Aix-Marseille University

Internship Report

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1 Introduction

Internship took place on April and May 2020 in Aix en Provence. The aim of the internship was to apply new statistical tools to EEG signal at rest state. Then compare the effects with EEG signals before and after psychology therapy.

Statistical tool which was mentioned earlier is Frequency-Specific Change-Point Detection (FreSped) method and will be explained in futher part of report. I had possibility to discover this method on Brain Imaging classes which were held by professor Freyermuth at Aix Marseille University. This classes as well as an internship were part of my Erasmus exchange at the university.

EEG signal which I worked with was measured as a part of psychologist experiment which is described in [1]. Experimental group was 17 military veterans diagnosed with post traumatic stress disorder (PTSD) recruited in the military hospital Sainte-Anne at Toulon, France. Military patients received therapy - eye movement desensitization and reprocessing (EMDR). EMDR is a psychotherapy of choice for the treatment of PTSD. EMDR is a form of psychotherapy developed by Francine Shapiro. In the therapy the person is asked to recall distressing images then the therapist directs the patient in one type of stimulation for example side-to-side eye movements or hand tapping.Patients could receive a maximum of eight EMDR sessions which were planned every 7 to 17 days. EEG was measured before and after treatment.

The report is organized as follows. Chapter 2 present an explanation of technical issues. Chapter 3 contains analysis with step by step procedures with description. The summary of work can be found in chapter 4. The code which was used to analyse EEG signal was placed in Appendix.

2 Technical description

This chapter gives better insight into the topic. It contains the descriptions of dataset and used method.

Dataset: data set contains 34 files (.vhdr) of EEG signal from 17 participants before treatment and 17 files of EEG signal from the same 17 participants after treatment. Every EEG signal is divided into two parts: rest part and trauma part. Rest part is a segment where participant was asked to relax and imagine f.e. "safe place". Trauma part is a segment where participant was asked to remind traumatic event from past. EEG signals were recorded on 64 channels. Below,the example of 64-channels location on sculpture is shown, [4].

File: file .vhdr contains the metadata and links to the other two files, .vmrk contains the triggers and other events in the samples, and .eeg contains the signals at every sample for every channel recorded. Function read_vhdr() (R) creates a list with data frames for the signal, events, segments information, and incorporates in its attributes generic EEG information.

In analysis FreSpeD method was used. The idea is to find change points and their number and then knowing this things to divide data into peacewise-stationary time series.

Change point detection. Change points are abrupt variations in time series data. Change point analysis is research area which consist in testing the presence of changes in mean, variance or trend in time series data.

Arguably the simplest, 'canonical' model with change-points is that of the form:

$$x_T = F_T + \varepsilon_T,\ T = 1, \ldots, T,$$

where f_t is a deterministic, one-dimensional, piece wise-constant signal with change-points

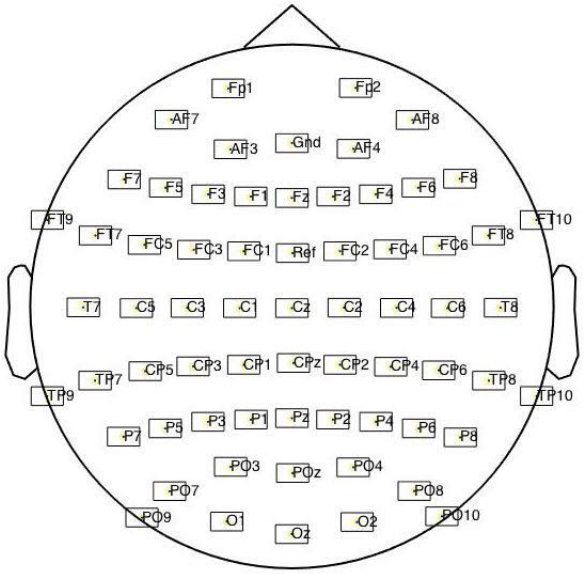

Figure 1: Visualization of 64 channels.

whose number and locations are unknown. More about changing point [2]. On the graph below, an example of time series with few changing points was presented, [2].

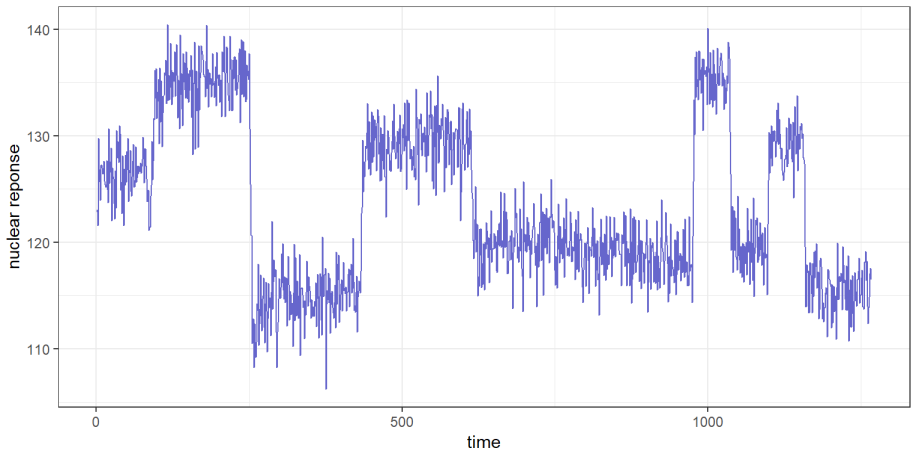

Figure 2: Example of time series with changing points.

