Jalon 4

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Abstract

This is a project report of what progress has been done in this one month. Comparative experiments of two different phases: story phase and meditation phase were designed to search for the differences between the active thinking state and the relaxation state. The story phase used a escape room game as script to stimulate the thinking of experiment subjects; the mediation phase follows the Su-Soku protocol to relax the meditator. 16 experiments have been finished. Initial analysis of correlation between 5 biomarkers(Skin Conductance, Skin Temperature, Heart Rate, Heart Rate Variability, Respiration) was done through Rstudio Version 1.0.153. The initial comparison of these five biomarkers as well as 4 frequency band of EEG during story phase and meditation phase was presented and discussed in this report.

1 Experiment

1.1 Subject

So far, a total of 16 undergraduate students were recruited to participate in this study. Until now, 16 experiments have been done: 8 males and 8 females. Except one special participant(52 years old, male), the rest experiment subjects have an average age of 20.64 years (S.D.=0.81 years, range=19–22 years). They are 9 French students, 3 Chinese students, 2 Moroccans and 1 Polish student. They were all free from cardiac, pulmonary, metabolic and other diseases that would cause autonomic nervous system dysfunctions. All subjects were nonsmokers and medication-free and none of them were habitual drinker. Most subjects didn't have practiced any form of meditation technique before. One of them had auto-hypnose meditation less than 3 times for one month, two of them had regular meditation 1 or 2 times for every week. We also have feedback questionnaires after their experiments. What needs to be mentioned is the special participant, who has long-term meditation experience(1-2times every day), was invited as our experiments subjects in order to have a comparison with the non-experienced experiment subjects.

1.2 Experimental Protocol

From the beginning of the S8, we have carried out experiments in a large scale with 16 test subjects participating in our experiments. In order to do the experiments in a scientific and rigorous way, we have established an experimental protocol and modified it since the first experiment of the last semester. In this part we will present you the final version of our experiential protocol which we used in the large scale experiment.

1.2.1 Prerequisite of the Experiment

Type of Meditation: After recruiting and choosing test subjects, we still have an important thing to decide before carrying out the experiment. That is: which type of meditation will we ask our test subject to use for our experiments. After a lot of discussions, we finally chose Su-soku meditation, which is counting breaths while inspiring. There are two reasons why we chose this type of meditation. Firstly, Su-soku meditation is simple and especially easy to learn and perform for beginners. This is very useful when most of our test subjects recruited are non-meditators. Secondly, Su-soku meditation are trackable, which means we can get to know whether they lost their focus during mediation or not through their number counting of breathing.

Baseline: Story Phase After choosing the type of meditation,we need to have a baseline to serve as a comparative experiment with the meditation phase. In order to have a clear distinction between meditation phase, instead of just letting our test subject sitting there with eye closed (to avoid artifact when eyes blink) and doing nothing, we want the mind of the subject to be busy and not to be relaxed during this phase. We came up with an idea: we read an interesting story to our test subjects to grab their mind during the whole phase. In the story, we add some questions that need intense intellectual activity to be solved. To avoid artifact when talking and ERPs (Event-related potentials), the subject needs to remember the answer to all the questions and answer them after the phase come to an end. After 3 versions of story being tried, we finally came up with an "Escape room" story that satisfied all our needs. In this story, the test subject plays the role of a prince/princess (Prince for males and princess for females) o save his/her princess/prince. This story is attached in the annex.

Experiment Environment: In order to give good conditions to our test subjects to relax and perform a better quality of meditation, the environment needs to be low-light and to have comfortable temperature. In addition we limit the noise and the perturbation to the lowest level. If there are still environmental perturbations such as a loud noise, we well record the time and remove the relevant part of EEG recording.

1.2.2 Process of the Experiment

The following table shows the exact process of conducting the experiment from the beginning to the end when we first do the story phase and then meditation phase. Suggested by our supervisor, because we have quite a few test subjects, we can actually do half of the experiments with story phase first and another half with meditation phase first. In this way we have another variable to study and maybe we can get interesting result of the difference between which phase is done first.

Table 1: The process of the whole experiment

Test subject	**Experimenter**
Enter the Room	Greet, invite to seat. Explain how EEG works and what are the 2 phases. Asked to sit as still as possible.
Sit and listen	Put helmet on the subject + sensors (heartbeat, skin temperature, skin conductance, breathing rate)
	Calibration.
Listen to instructions	Interpreter the 1st phase in detail. Suggest short practice.
Practice 1st phase.	
	Beginning of 1st phase.
1st phase: Story phase(8 min)	
Answer questions	Ask how many questions they solved and give them answers. Ask how they feel (questionnaire);Suggest them to take a 3-min break.
Listen to instructions	Detail 2nd phase.
Practise 2nd Phase.	
	Beginning of 2nd phase.
2nd phase: Meditation phase (10 min)	
Answer questions	Ask how they feel for meditation phase(questionnaire)
Finish the experiment and leave.	Remove equipment and give thanks to test subjects.

1.2.3 Story Phase

Duration: 8mins

Instructions given to test subjects: This phase is designed to be a "control phase", it serves as a baseline to be compared with meditation. Please listen carefully. I am going to read you a story. What's specific about this story is that you're going to participate. It is a sort of escape game, where you have to go through different chambers and solve enigmas to move on to the next chamber. You should solve, or try to solve, the enigmas in your head. I am going to repeat each enigma and let you some time, about 40s, to solve it. If one of them is too difficult and you can't solve it during that time, it's okay, please just focus on the continuing of the story. No matter what happens the story keeps going on, and it's important that you don't lose track of the story. I shall remind you that you need to close your eyes during the whole phase and move as little as possible.

Table 2: The procedure of story phase

Test subject	**Experimenter**
Close eyes	Ask to close eyes when ready
Listen to story and make computations	Tell the story and Record the EEG in Biotrace+
	Note the precise time if the test subject move in order to remove the artifacts later when doing analysis.
	Stop recording 5s before the end of the story
Open eyes	Story ends and ask the subject to open their eyes
Answer the questions in Story	Ask how many questions they solved in the story and the answers to those questions
Answer the questionnaire	Ask them to fill a questionnaire to know how they felt.

1.2.4 Meditation Phase

Duration: 10mins **Instructions given to test subjects:** This is the "core exercise" of the experiment. We are going to ask you to meditate, but not any type of meditation : you're going to perform Su-soku meditation. Su-soku meditation is based on respiration counting. Close your eyes, breath very slowly and largely. Count when you inspire (3s), then expire (4s). Try to empty your mind and focus only on breathing. Free your muscles from any tension. Count to 100. You should count every breathing, even if you think it's too small. We might stop you before you reach 100 (depends on the subject: see in practice). If we have not stopped you by touching your shoulder before you reached 100, please start counting again from 1.

Table 3: The procedure of mediation phase

Test subject	**Experimenter**
Close eyes	Ask to close eyes
Start counting	Ask to start counting and start recording EEG in Biotrace+
	Note the precise time if the test subject move in order to remove the artifacts later when doing analyse.
	After 10 min, stop recording EEG in Biotrace+
Stop counting and open their eyes	Tell the test subject in low voice that they can open their Eyes
Answer questions	Ask how many times of breathing they counted. Ask them to fill a questionnaire about how relaxed they felt.

1.3 Feedback of Test Subjects

In order to know the feedback of our test subjects and improve our experimental protocol, we have two questionnaires for our test subjects to answer, one after each phase. The answer to those questionnaires will be taken into account in future analysis as new variables to study the relation between their EEG and their personal feelings of relaxations. In this report we will just show the direct result of the questionnaire as a feedback for our experiments.

The questions can be answered with Yes or No, in order to be more precise, we define the answer to questions are ranging from 1(completely false) to 5(totally right)

1.3.1 Questionnaire of the Story Phase

For the story phase we have prepared 5 questions for our test subjects to solve. Generally speaking, the story just reached to the expectation. All our test subjects felt intellectually stimulated by the story. From 1 point to 5 points, they all gave more than 3 points. In addition more than half of them gave 5 points in terms of intellectual stimulation.

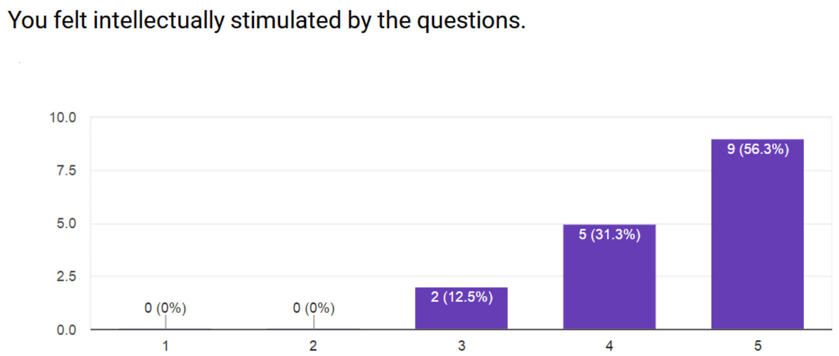

Figure 1: Level of Intellectual Stimulation

We got positive remarks for the clearness of questions from our test subjects too, more than 90% of the test subjects think that all the questions are very understandable. The story successfully catches the attention of the test subjects with only 6.3% of the subjects lost their focus during the story phase.

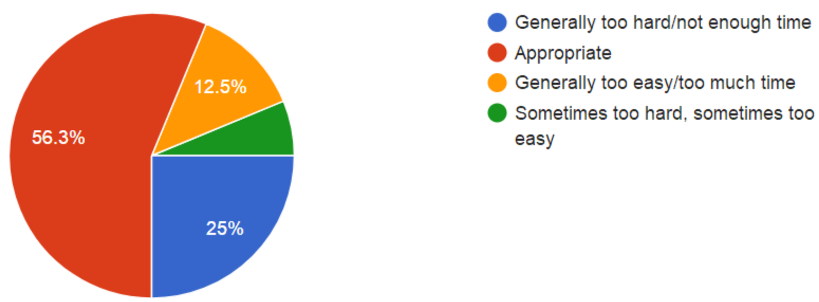

Figure 2: The difficulty of each question

In terms of the difficulty and time given to the question, more than half of our test subjects thought the difficulty and time are appropriate. If we take a closer look at the percentage of people who solved each question, there are still some difference of the level of difficulty for each question. We can find out that the last question, which is about space imagination, was the easiest with 75% of the subjects solved it.The 4th question seems to be the most difficult one with only 25% of subjects could solve. We think it was because memorizing all the words and regroup them to the name of a city is not a easy job without the help of a pen and a piece of paper.

