-30 Hz	-3.16 dB	- 1.44 dB (30 Hz)	- 7.72 dB (9 Hz)
OZ	2-30 Hz	- 2.58 dB	- 1.09 dB (27 Hz)	- 7.94 dB (9 Hz)
FZ	6-12 Hz	- 3.92 dB	- 1.21 dB (6 Hz)	- 7.98 dB (10 Hz)
CZ	2-12 Hz	- 3.3 dB	- 1.14 dB (3 Hz)	- 7.93 dB (10 Hz)

PZ	5-13 Hz	- 3.86 dB	- 1.37 dB (13 Hz)	- 5.17 dB (8 Hz)

Table 11: The table shows the cluster range, median difference, minimum difference (frequency) and maximum difference (frequency) for subject four in the eye condition.

Subject 7

Electrode	**Cluster range**	**Median difference**	**Minimum difference in Cluster (Frequency)**	**Maximum difference in Cluster (Frequency)**
O1	8-9 Hz	-1.45 dB	- 1.43 dB (8 Hz)	-1.47 dB (9 Hz)
O2	9-14 Hz	- 2.49 dB	- 1.54 dB (14 Hz)	- 3.62 dB (10 Hz)
OZ	No Cluster	/	/	/
FZ	9-10 Hz	- 1.8 dB	-1.36 dB (9 Hz)	- 2.25 dB (10 Hz)
CZ	9-11 Hz	- 1.43 dB	- 1.25 dB (11 Hz)	- 1.96 dB (10 Hz)
PZ	12-14 Hz	- 1.27 dB	- 1.15 dB (12 Hz)	- 2.32 dB (13 Hz)

Table 12: The table shows the cluster range, median difference, minimum difference (frequency) and maximum difference (frequency) for subject seven in the eye condition.

Subject 8

Electrode	**Cluster range**	**Median difference**	**Minimum difference in Cluster (Frequency)**	**Maximum difference in Cluster (Frequency)**
O1 (36)	6-14 Hz	- 2.13 dB	- 1.03 dB (13 Hz)	- 3.96 dB (10 Hz)
O2 (32)	7-11 Hz	- 2.35 dB	- 1.6 dB (7 Hz)	- 3.44 dB (10 Hz)
OZ (31)	6-11 Hz	- 2.45 dB	- 1.32 dB (6 Hz)	- 3.59 dB (10 Hz)

FZ	7-8 Hz	- 2.48 dB	- 2.34 dB (7 Hz)	- 2.62 dB (8 Hz)
CZ	7-10 Hz	- 1.89 dB	- 1.66 dB (7 Hz)	- 3.32 dB (8 Hz)
PZ	7-9 Hz	- 3.01 dB	-1.9 dB (9 Hz)	- 3.44 dB (8 Hz)

Table 13: The table shows the cluster range, median difference, minimum difference (frequency) and maximum difference (frequency) for subject eight in the eye condition.