Algorithm of detecting change points is a sequential approach: first, one change point is detected in the complete input signal, then series is split around this change point, then the operation is repeated on the two resulting sub-signals.

Figure 3 shows below the scheme of how this procedure works, [3].

FreSpeD method: was deeply describe in work [5]. Authors of the paper delivered also R package *FreSped*. The method is based on binary segmentation algorithm and CUSUM test statistics. In time series analysis, the CUSUM statistics use the sequence of residual deviations from a model to indicate whether the autoregressive model is misspecified. FreSpeD method:

- estimate unknown autospectral and cross-coherance quantities
- estimate number and location of change points - this is the main point in the whole method. We use in this step binary segmentation algorithm which uses itself CUSUM. Its disadvantage is that the necessary is a relatively large space between breaks.

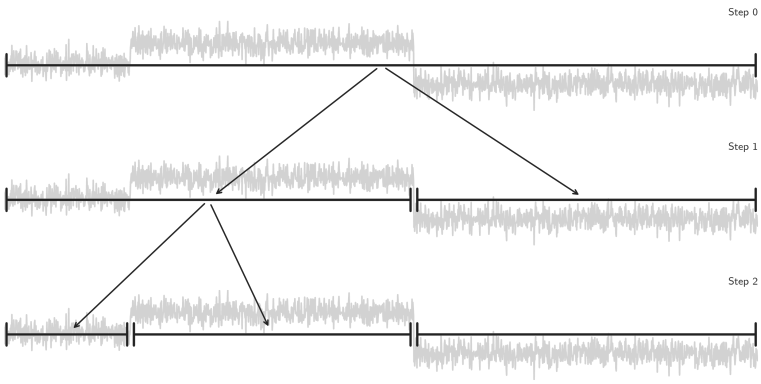

Figure 3: Schematic view of the binary segmentation algorithm.

3 Analysis

The analysis was started with research of programs where EEG signal analysis saved in .vhdr file is possible. The following possibilities were found:

1. MatLab ([9], [10])
2. Python ([6])
3. R ([7], [8])

Program which was chosen to work with was R, mainly from technical issues but recommended program is MatLab because of precise pre-processing process and variety of visualization options. Before applying FreSpeD method to EEG signal, pre-processing step is necessary. Pre-processing was made on all of the 64 channels but applying FreSpeD method was made on chosen 13:26 channels, which are: "FC6", "T7", "C3", "Cz", "C4", "T8", "TP9", "CP5", "CP1", "CP2", "CP6", "TP10", "P7", "P3". Computing on all 64 would be very time consuming, that is why 13 channels were chosen.

3.1 Pre-processing

This subsection will show how to prepare EEG signals to apply method. More information about pre-processing EEG can be found [10], [11] or [12]. In pre-processing we will focus on further steps:

- **Deleting bad channels.** Bad channels can result from a cap shift (usually due to muscle contraction or the participant scratching their head) resulting in the gel not forming a good connection between scalp and electrode, sweat, poor cap fit, or poor gelling of the cap. That is why, bad channels should be deleted. Another way of deal with bad channel is interpolation, more in [11].
- **Re-referencing.** Sometimes it is called also the offline reference. The idea is to express the voltage at the EEG scalp channels with respect to another, new reference. It can be composed of any recorded channel or an average of several channels.
- **Filtering.** Removing very high and very low frequencies that are unlikely to contain the signal that is relevant to us. Low-pass filter was set 0.1 Hz and high-pass filter 80 Hz.

- **Artifacts.** Artifacts are parts of the recorded signal that arise from sources other than the source of interest (i.e., neuronal activity in the brain). As such, artifacts are a form of interference or noise relative to the signal of interest. Possible causes of such interference: environmental artifacts, instrumentation artifacts, biological artifacts. Example of artifact is eye movement.

The R library which were used in this analysis is limited therefore artifacts wasn't deleted before applying FreSpeD method. This issue can cost wrong interpretation of output. Nevertheless, it is easy to check amount of artifacts. 9th patient on which pre-processing will be showed, has 0 artifacts in the EEG signal.

When interpreting number of changing points, one has to remember that in combining fragments after and before treatment time duration of EEG signal can be different in those fragments. On example of 9th patient we can observe that baseline before treatment has 50 ms and baseline after has 36 ms. If it comes to trauma segment we have 30 ms before treatment and 51 ms after treatment.

Removing bad channels is a critical step particularly for average referencing. This is because average reference signal is an average of all channels. Having channels that are noisy all the time, including such channels to average will introduce noise to all the channels. That is why pre-processing will be started with visualisation of raw data and then deleting bad channels. Raw EEG data is a complex wave form of not simply brainwave activity, but the electrical activity of nearby muscles, electrode motion interference and what is called "ambient noise" (caused by electrical supplies and appliances in the room). The process will be presented on participant 9 before treatment.

Below, on figure 4 we can see raw EEG data of patient 9 before treatment.