1.3.2 Questionnaire of the Meditation Phase

The questions in this questionnaire is mainly about the feelings of test subjects in meditation phase. We fixed 10min for the meditation phase, more than 80% of the test subjects thought the time was appropriate for them.

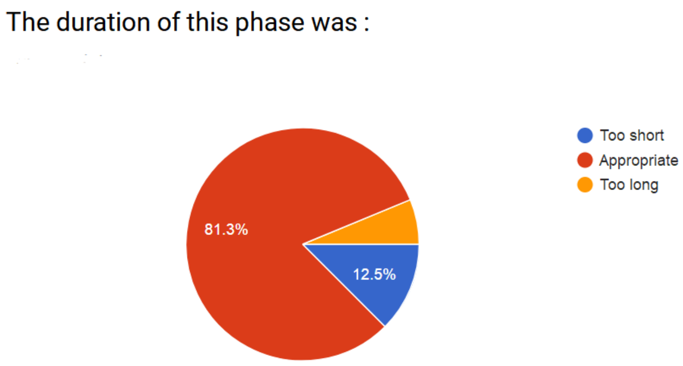

Figure 3: Meditation Duration

In terms of the level of focus during the meditation phase, all the subjects gave more than 3 points to confirm that they kept focus during the whole phases. More than 80% of the test subject gave more than 4 points. However, this doesn't mean that all the test subject have perfect focus all the time. if we asked the question in the opposite way: "You mind often wandered out of control" The answer is like normal distribution. Quite a few subject confirmed the loss of focus on meditation phase. However, we need to be aware of the subjectivity of these questions. It is difficult to give a quantified value of the level of focus.

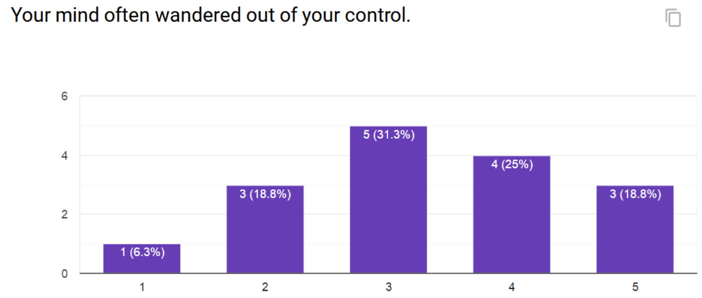

Figure 4: Level the Lose of Focus

We also asked if the subject felt asleep and their self-awareness during meditation,the answer was not consistent. However, in future analysis, we can take the sleepiness and self-awareness as variables and study their influence on EEG and relaxation.

We have very consistent result in terms of the level of relaxation alone the process of meditation phase, almost all of our subjects got more and more relaxed throughout the phase. This showed that the Su-soku meditation that we chose worked well for beginners.

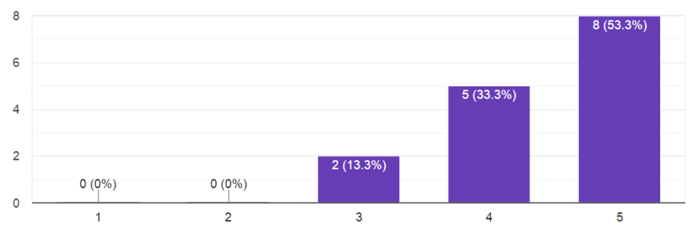

Figure 5: Answer to "You felt increasingly relaxed through out the phase"

2 Data analysis

2.1 General tendencies

2.1.1 Pre-processing

This is a reminder of Jalon 3.
The raw data is pre-filtered in the software before being exported, with a third order bandpass filter selecting frequencies between 0.5 and 40Hz. The potential peak 45Hz noise due to the surrounding electrical network is therefore cut out, as well as the slow macroscopic potential variations undergone by the electrodes for an unknown reason.

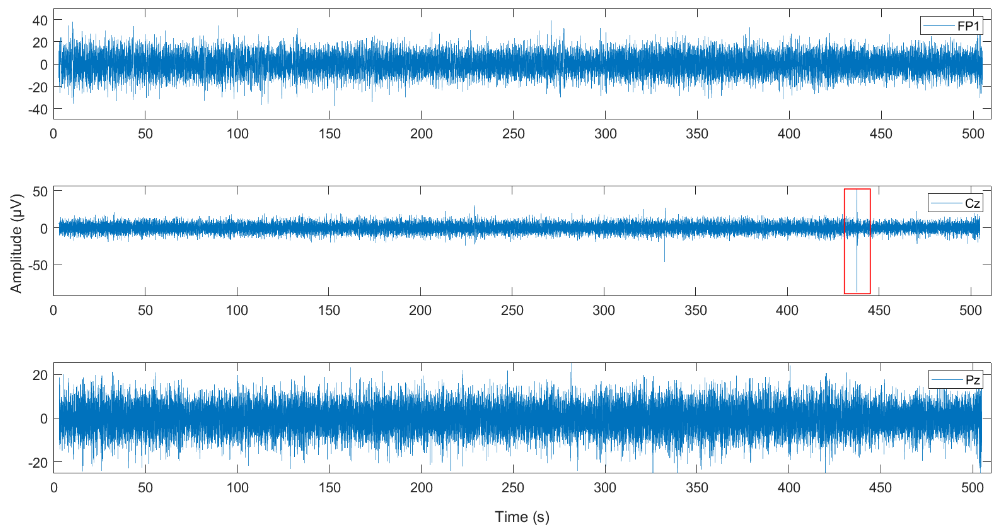

Figure 6: Plot of EEG amplitude against time for 3 different electrodes.
Test subject : Hugues Mounier, 52 y.o, experienced meditator

The portion of signal (from electrode Cz) framed in red is detailed below. Its very high amplitude and precise localisation in time designate it as an artifact. It shows a very precise pattern which can be found in the majority of other experiments. It can occur in other electrodes, and doesn't appear simultaneously in all electrodes. This is most seemingly due to some face muscle movement : but here, the fact that it only occurs in the central area (C) and not the prefrontal area (FP), closer to the forehead, is quite startling.

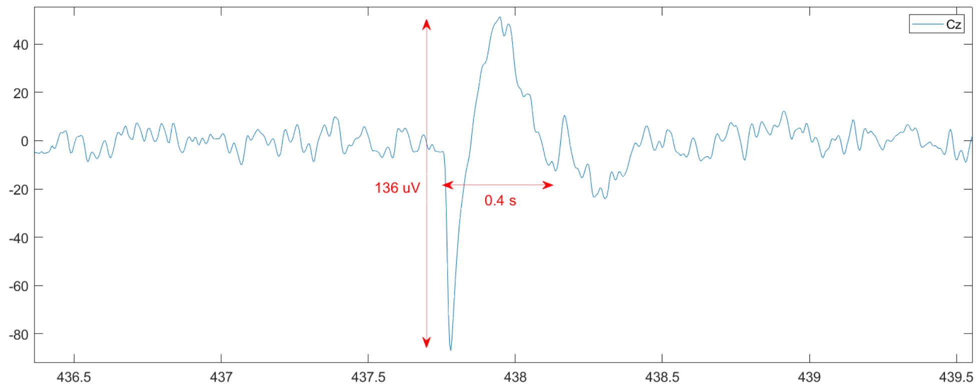

Figure 7: An artifact in electrode Cz. Nature : unknown yet.

The time period of this oscillatory artifact (around 0.5s) place it in the category of Delta frequencies(shown in Figure7), which could lead to think that the computation of power in the Delta band is artificially boosted by this kind of artifacts. If these artifacts are more present in one phase than in the other, the variations of power become affected, hence the importance of dealing with these artifacts, which hasn't been done yet. However, their impact should not be too prominent given their short duration and limited number of occurrences.

2.1.2 Definition of the variations of band power

Let BAND1 be a frequency band of interest among bands Delta, Theta, Alpha and Gamma, and AREA1 be a brain area of interest among areas FP (prefrontal), F (frontal), O (occipital), C (central), T (temporal) and P (parietal).
Let $M_{electrode}^{band}$ and $S_{electrode}^{band}$ designate respectively the power in a given band for a given electrode during the Meditation phase and the Story phase (averaged over the full duration of the phase). Then the comparative variations of power during the Meditation phase against the Story phase for BAND1 (ex : Alpha) in AREA1 (ex : FP) are defined as :

$$\textbf{Relative variation of BAND1 power} = \frac{\sum_{electrode \in AREA1} M_{electrode}^{BAND1} - \sum_{electrode \in AREA1} S_{electrode \in AREA1}^{BAND1}}{\sum_{electrode \in AREA1} S_{electrode}^{BAND1}}$$

$$\textbf{Variation of relative BAND1 power} = \frac{\sum_{electrode \in AREA1} M_{electrode}^{BAND1}}{\sum_{band \in bands} M_{electrode}^{band}} - \frac{\sum_{electrode \in AREA1} S_{electrode}^{BAND1}}{\sum_{band \in bands} S_{electrode}^{band}}$$

2.1.3 Results

The following box-plot graphs show the distribution of these 2 kinds of variations for each frequency band (Delta, Theta, Alpha, Gamma) and each brain area (FP, F, O, C, T, P). For each pair [band, area] 16 points are taken into account, corresponding to the 16 experiment subjects. The distribution is represented as box-plots using MATLAB's embedded function *boxplot*, which displays the median variation, first quartile and third quartile, as well as minimum and maximum values. The isolated points are outliers (extreme points) which are automatically discarded by MATLAB when performing the box-plot.

