

EEG DATA PROCESSING IN ADHD DIAGNOSIS AND NEUROFEEDBACK

Zoran Šverko* – Saša Vlahinić – Miroslav Vrankić – Ivan Markovinović

Department of Automation and Electronics, Faculty of Engineering, University of Rijeka, Vukovarska 58, 51000 Rijeka, Croatia

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Abstract:

In this paper, EEG data processing was conducted in order to define the parameters for neurofeedback. A new survey was conducted based on a brief review of previous research. Two groups of participants were chosen: ADHD (3) and non-ADHD (14). The main part of this study includes EEG signal data pre-processing and processing. We have outlined statistical features of observed EEG signals such as mean value, grand-mean value and their ratios. It can be concluded that an increase in grand-mean values of power theta-low beta ratio on Cz electrode gives confirmation of previous research. The value of alpha-delta power ratio higher than 1 on C3, Cz, P3, Pz, P4 in ADHD group is proposed as a new approach to classification. Based on these conclusions we will design a neurofeedback protocol as a continuation of this work.

1 Introduction

Attention-deficit hyperactivity disorder (ADHD) is a mental disorder of the neurodevelopmental type [1], [2]. It is characterized by problems with paying attention, excessive activity or difficulty in controlling behavior which is not appropriate for a person's age [3], [4]. When it comes to children, problems with paying attention may result in poor school performance [3]. As of 2015, ADHD is estimated to affect about 51.1 million people globally [5]. Neurofeedback is a type of biofeedback that measures brain waves to produce a signal that can be used as a feedback to teach self-regulation of brain function. Video or sound are commonly used for neurofeedback [6]. In neurofeedback, electroencephalography (EEG) signals of ADHD participants are recorded in real time in order to stimulate participants with sound, video and pictures.

EEG is an electrophysiological monitoring method that records electrical activity of the brain [7]. Thus, EEG provides signatures of neural activities [8]. Furthermore, multimodal approach is advised for the cure of ADHD. This approach is a combination of different types of treatments: medication (stimulants), psychoeducation, psychological treatment. As a consequence of personal preferences, some participants or their parents are unwilling to use medication. Because of that reason, neurofeedback has a great opportunity to become a drug-free alternative treatment for ADHD [9]. In order to record the signals, electrodes are commonly placed on the scalp. Figure 1 shows the placement of electrodes. EEG signals can be recorded with a different number of electrodes. In general, one or a few electrodes are used during neurofeedback protocol. We can observe EEG signals as waveforms that are defined by their amplitude, frequency and

* Corresponding author. Tel.: +385 51 505720
E-mail address: zsverko@riteh.hr

place of origin. EEG waveforms are usually separated into delta, theta, alpha, beta and gamma waves. Delta waves usually appear in a person's deep sleep, in children and in case of severe brain illnesses. Their frequency lies between 1 to 4 Hz, the amplitude ranges from 60 to 100 μV and the place of origin is the cortex. The theta wave frequencies are between 4 and 8 Hz, the amplitude goes up to 70 μV , and the places of origin are the temporal and the parietal lobe. They appear in all age groups and are caused by stress during examination tests [10], emotional disappointment, frustration and also idling thinking. A frequency of 8 to 13 Hz, amplitude up to 50 μV are typical parameters of alpha waves. The place of origin is the occipital lobe. They most often appear in an awake but relaxed state, when participants are unfocused. Beta waves appear during mental activity. Their frequency is between 13 and 30 Hz and their amplitude amounts up to 20 μV . The places of origin are the frontal and the parietal lobe. During the EEG signal recording, after participant's eyes are closed and the participant opens the eyes, alpha waves are blocked and beta waves appear. Gamma waves appear during high-level information processing. Their frequency is from 35 to 45 Hz.

In literature, there are several different approaches to the analysis and comparison of EEG signals in participants suffering from different types of disorders and with different professions. Bhattacharya [11] gives a description of phase synchrony analysis of EEG. Differences in two groups, musicians and non-musicians were compared. An increase in phase synchrony, in delta and, more pronounced, in gamma frequency bands was observed in musicians, when the music listening task is compared to the resting phase or to the control condition. An increase in delta band was observed in non-musicians [11].

Differences between EEG signals of visual artists and non-artists were analyzed [12] using the power spectral density (PSD) during visual perception and mental imagery of paintings. The relative power values of the EEG signals were calculated [12]. The relative low beta (15 – 18 Hz) enhancement in Fp1, was proposed as the neurofeedback protocol for visual perception and mental imagery improvement of novice artists [12]. The difference between chess experts and novices was found in the delta frequency band, during resting time [13]. In the case of expert golfers, an increase in the right-hemisphere alpha wave activity is related to decreased errors [14]. There are numerous examples in literature applied in patients with psychological disorders. The relative

power analysis of EEG signals has been conducted for participants with medically diagnosed autism [15]. The increasing value of the relative power in the gamma frequency band was shown during 18 sessions of neurofeedback protocol.