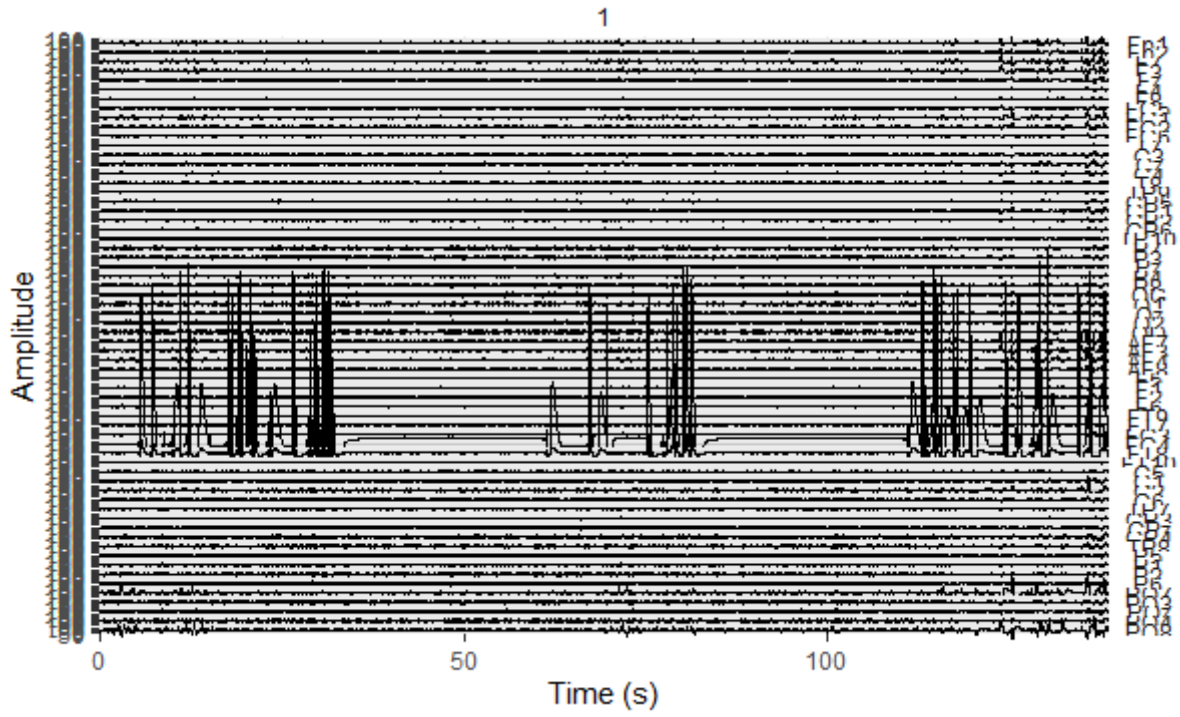

Figure 4: Participant 9 before treatment - raw EEG data

First step is excluding channels FC4, FT8 as they are bad channels. On plot 5 we can see how it looks like after this step.

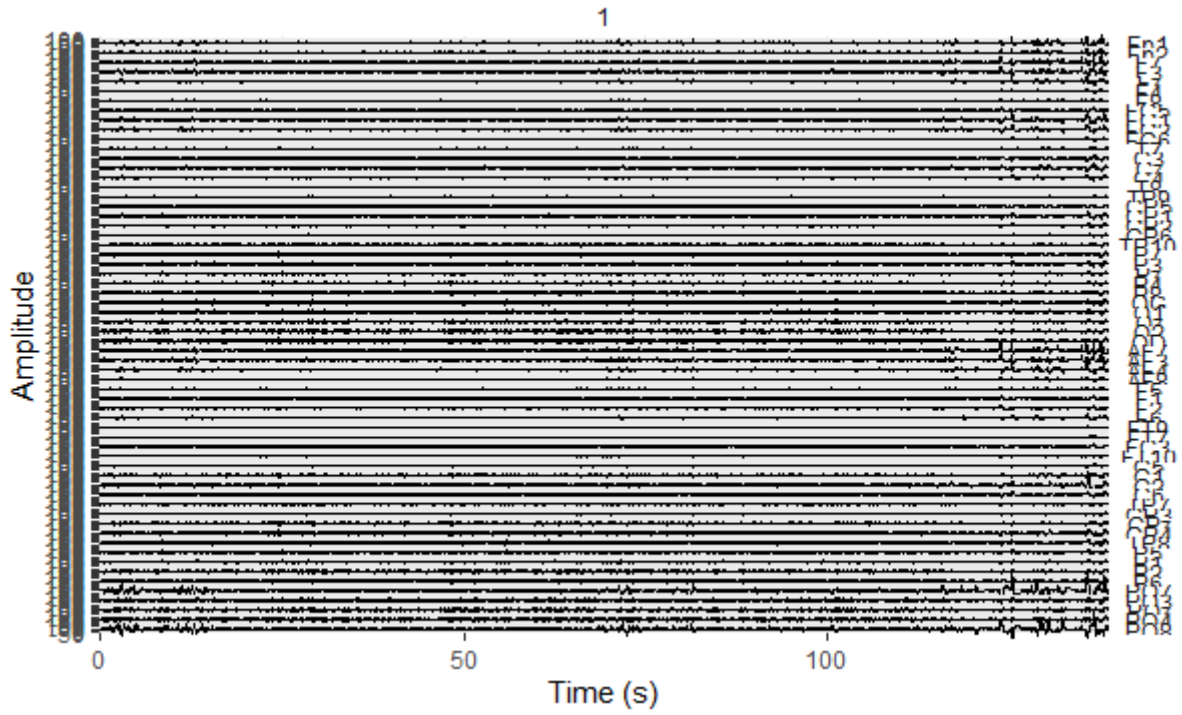

Figure 5: Participant 9 before treatment - after excluding channels FC4, FT8

The figure isn't very clear when plotting all of the channels. That is why further steps of pre-processing will be shown only on chosen channels. The channel which will present steps of pre-processing will be used in next subsection to present FreSpeD method.