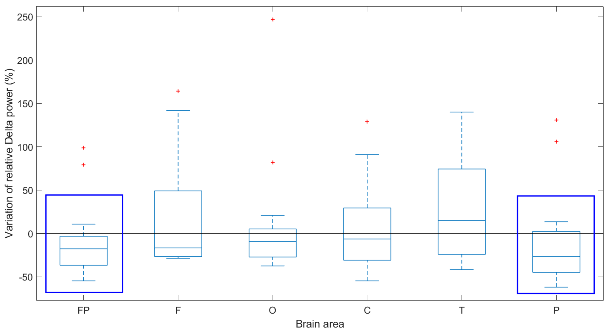

Figure 8: Relative variations of Delta power

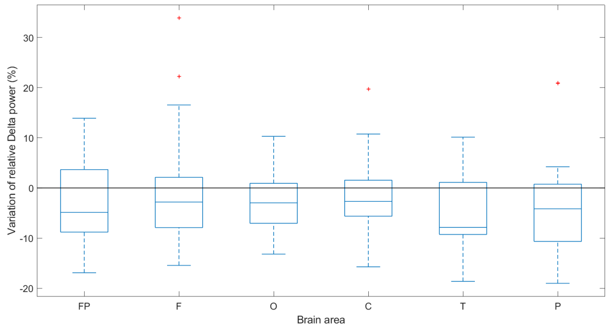

Figure 9: Variations of relative Delta power

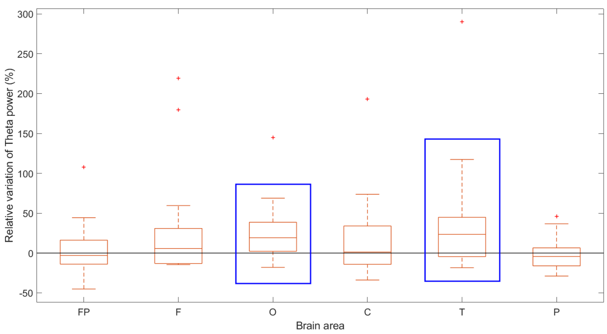

Figure 10: Relative variations of Theta power

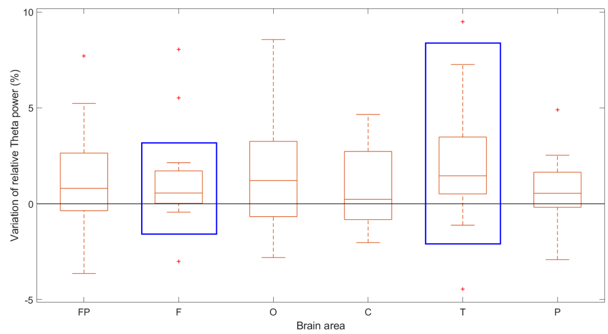

Figure 11: Variations of relative Theta power

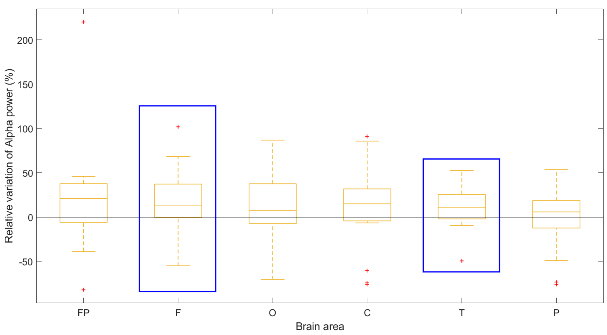

Figure 12: Relative variations of Alpha power

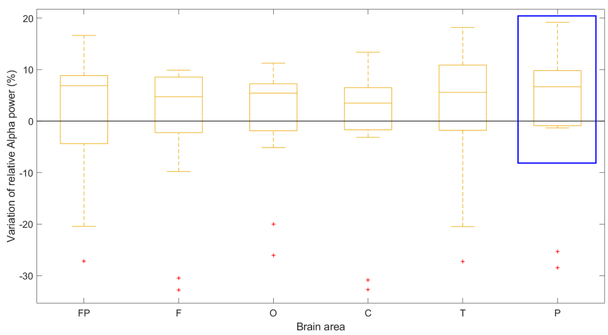

Figure 13: Variations of relative Alpha power

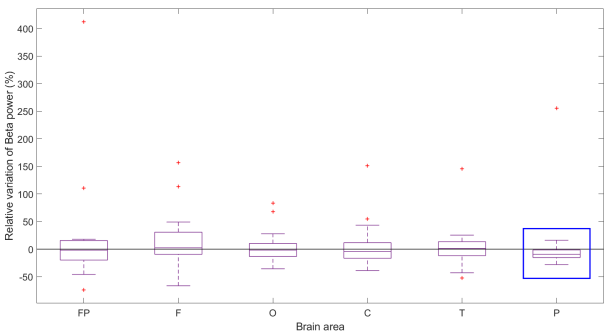

Figure 14: Relative variations of Beta power

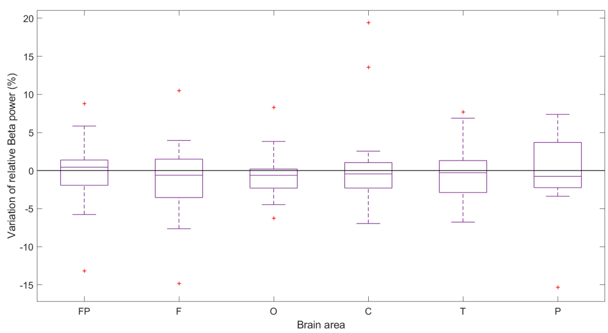

Figure 15: Variations of relative Beta power

In order to distinguish the two states, we are looking for some significant power variations between the Meditation phase and the Story phase, which should be rendered by some boxes being situated completely above/below zero. This would mean that -ignoring outlying points- during Meditation, at least 75% of the subjects have shown an increase/a decrease of power for the concerned pair [band, area].
Such pairs are indeed noticeable (framed in blue), and constitute promising features to allow the distinction between a relaxed state and an active thinking state. These pairs are :

- For relative variations of band power
  - Delta, FP (decreasing)
  - Delta, P (decreasing)
  - Theta, O (increasing)
  - Theta, T (increasing)
  - Alpha, F (increasing)
  - Alpha, T (increasing)
  - Beta, P (decreasing)
- For variations of relative band power :
  - Theta, F (increasing)
  - Theta, T (increasing)
  - Alpha, P (increasing)

2.2 Analysis of correlation between bio-markers an EEG signals

2.2.1 Introduction

After conducting the experiment, it's necessary to refine raw data that has been collected from the experiment in order to draw the conclusion. In our case, the raw data collected is the amplitude of EEG signals according to time, heart rate (beats per minute (BPM)), skin conductance (Galvanic Skin Response (GSR)), skin temperature as well as respiration rate (breaths per minute), which contains too many data to analyze it sensibly. So we need to organize and manipulate the raw data using deconstruction analysis techniques. Considering the individual personality trait, we estimate that the regression model for each individual will be different. The analysis below is based on one single subject.
In this section, we will represent firstly our final objective of building a new and universal data frame for each subject and the pipeline to achieve it. Then we will talk about how to select data and define new useful features basing on raw data. Afterwards, we will look in the general representation of our new data frame and find out which bio-marker seem more correlated at first glance then do the statistical analysis focusing on them. At the end, we will talk about the future work needed to be done and the conclusion that we draw by far. One remark is that the unit of the variables is less important their tendency, so we will not specify them at the following sections. For the convenience, we note heart rate variability as HRV, skin conductance as SC, skin temperature as ST; respiration rate as Resp.

2.2.2 Final Objective and Pipeline

We remind the goal of this project is to find out the correlation between different bio-markers and EEG signals and build a classification interface according to the correlation that we discover. So the ultimate objective of analyzing data is to build a matrix of samples called "df" (for the convenience of further reference, df refers to data frame in R language) consisting of features(variables) extracted from our experiments. We define our matrix *df* using each second as one sample, and at each second, we consider the power of four different bands of each electrode as well as the interpolation (if necessary) of other bio-markers. The reason of doing so is that the change per second is great in EEG signal, the information during one second interval is enough to be considered as a sample. Besides, by doing so, we enrich our training data set of each experiment. Of course, we can add the derived variable in this matrix, for example, the heart rate variability that we will define lately and the average band power of different zone of the brain. Once the *df* is built, it's crucial to do the statistic analysis on seemingly correlated bio-markers. Eventually, we will apply the machine learning technique to classify the status(bi-classification : whether the subject is meditating or not) given one second's data.

2.2.3 Data Reading and Data Selection

According to our protocol, we store two data sets each experiment. The first step of analyzing is to remove the bad data point or the data point when the subject did not enter the defined phase. In other words, we take into account 450 second for story phase which lasts normally 480 second. That's to say, we will cut off 30 seconds whether from the beginning or at the end or the data point which is abnormal(cutting abnormal data is done exhaustively and manually, we can develop an algorithm to do this work in future). We will do the same thing for meditation phase except that we consider 580 second due to the fact that meditation phase lasts strictly 600 second. After building desired features for those two matrix, we will combine them as our final matrix. It's important to note that there is a break between story phase and meditation phase. So the combination two matrix of two phase is simply the concatenation of data points.

2.2.4 Representing Variables and Their Definition

The relevant variables are the average power of four bands of each electrode, respiration rate, skin temperature, skin conductance, heart rate variability.

1. Average power is a measure that estimates the magnitude of oscillatory amplitude within a defined time window. For example, the average power of FP1 Alpha band is the mean of absolute value of spectrum density (the absolute value of a complex number) of each frequency in alpha band. Practically, we obtained by doing the spectrum, we do a time-frequency analysis of an electrode then select the frequencies in alpha band and calculate their mean.

2. Respiration rate, skin temperature, skin conductance per second are obtained by interpolating raw data point. In practice, this is done by using approx function in R which return a list of points which linearly interpolate given data points.

3. we define heart rate variability as RMSSD (Root mean square of the successive differences). This is illustrated by the figure below. Practically, we use $60/BPM$ to represent the R-R interval, from which we calculate the RMSSD.