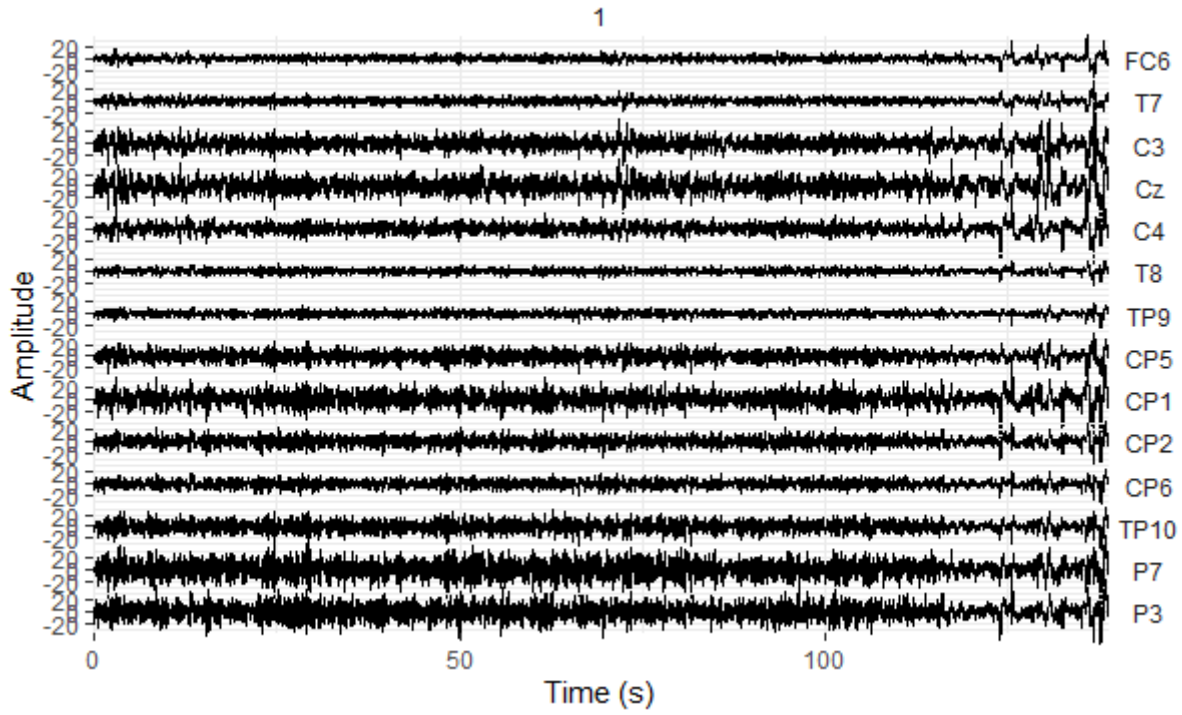

Figure 6: Participant 9 before treatment - chosen channels

On figure 7 we can observe EEG signal after re-referencing using average from the channel after excluding bad one.

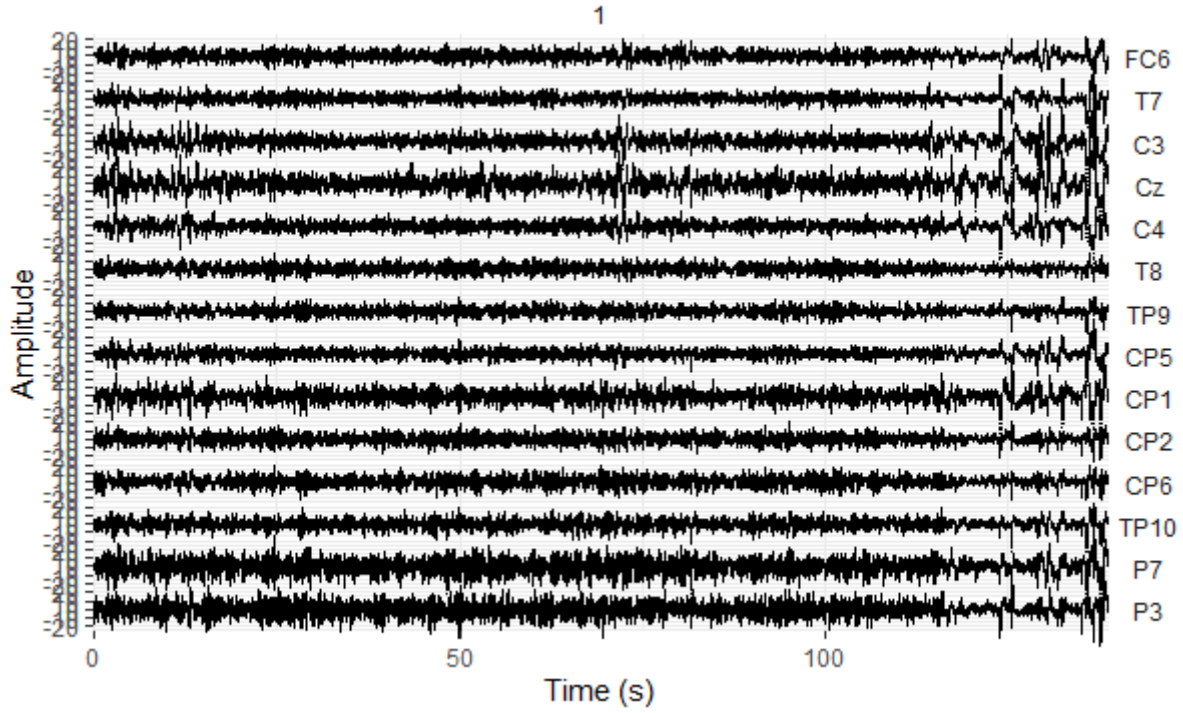

Figure 7: Participant 9 before treatment - after re-referencing

Figure 8 present EEG signal after filtering. As it was mentioned in the description of pre-processing steps low-pass filter was set on 0.1Hz and high-pass filter 80Hz.

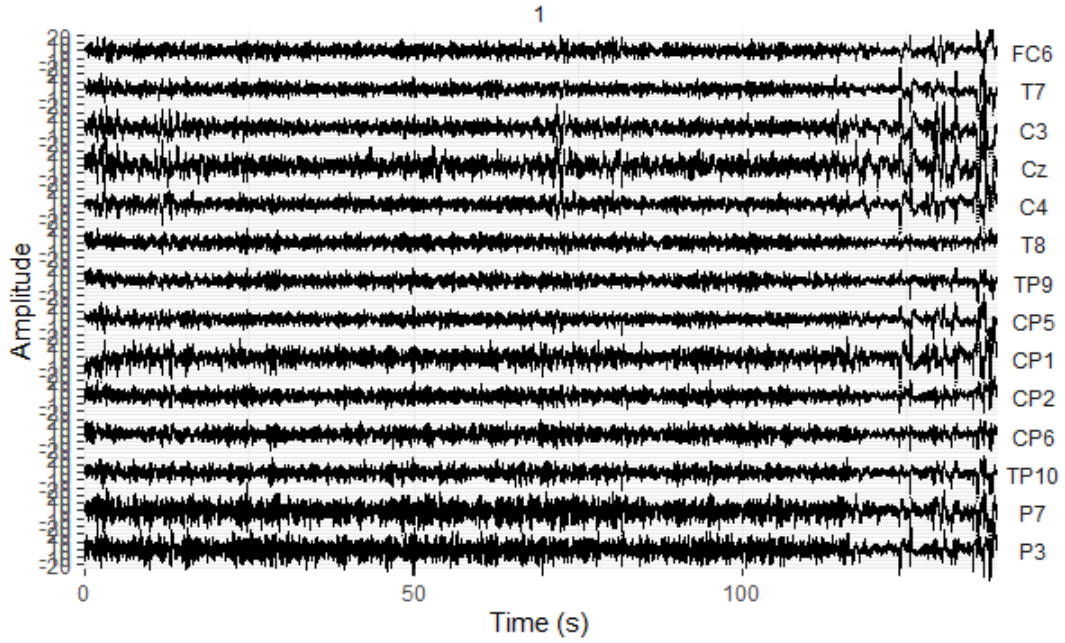

Figure 8: Participant 9 before treatment - after filtering

The last step will be to check the number of artifacts. So far every step was presented on

the whole EEG signal. Now, we will focus on fragments which we are interested in. Those are *baseline* and *trauma*. The signal outside those fragments are noisy that is why they could generate high number of artifacts. 9 and 10 shows number of artifacts on those two fragments.

```
> d51 <- eeg_segment(d5, .description == "BaselineDÄ,Â©but", end = .description == "Base
lineFin") %>%
+   select("FC6","T7","C3","Cz","C4","T8","TP9","CP5","CP1","CP2","CP6","TP10","P7","P3"
) %>%
+   eeg_artif_minmax(threshold = 100, window = 200, unit = "ms")
# Total of 1 segments found.
# Object size in memory 61.2 Mb after segmentation.
# Number of intervals with artifacts: 0
```

Figure 9: Participant 9 before treatment (baseline) - artifacts

```
> d52<-eeg_segment(d5, .description == "TraumaDÄ,Â©but", end = .description == "TraumaFi
n") %>%
+   select("FC6","T7","C3","Cz","C4","T8","TP9","CP5","CP1","CP2","CP6","TP10","P7","P3"
) %>%
+   eeg_artif_minmax(threshold = 100, window = 200, unit = "ms")
# Total of 1 segments found.
# Object size in memory 36.7 Mb after segmentation.
# Number of intervals with artifacts: 0
```

Figure 10: Participant 9 before treatment (trauma) - artifacts

3.2 Applying FreSped method

After pre-processing, FreSped method will be applied separately to baseline segment and trauma segment. In this paragraph we will compare after and before EMDR treatment output.

First, we will compare baseline segment of participant 9 before and after EMDR. Below on figures 11 and 12 we can observe number of change point over frequency. On figures 13 and 14 we can compare number of change point in time.

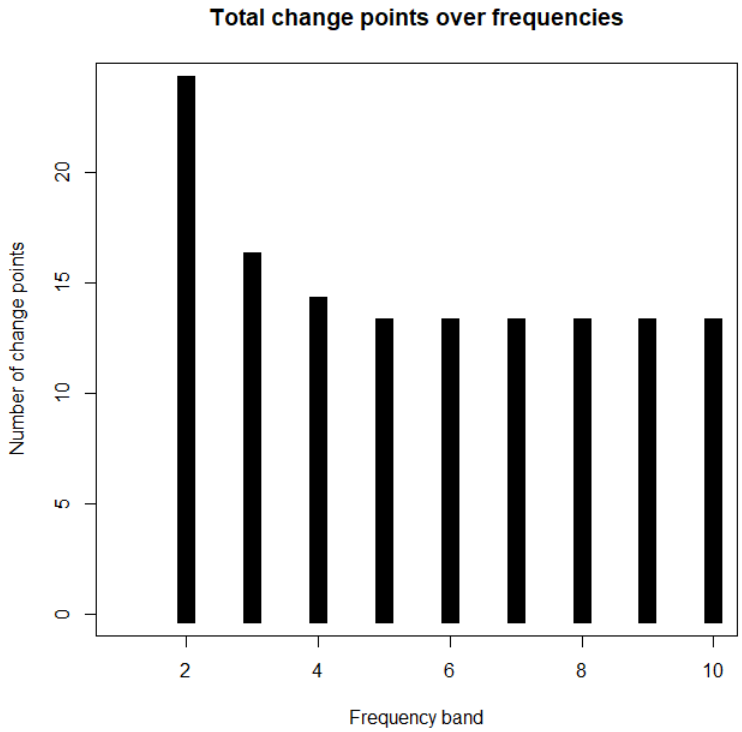

Figure 11: Participant 9 before treatment (baseline) - change point over frequency