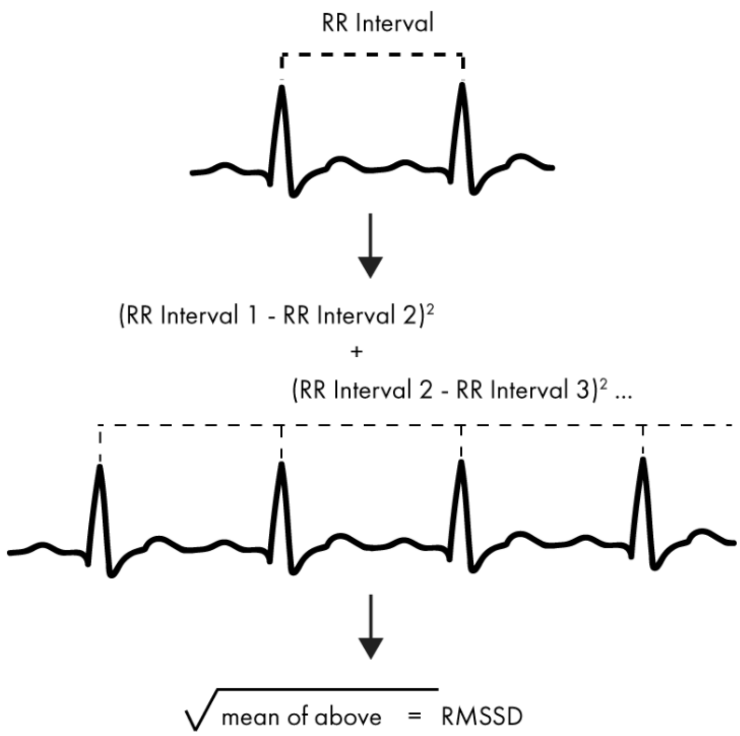

Figure 16: Calculation of HRV

2.2.5 Representation according to time

In this section, we represent the different bio-marker against time of one subject.
The four figures below are respectively the variation in FP1 electrode of alpha power, beta power, theta power and delta power. The red line is obtained by doing a regression locally, the blue line is calculated by doing the same non-parametric regression but with a smaller line span. The line span parameter define generally the length of window by increasing the weight of neighborhood points at time t. Small line span means that we emphasized more in closest point so small window. And the pink line marks the transition of different phases. From figure17 we can see clearly that alpha power is increasing when the subject was doing meditation. In addition, the delta(see figure 20) and theta power(see figure 19) is descending. Nevertheless, the tendency of Beta power is fluctuating. Then we are going to see the tendencies of other bio-markers.

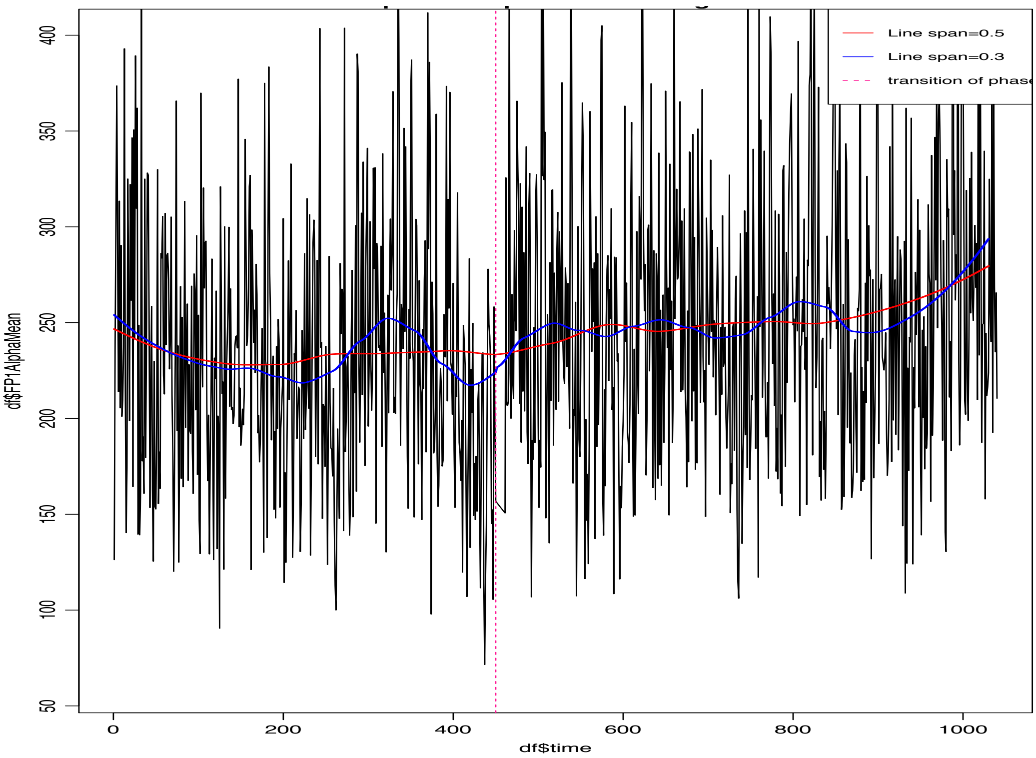

Figure 17: Alpha average power in FP1 electrode against Time during story phase(left) and meditation phase(right)

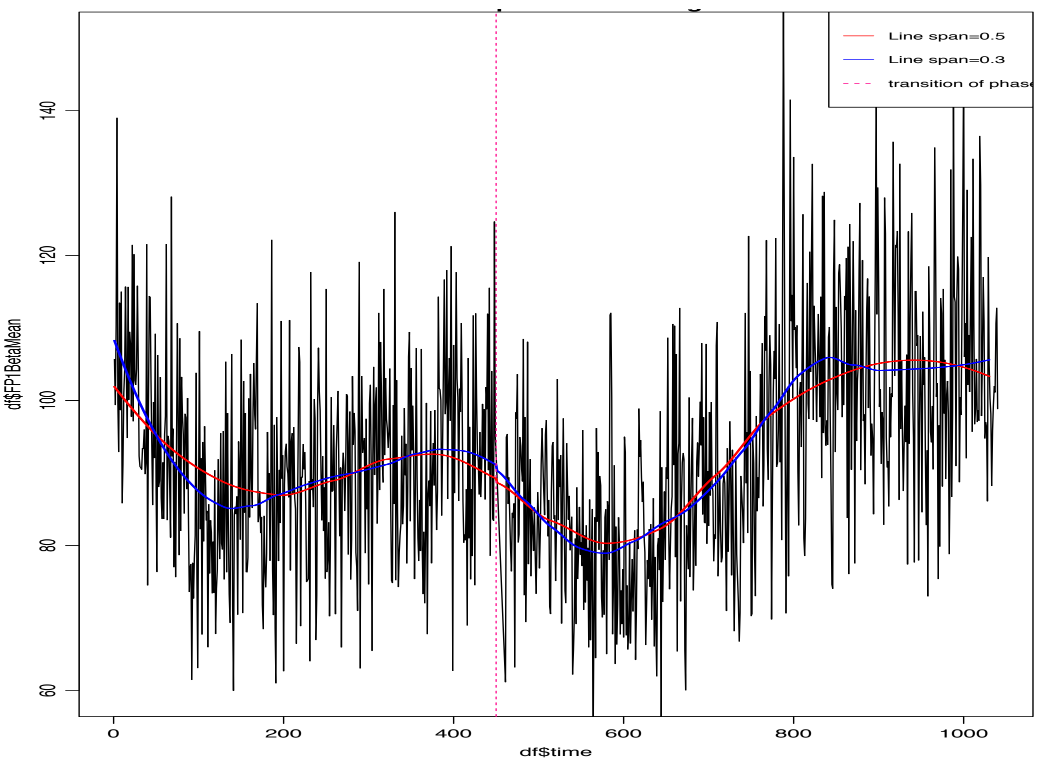

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Figure 18: Beta average power against time in FP1 electrode against Time during story phase(left) and meditation phase(right)

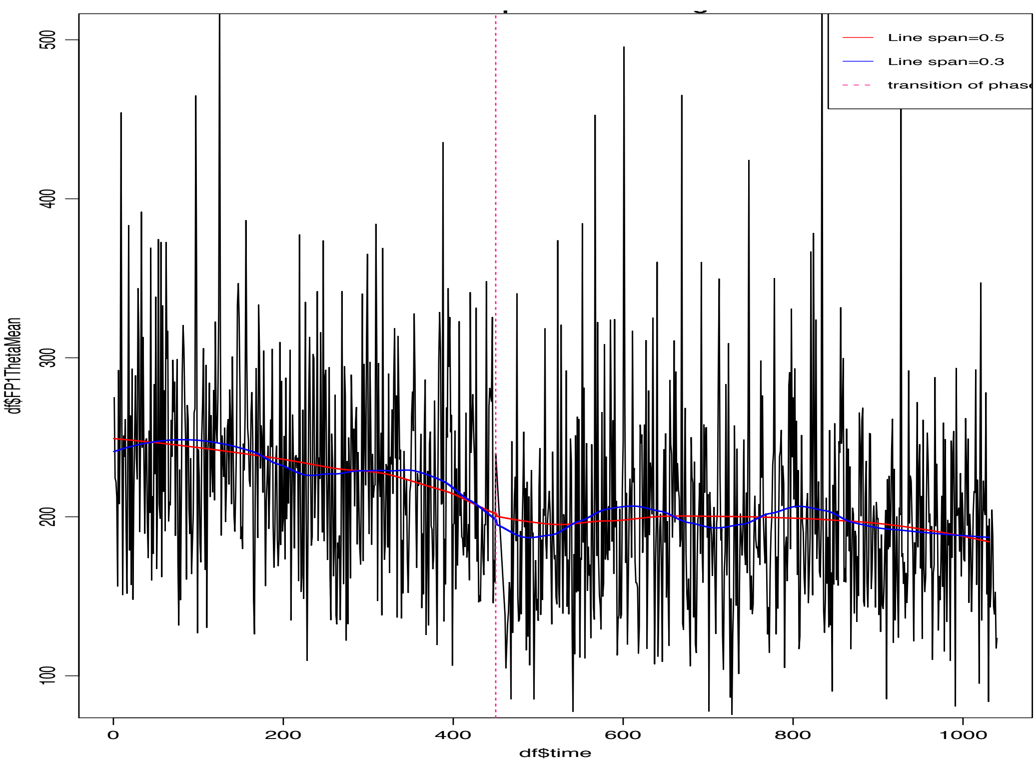

Figure 19: Theta average power against time in FP1 electrode against Time during story phase(left) and meditation phase(right)