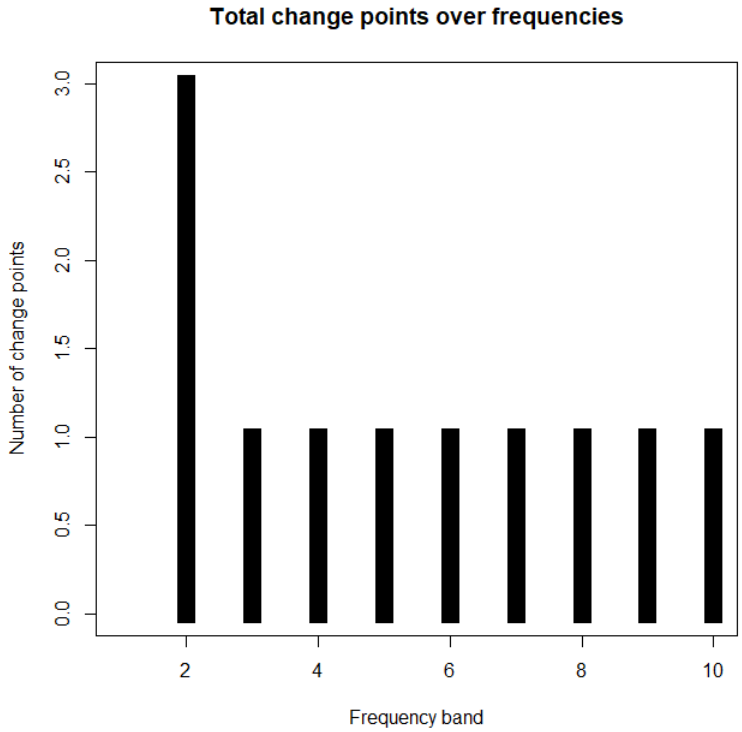

Figure 12: Participant 9 after treatment (baseline) - change point over frequency

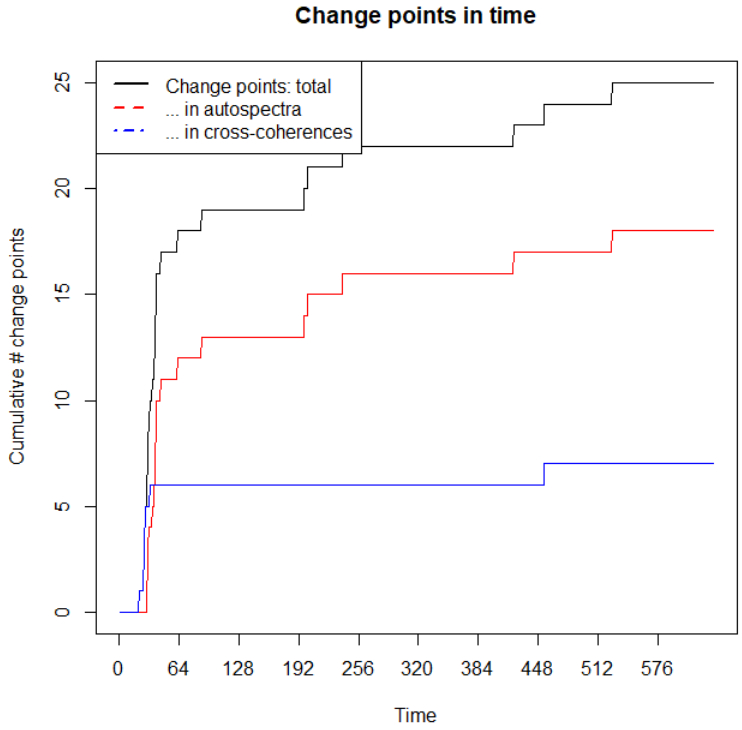

Figure 13: Participant 9 before treatment (baseline) - change point in time

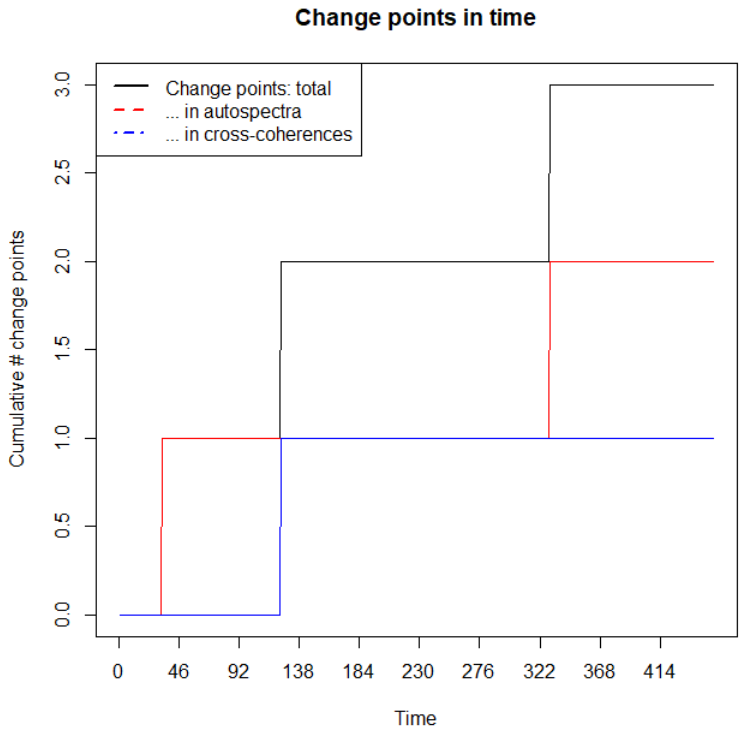

Figure 14: Participant 9 after treatment (baseline) - change point in time

Now, on figures 15 and 16 we can observe number of change point over frequency in participant 9 in trauma segment. On figures 13 and 18 we can compare number of change point in

time in participant 9 in trauma segment.