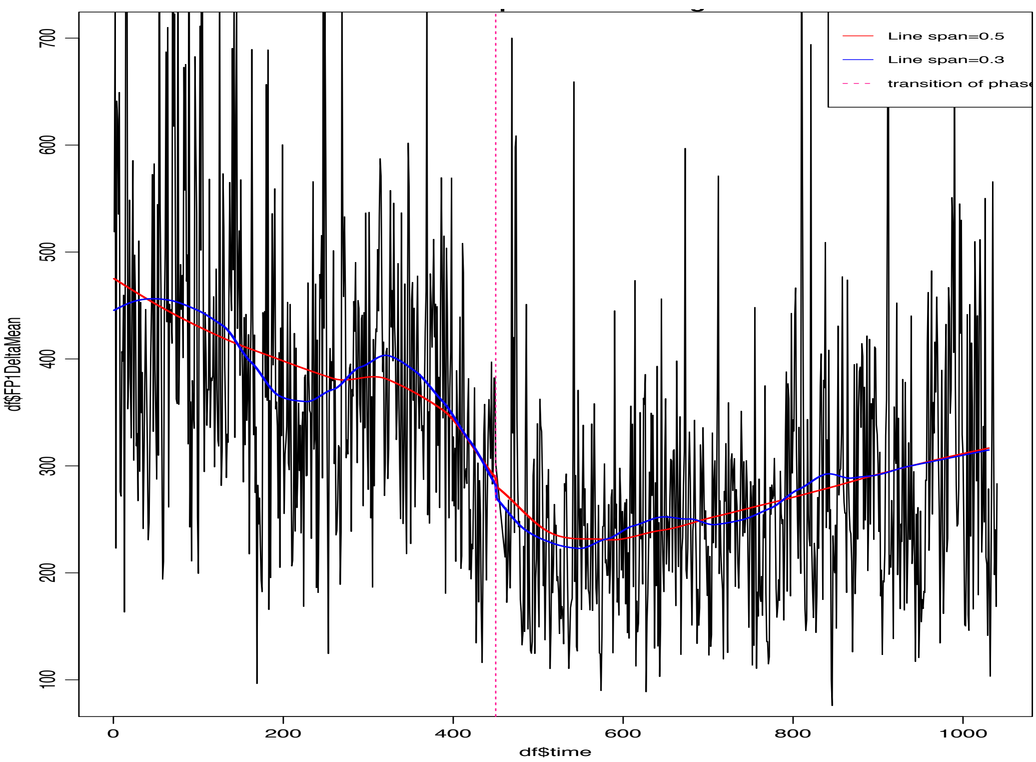

Figure 20: Delta average power against time in FP1 electrode against Time during story phase(left) and meditation phase(right)

The five images below represent respectively five conventional bio-markers: Skin Conductance, Skin Temperature, Heart Rate, Heart Rate Variability, Respiration. Just as we mentioned before: The red line is obtained by doing a regression locally; the blue line is calculated by doing the same non-parametric regression but with a smaller span(window);the pink line marks the transition of different phases(left one is the story phase, the right one is the meditation phase). From Figure21,it is obvious that the skin conductance decreases when one is doing meditation, the leap of the transition may be due to physical situation, noticing that the subject took a break and answered the survey right after story phase. As for the skin temperature, we can spot that it decrease during story phase and increase again during meditation phase which coherent with acknowledged conclusion that skin temperature go down when one is stress, increase when one is relaxed. However, the heart rate is not a helpful bio-marker to understand the mind state, in fact it (see Figure 23) shows no evident change during these two different phases. That's why we introduced heart rate variability(see Figure 24) which decreases significantly during the meditation phase corresponding to the fact that: HRV is closed linked to the respiration rate. However, one can notice the value of HRV at the beginning is very high, we assume subject was not used to the measuring device. Finally, the respiration become more stable and slow (see Figure25) during meditation simply because the type of meditation that the subject practiced is a breath-controlling meditation.

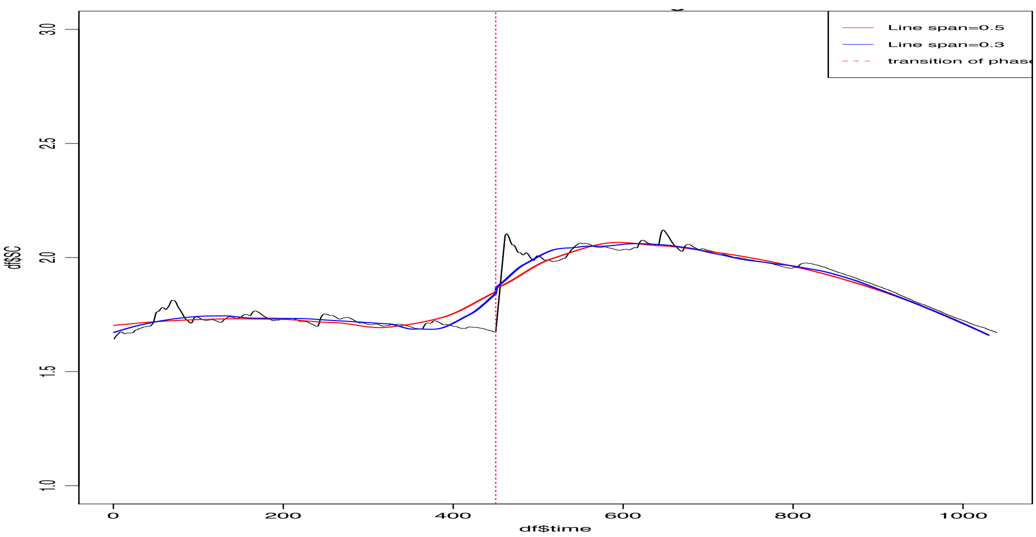

Figure 21: Skin conductance (micro siemens) against time

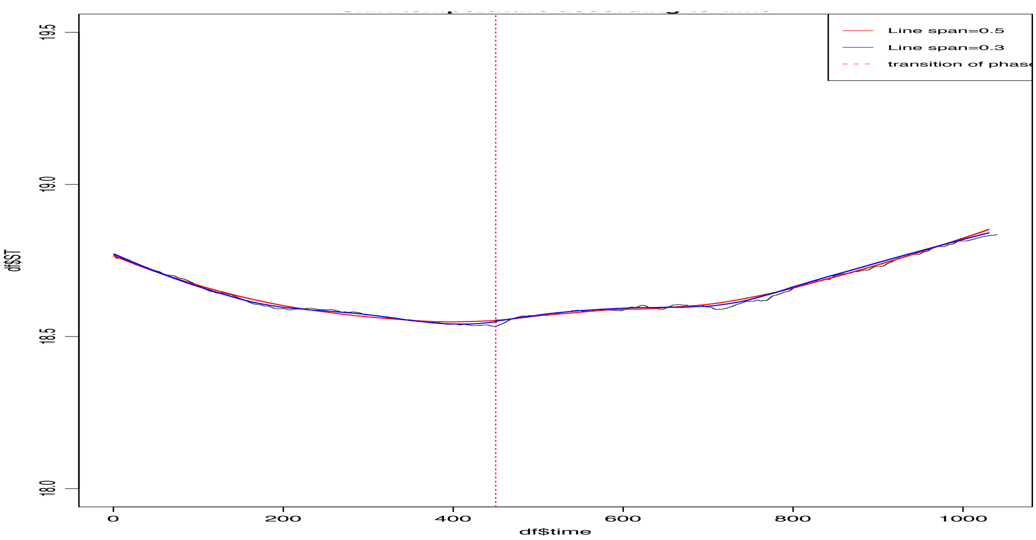

Figure 22: Skin Temperature(degree Celsius) against time

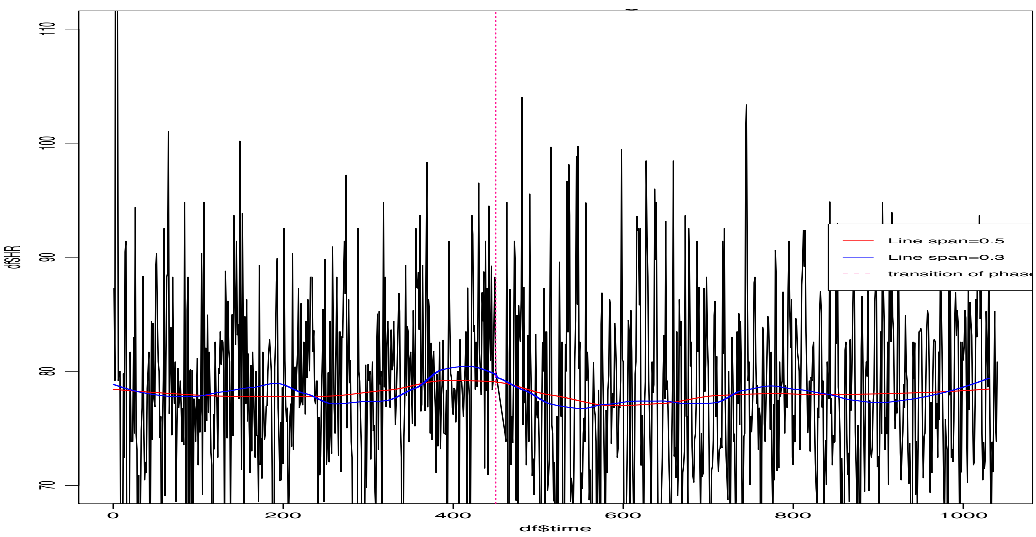

Figure 23: Heart Rate (BPM) against time

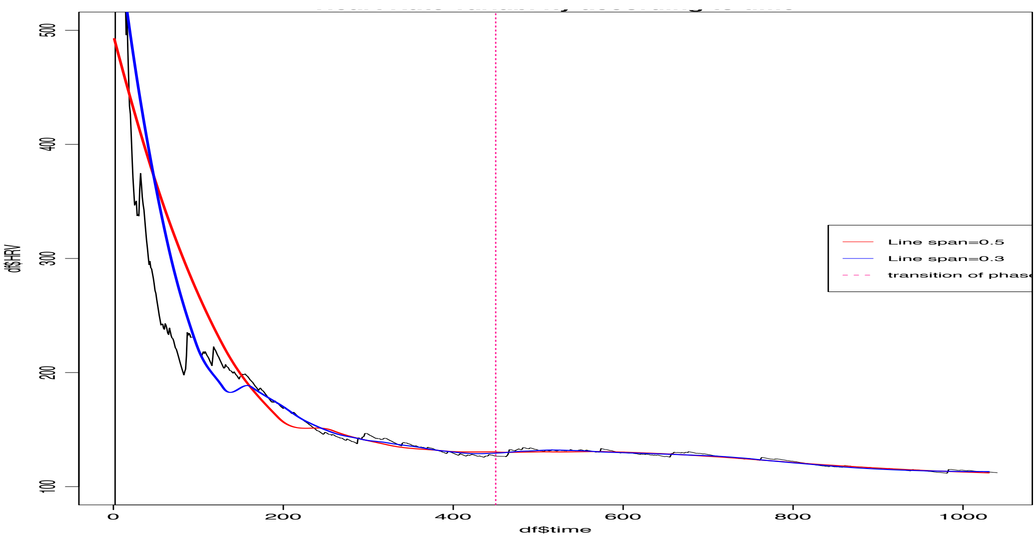

Figure 24: Heart rate variability against time

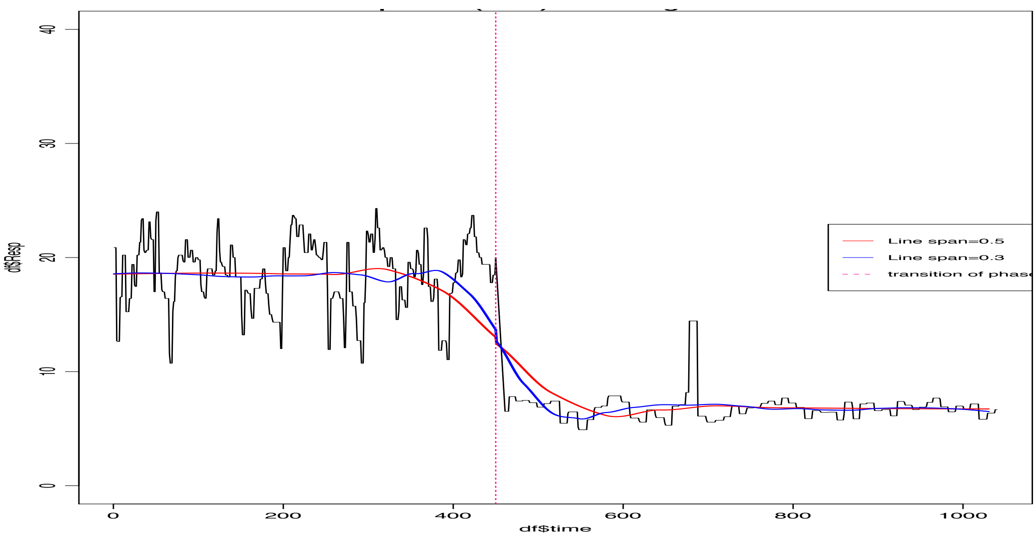

Figure 25: Respiration (number of breath per minute) against time

Now we are going to see the representation scatter plot of different bio-marker and decide those that are correlated then start the detailed analysis on them.

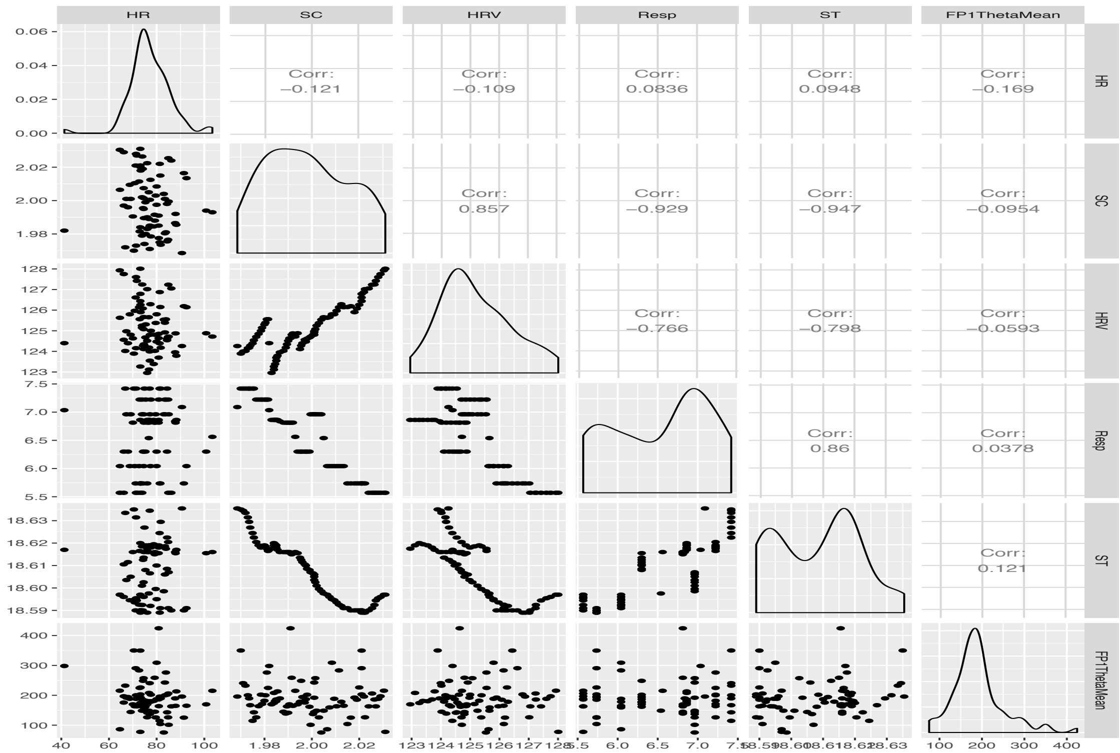

Figure 26: pairs of conventional bio-markers and average power of FP1 theta band

The ij^{th} scatterplot contains i^{th} bio-marker (shown in the horizontal title at the top) plotted against j^{th} bio-marker (shown in the vertical title in the right). In left-diagonal panel, in each plot, the coordinate (x[i],y[j]) of every point represent the value x of against of i^{th} bio-marker against j^{th} bio-marker. The value in ij^{th} scatterplot shows us the correlation between i^{th} bio-marker and j^{th} bio-marker.In right-diagonal panel, the corr shows the correlation coefficients. In this figure, heart rate(hr) appears to be a mess since the points are scattered randomly. Strong correlation is shown between Skin Conductance(SC), Respiration(Resp), Skin Temperature(ST) and Heart Rate Variability (HRV). In the next section, we have good reason to understand in particular the correlation of SC and HRV then the correlation between HRV and EEG signal(for example, we choose average power of FP1 Theta band)

2.2.6 Analyse BiVariable and UniVariable

Primly, we want to see the boundary of skin conductance on order to set up rightly the limit of y axis as well as those of x axis. By doing so, we can remove some abnormal data point whose value is much higher or slower.

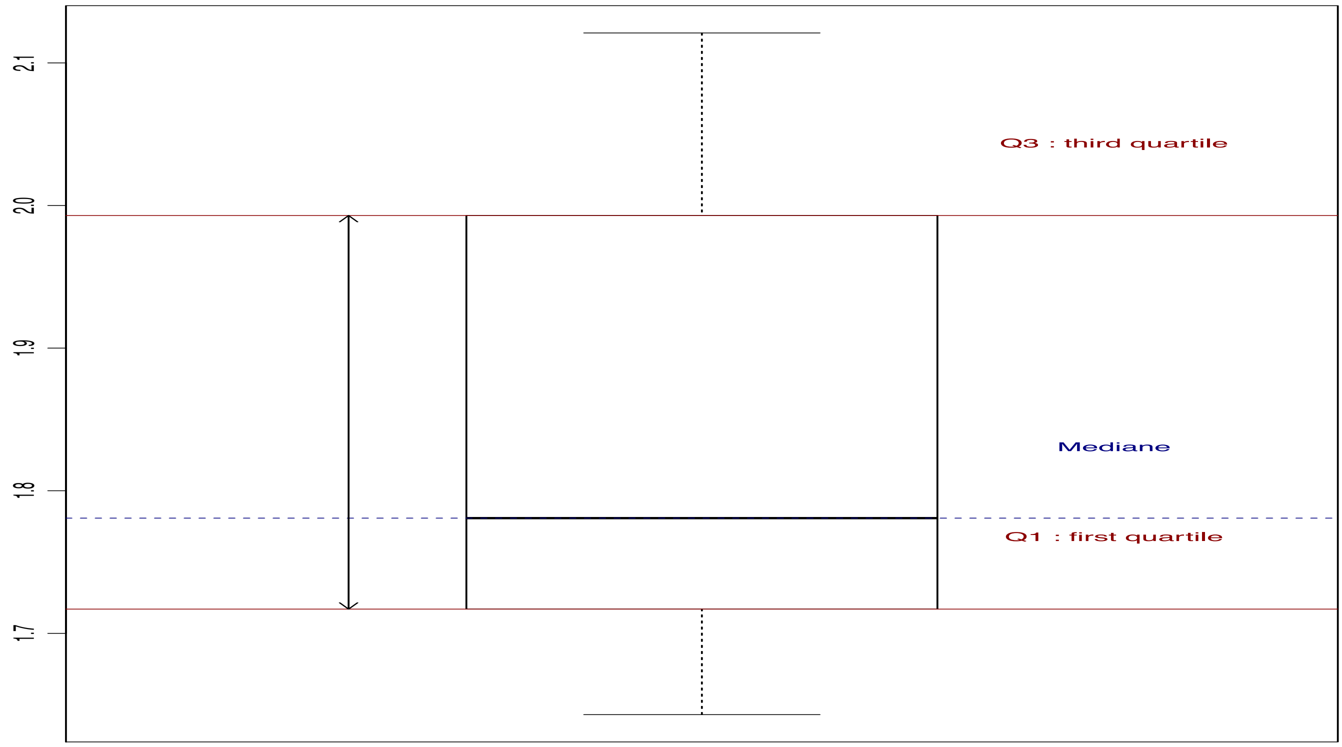

Figure 27: boxplot of skin conductance

As shown above, the value of skin conductance contains mainly values in [1,7,2.1]. Therefore, we would like to plot skin conductance against heart rate variability in this interval to see clearly the tendency.