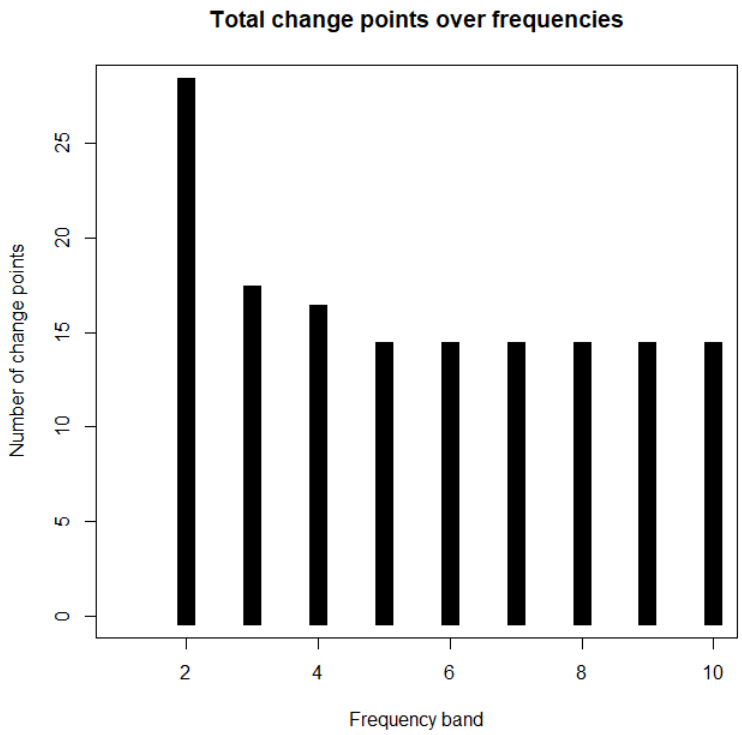

Figure 15: Participant 9 before treatment (trauma) - change point over frequency

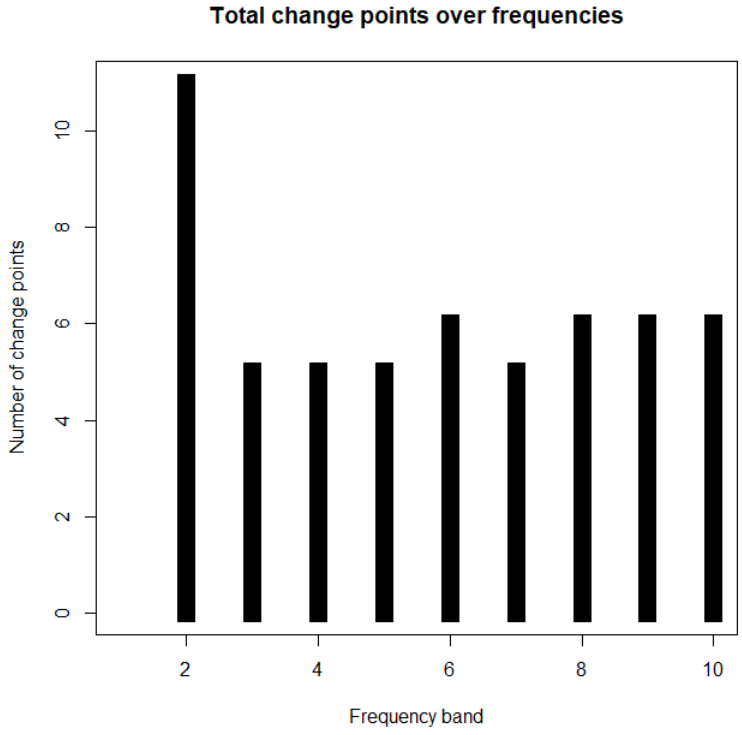

Figure 16: Participant 9 after treatment (trauma) - change point over frequency

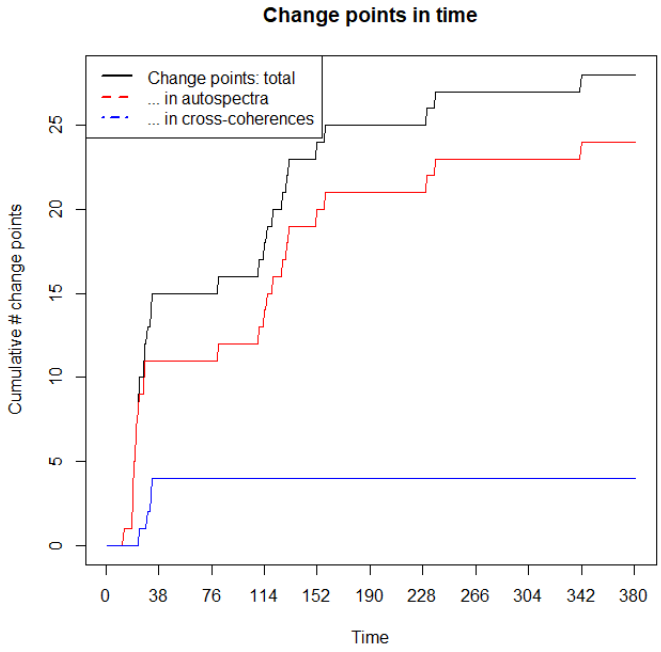

Figure 17: Participant 9 before treatment (trauma) - change point in time

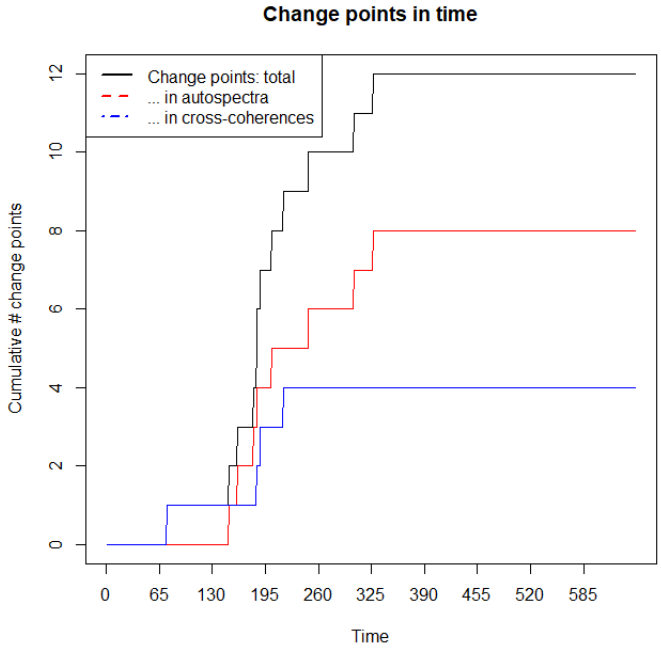

Figure 18: Participant 9 after treatment (trauma) - change point in time

4 Conclusion

The main idea of this report was to present step by step instructions and explain them to create manual for users where they can find all the necessary information to understand the topic. Participant 9 was chosen as an example to show how important is visualization of the raw data to check occurrence of bad channels (when not excluded can affect analysis badly). We could see on graphs is section 3.2 that number of changing points was less in participant 9 after treatment (as well in baseline as in trauma segment). When considering separately number of change points in cross-coherences and autospectra conclusion would be the same. It is important also that segments can have different time duration. Participant 9 baseline segment before treatment has 50 ms, after treatment has 36 ms. Participant 9 trauma segment before treatment has 30 ms, after treatment has 51 ms. So, it total we will get 0.5 change point per ms in baseline before treatment, 0.08 change point per ms in baseline after treatment, 0.93 change point per ms in trauma before treatment and finally 0.23 change point per ms in trauma after treatment.

This internship gave me possibility of learning real data analysis, applying statistics method to EEG signal and also giving an oral reports. After finishing internship I got more familiar with R programming and more aware about amount of information, tutorials and self-development materials for technical skills in the internet.

I would like express my gratitude to professor Jean-Marc Freyermuth, professor Arnaud Rey and professor Stephanie Khalfa for organizing and giving me the opportunity of having this internship. I am grateful for your help, explanation of problems and also giving ideas and tips professional, social and travel.

5 Appendix

In this section, there will be presented code of pre-processing of EEG signal and applied FreSpeD method. The code was written in R.

```
library(dplyr)
library(stringr)
library(eeguana)
#to download eeguana put: devtools::install_github("bnicenboim/eeguana")
library(FreSpeD)
library(breakfast,quietly=TRUE)
library(ggplot2,quietly=TRUE)
library(eegkit,quietly=TRUE)

d <- read_vhdr("...")

#PREPROCESSING
d <- eeg_filt_band_pass(d, freq = c(.1, 80))
d <- eeg_rereference(d, ref = channel_names(d))

d11 <- eeg_segment(d, .description == "BaselineDebut",
end = .description == "BaselineFin")
d12 <- eeg_segment(d, .description == "TraumaDebut",
end = .description == "TraumaFin")

#APPLYING METHOD
d11 <- d11[[".signal"]]
a1 <- d11[,13:26] #BASELINE
d12 <- d12[[".signal"]]
a2 <- d12[,13:26]#TRAUMA
cp11 <- FreSpeD(a1, windowLen = 200, plot = FALSE)
cp12 <- FreSpeD(a2, windowLen = 200, plot = FALSE)
FreSpeD_plot(X=a1, cp=cp11, id=1, windowLen = 800)
FreSpeD_plot(X=a2, cp=cp12, id=1, windowLen = 800)

FreSpeD_summary(cp11, channelNames = names(a1), plot = TRUE)
FreSpeD_summary(cp12, channelNames = names(a2), plot = TRUE)
```

References

[1] Rousseau, P. F., Malbos, E., Verger, A., Nicolas, F., Lançon, C., Khalfa, S., & Guedj, E. (2019). Increase of precuneus metabolism correlates with reduction of PTSD symptoms after EMDR therapy in military veterans: an 18F-FDG PET study during virtual reality exposure to war. European journal of nuclear medicine and molecular imaging, 46(9), 1817-1821.

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