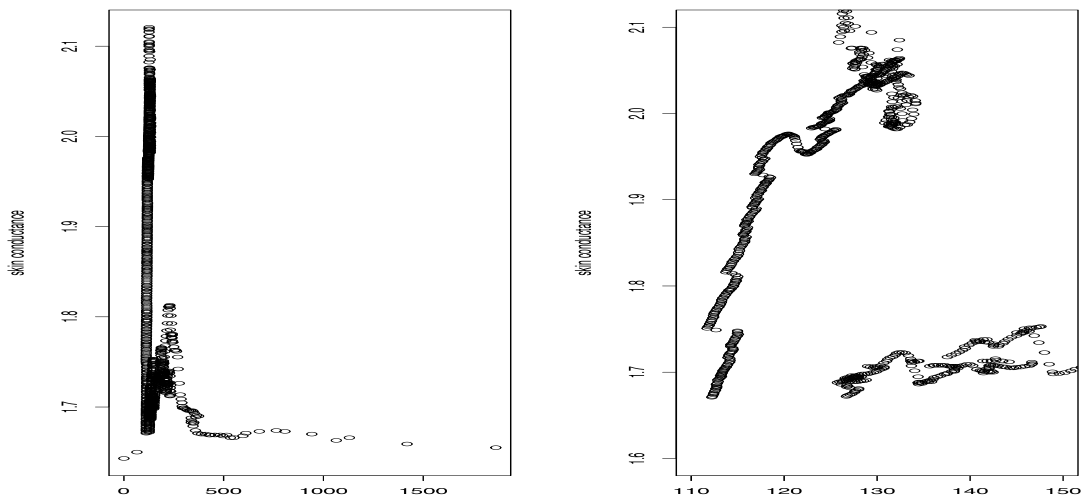

Figure 28: overall data of SC against HRV(left) and local data cluster(right)

Table 4: residuals of model HRV SC

	Min	first quartile	median	three quartile	Max
HRV-SC	-0.07967	-0.0211 0	0.00678	0.02082	0.10471

Table 5: coefficients of HRV SC

Intercept	HRV	p-value
0.67846	0.010419	<2.2e-16

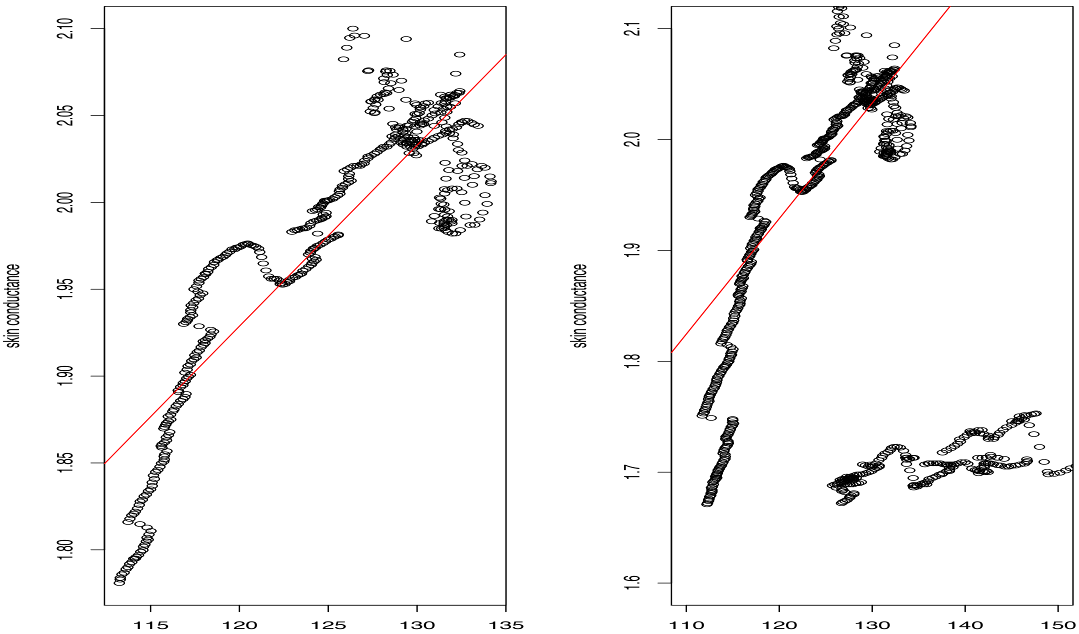

Figure 29: regression of HRV-SC

The left figure of 28 shows all the data point, we spot that the points on the right side are possibly false. When we zoom in to see what is happening on the left side, the right figure demonstrates that there are two tendencies. One is that skin conductance increases rapidly with the growth of heart rate variability. The other one advanced slower. Since the first tendency (whose slope is steeper) contains more points, it is logical to do a linear regression on it(shown on 29).

We now analyze the statistic value of this linear model. As we can see the residuals (predicted value minus observed value) are not large, and they are around 0 which indicates the fitted regression is accurate. Furthermore, we will do a hypothesized test H0: the coefficients HRV equals to 0 against H1: the coefficients HRV is not equal to 0. The p-value obtained is smaller than $2.2e^{-16}$ which shows that we have good reason to trust the correlation between HRV and SC (we discard the hypothesis H0). Now, we turn to the analysis between average power of FP1 Theta band and HRV.

Table 6: residuals of model HRV average power of FP1 theta band

	Min	first quartile	median	three quartile	Max
HRV-FP1Theta	-129.38	-37.341	-5.2860	35.458	186.08

Table 7: coefficients of HRV average power of FP1 theta band

Intercept	HRV	p-value
53.2772	1.1651	<1.72e-07

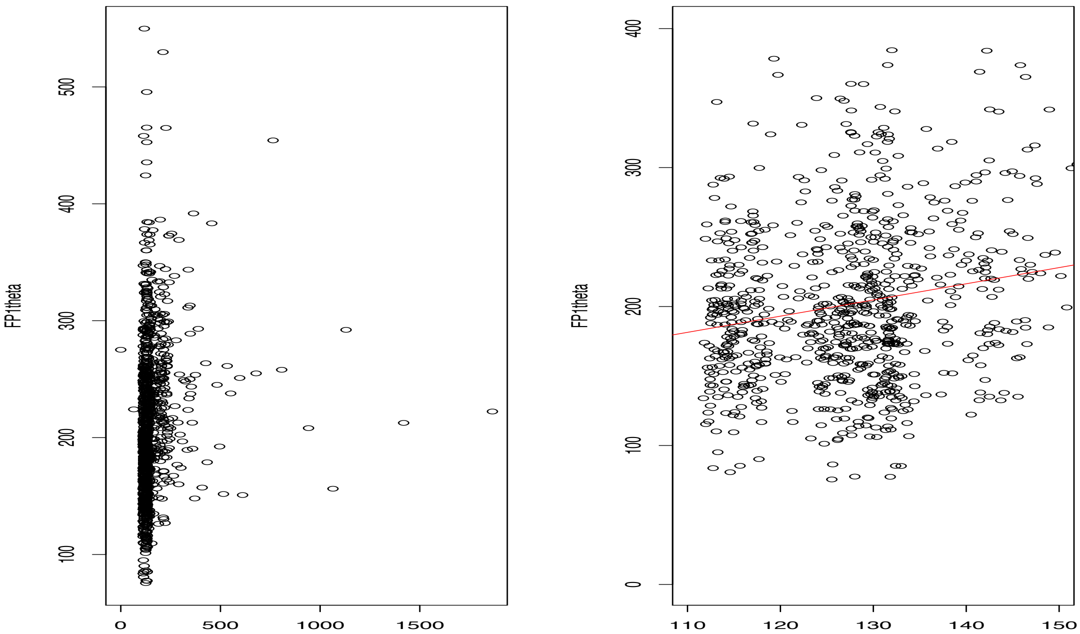

Figure 30: representation of average power of FP1 theta band against HRV(left) and regression model(right)

In figure 30, we will eliminate the bad data point situated on the right side as before. Even though the data point is seemingly random, we can still notice average power of FP1 Theta band is increasing with the growth of HRV with great uncertainly. Let's dive into the summary of the linear model between average power of FP1 Theta band and HRV. The residuals are rather big but its mean is about 0. Furthermore, the small p-value justify our assumption of existing correlation between HRV and average power of FP1 Theta band. All of this can lead us to draw a conclusion, it's possible to use only EEG signals to classify mind state since EEG signals are linked to the well acknowledged bio-marker that correlated with mind state.

2.2.7 Conclusion

The possibility of using EEG signal to classify one's mind state remains unknown and challenging. The main issue is to deal with the wave signal which is unlike the conventional bio-markers. However, we discover that EEG signal power, especially average power of theta band in FP1 electrode is correlated with heart rate variability which shows the great potential of EEG signals. In addition, we notice that the direct use of power maybe be not enough to well fit a model, we can fit a polynomial model or even we can add derived terms of EEG signals such as log() in our training data set. To sum up, so far we established a protocol to analysis the correlation of EEG signals and other bio-markers. What needs to be done in the future is feature engineering on EEG signals, and develop classifying model.

3 Future work

3.1 Data analysis–Extensions of acquired data matrix

The analysis of correlation between EEG signals and other bio-markers reveals that we can actually use EEG signals to classify mind state. Moreover, if we are able to detect and delete the bad data point, the correlation can be seen evidently, and the precision of the prediction of our model is guarantied. So one work needs to be done is to develop a method to remove the bad data points efficiently as well as accurately. The most important task is without doubt the regression model takes EEG signals as test data, and return a label (0 or 1) to represent the subject's mind state. The classification model can be easily achieved by using embedded machine learning functions. For example, Support Vector Machine (SVM), k-Nearest Neighbor (k-NN) and Artificial Neural Network (ANN), these methods have been proved to reach a high precision [2]. Finally, the hard part is to construct new features from EEG signals which are highly linked to the mind state. The possible new feature will be the mean value, standard derivation, skewness and kurtoist [2]. The next section we will introduce a new feature that is always considered in the brain research: Phase-amplitude coupling.

3.2 Phase-amplitude coupling

3.2.1 Introduction

2013, Lisman [5] pointed out that the exchange of information between different brain regions is actually completed by the orderly neural coding mechanism between the two signals' oscillations.

Overall, there are three ways to explore the relationships between different frequency signals. Amplitude-amplitude coupling, phase-phase coupling, and phase-amplitude coupling.Among them, phase-amplitude coupling, especially between low frequency and high frequency, may be related to the process of long-time memory and the integration of information exchange between neurons.

Phase-amplitude coupling, as the name implies, is used to measure the modulation of the phase of one signal to the amplitude of another.The higher frequency of EEG is in charge of the rapid information processing of local brain region, while low frequency is not only related to external sensory input and motion events, but also to internal learning and memory cognitive drive [1].

The phase-amplitude coupling of theta and gamma may be related to the communication and change of information between neurons in learning and other tasks.Some studies have also shown that the phase-amplitude coupling of delta-gamma is modulated in the process of visual motion control, brain fatigue and so on [6][3][4].

Phase-amplitude coupling plays an important role in revealing the mechanism of information transmission of the cerebral cortex in different work tasks. In this way, more and more people begin to apply phase-amplitude coupling to EEG research.

3.2.2 Expected results and our plan

The information available shows that, between quiet state and fatigue state, there will be a significant difference of PAC of theta phase and gamma amplitude. In both states, the PAC results are in vertical banded distribution. If fatigue, the coupling value as a whole shows a decreasing trend. PAC of delta and gamma is the opposite(show in figure below).

The coupling value shows the strength of coupling. The higher value, the stronger coupling between this two electrodes. Each pixel shows the coupling value of two variables, gamma amplitude of the electrode corresponding to the abscissa, theta phase of the electrode corresponding to the ordinate.

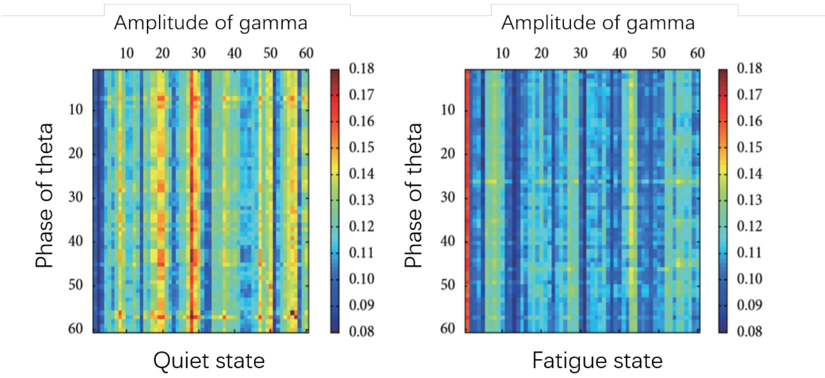

Figure 31: PAC result of theta and gamma (EEG with 60 electrodes)

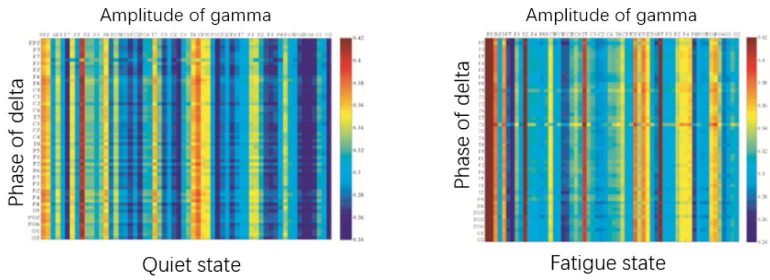

Figure 32: PAC result of delta and gamma

In the days to come, we will explore whether there is such a coupling relationship in the state of meditation and thinking. If there is, we will try to study these differences between different brain regions in the two states. Finally, apply the results to our final results-"classifiers".

As for the calculation method, firstly, the theta (or delta) and gamma signals in the meditative state and thinking state are extracted respectively. Then, the amplitude and phase are extracted by the Hilbert transform. Data processing is carried out by means of phase locking value. We will analyze the difference PAC result between the two states.

3.3 Experienced meditators recruitment

In consideration of the requirement of comparative experiment, more experienced meditators are expected for our experiment. So far, among our experiment subjects, only one people who has long-time professional meditation experience, the others almost have no meditation related activities before. According to our initial analysis, there exists obvious difference between experienced meditator and non-experienced one. There are many variables who account to the influence. So it is indispensable to recruit more experienced meditators to get involved in our experiments. If things go well, more data analysis on the difference between two phases(solving question phase and meditation phase) as well as the difference between different levels' meditators, Will enable us to have a deeper comprehension on EEG during relaxation.

3.4 Exhibition in the CS^2

CS^2 on Thursday, March 28, is the second edition of CS2, the Scientific Congress of the Saclay Campus.

The day revolves around four axes: Evolution & Dynamics, Intelligibility, Interactions, Risks and Dangers.

Excellent researchers from the Saclay Plateau and elsewhere will present their work at conferences, punctuated by visits to laboratories and scientific stands.

In consideration that our research is also about interaction, we are deciding to have one our own stall in CS^2. There is only less than one month left. Once the decision made, several improvements need to be done:

(a) Finish the data analysis on the correlation between the EEG and biomarkers during two different phases.

(b) Build an initial classifier of relaxation and active thinking status according to the EEG signal combining with the other biomarkers.

(c) Create a simple interaction based on the classifier. For example, one interaction of emoji showing: When the system detected the relaxation status, the screen will turn to a smile face, else a sad face.

Appendices

A

Escape Dungeon

If the subject is a female: prince $< - >$ princess

The princess has fallen into a deep sleeping after touching the cursed spinning wheel. A hundred years have passed and a prince from another family spies the hidden castle during a hunting expedition. His attendants tell him differing stories regarding the castle: within the castle lies a beautiful princess who is doomed to sleep for a hundred years until a king's son comes and awakes her. The prince then braves the tall trees, brambles and thorns which part at his approach, and enters the castle. However... you, the prince, cannot enter the princess's room until he has solved every challenge in the 5 upcoming rooms.

The first room is called: 24 room. You are given 4 cards, with a number on each card. You can only use addition, subtraction and multiplication one time to get the final result that should be 24. Your cards are: 4,3,8,1 (repeat). You can change the order of the card. How can you get 24 with these cards?

—45s—

The prince is very intelligent, and the moment he solves out the problem, the door leading to the next room is opened.

The second room is called: Give me four. What comes to your eyes are two glass cups, their volumes are respectively 5L and 3L. Then there is a magical flower nearby that needs to be watered with exactly 4L in order to bloom and trigger the opening of the door. How can you get 4L from these cups?

—45s—

The prince is intelligent. So, the door leading to the next room is successfully opened.

The third room is called: The lost city. Several letters are incised on the wall: pitiful, attentive, rapid, intelligent, strange, generous, neat, obscure, ubiquitous. The lost city is hidden in the first letter of these nine letters. So the prince looks at these letters again: pitiful, attentive, rapid, intelligent, strange, generous, neat, obscure, ubiquitous. What name of a faraway city can you form with these letters?

—45s—

Wow amazing! It is his favorite city. He definitely wants to go there for one exchange semester. The door to the fourth room opens.

The forth room is called: Unsolved age. There is a lock with a two-digits password, it reads that only the right age of the daughter can open the lock. The prince looks around and find three statues that look like a family: the mother, the father and the daughter. The father says: I am 39 years old, I am 6 years older than my wife. The mother says: in 3 years, I will be 3 times older than my daughter. How old is the daughter?

—45s—

A piece of cake for our clever prince. The door opens, and he sees the beautiful princess lying on a bed in a glass room. She is so beautiful that the prince wants to awake her as soon as possible. If he passes the fifth door, he can save the princess.

This final room is called: The mirror world. Only entering the right time, the door can be opened. If you are wrong for three times, the princess will be constraint here forever. The prince looks up, he finds a big clock without numbers on its surface. while its hour hand pointed to the middle place of 5 o'clock and 6 clock, and its minute hand pointed to the place of 8 o'clock, so he tries to enter at 5:40... but nothing happens. Suddenly he remembers the name of this room. It is the mirror world. So the things should be inversed. At what time should he enter?

—45s—

And finally, the last door opens.

Finally he comes across the chamber where the Princess lies asleep on the bed. Struck by the radiant beauty before him, he falls on his knees before her. The enchantment comes to an end by a kiss and the princess awakens and converses with the prince for a long time.

B

Questionnaire

Story phase : what's your opinion?

Please answer the following questions according to how you felt during the previous phase.
For each affirmation, place the cursor depending on how strongly you agree.

1. **NAME First name**

2. **Enigmas solved :**
Plusieurs réponses possibles.
- [ ] 1
- [ ] 2
- [ ] 3
- [ ] 4
- [ ] 5

3. **You kept your focus during the whole phase.**
Une seule réponse possible.

	1	2	3	4	5	
Not true at all						Completely true

4. **You did NOT feel lost at any point during the phase.**
Une seule réponse possible.

	1	2	3	4	5	
Not true at all						Completely true

5. **All questions were understandable.**
Une seule réponse possible.

	1	2	3	4	5	
Not true at all						Completely true

6. **You felt intellectually stimulated by the questions.**
Une seule réponse possible.

	1	2	3	4	5	
Not true at all						Completely true

7. **The difficulty and time given for each question were:**
Une seule réponse possible.

- Generally too hard/not enough time
- Appropriate
- Generally too easy/too much time
- Sometimes too hard, sometimes too easy
- Autre : ____________________

8. **Comments:**

____
____
____
____
____

Meditation phase : what's your opinion?

Please answer the following questions according to how you felt during the previous phase.
For each affirmation, place the cursor depending on how strongly you agree.

1. **NAME First name**

2. **Respiration count :**

3. **You kept your focus during the whole phase.**
   Une seule réponse possible.

	1	2	3	4	5	
Not true at all	◯	◯	◯	◯	◯	Completely true

4. **Your mind often wandered out of your control.**
   Une seule réponse possible.

	1	2	3	4	5	
Not true at all	◯	◯	◯	◯	◯	Completely true

5. **You felt increasingly relaxed throughout the phase.**
   Une seule réponse possible.

	1	2	3	4	5	
Not true at all	◯	◯	◯	◯	◯	Completely true

6. **You felt increasingly self-aware throughout the phase.**
   Une seule réponse possible.

	1	2	3	4	5	
Not true at all	◯	◯	◯	◯	◯	Completely true

7. **You felt sleepy at times.**
   Une seule réponse possible.

	1	2	3	4	5	
Not true at all	◯	◯	◯	◯	◯	Completely true

8. **The duration of this phase was :**
Une seule réponse possible.

- Too short
- Appropriate
- Too long

9. **This experiment has made your day better:**
Une seule réponse possible.

	1	2	3	4	5	
Completely true						Completely true

10. **Comments:**

Fourni par
Google Forms

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