Commonly used methods and achievements of EEG diagnosis of ADHD were analyzed [16, 17]. Theta-beta power ratio (TBR) is a commonly used index for distinguishing between ADHD and non-ADHD, but unique and widely confirmed measure has not been determined so far. The increased value of the power TBR is thought to be indicative of a subgroup of ADHD [18] and less frequently used for classification of participants with ADHD compared to control group (non-ADHD) [19, 20]. In these papers, a measure was proposed stating that the mean TBR value of ADHD group exceeds 1.5 times standard deviation of mean TBR value for non-ADHD. The accuracy of diagnosis using this measure was 84%. EEG signals were recorded for 96 ADHD and 33 non-ADHD participants, with recording time of 90 sec [20]. The measuring was done on Cz electrode. The recordings of EEG signals in [21] were made on 97 ADHD and 62 non-ADHD participants. The differences in TBR had an 89% accuracy in assessment. EEG signals were recorded on Cz electrode and the recording time was 10 min. In the above-mentioned studies, the TBR measure had an excellent accuracy, but in the following studies it was not the case. In [22], EEG signals of 54 non-ADHD and 164 ADHD participants were studied, examined with the recording time of <10 minutes and the accuracy of diagnosis of the observed group was not calculated. The significant difference was seen in [22], in mean values and standard deviations of beta-theta ratio (BTR). Fp1 and Cz electrodes were observed in the research procedure. In [23], the study was conducted by using signals with 2 min recording time in 169 ADHD and 167 non-ADHD participants. In this research, electrodes of significance were Fz and FCz. Same as in the previously mentioned research, the accuracy wasn't given, but the mean value of TBR in ADHD participants was 38% higher than in non-ADHD. In [24], the absolute value of magnitude, the power value in theta and beta bands and their ratio were compared on Cz electrode with 63% accuracy of diagnostic using TBR differences (62 ADHD and 39 non-ADHD). Considering signals of 370 ADHD and 100 non-ADHD participants, in [25], the difference in TBR on Cz electrode was compared, and the obtained accuracy was only 38% (recording time was 5 min). In comparison, when measuring TBR signals on CZ in [26] and [27], the

accuracies of diagnostic were 53% (54 ADHD and 51 non-ADHD) and 49% (62 ADHD and 55 non-ADHD). In [28] many more electrodes were used for diagnosed disorder (9 frontal electrodes), and the differences in relative power of theta and beta bands, alpha-beta ratio and theta-alpha ratio were compared (7 ADHD and 3 non-ADHD, with a diagnose accuracy of 97%). In [29], the EEG signals of 80 ADHD and 59 healthy children were observed and power spectrum of each frequency band was calculated. One conclusion was that the power of beta band was significantly higher in ADHD participants [29].

In the treatment of ADHD most frequently used neurofeedback protocols are TBR, slow cortical potentials (SCP) and sensorimotor rhythm protocols [31, 32]. Neurofeedback trainings use skill learning principle to enable participants to acquire how to control their EEG and as a consequence of that change their brain state and activity to be approximate to a typically developing child [33]. A large number of participants is needed to analyze the effect of neurofeedback therapy [34].

Based on the results of previous studies, we decided to observe the mean and grand-mean values of magnitude and power theta-high beta ratios (THBR), but also the theta-alpha (TAR), theta-low beta (TLBR), alpha-delta (ADR) and delta-alpha (DAR) ratios on all epochs. In this study we decided to increase the number of electrodes and observe signals that were recorded on the F3, Fz, F4, C3, Cz, C4, P3, Pz and P4 electrodes, all shown in Figure 1 encircled in red.

2 Experimental investigation

2.1 EEG data signal processing

We used EEG raw data signal of people with ADHD and without ADHD. The recording conditions were opened eyes, closed eyes, hyperventilation, post-hyperventilation, body moving.

Figure 2 shows a block-diagram of data signal processing procedure. Raw data signals were normalized and DC component of observed signal was removed. The frequency range of interest is between 1 and 47 Hz. In the next step artifacts were removed. In neurofeedback, commonly used methods for artifacts use simple algorithms. We decided to remove artifacts in the following way: when the algorithm detects crossing over the maximum allowed value or minimum allowed value, the algorithm is searching backward the first zero

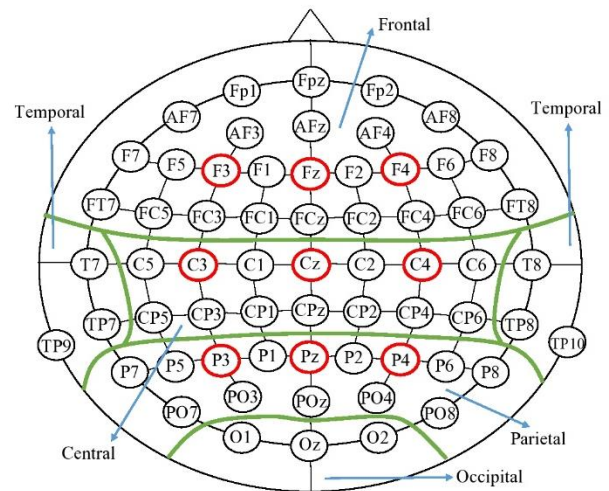


Figure 1. Placement of electrodes

crossing and forward the second zero crossing. Then the segment of the signal with values higher than the maximum allowable value or lower than the minimum allowable value is removed from further analysis. Figure 3 shows the visual description of artifacts' removal procedure. The procedure explained in this section was used for this preliminary study. We are planning to use a more complex way of artifacts removal in the future. The next step was a spectrum evaluation by using Fast Fourier Transform (FFT) [30]. The spectrum obtained by the FFT was divided into six observed frequency ranges (delta (δ_f))

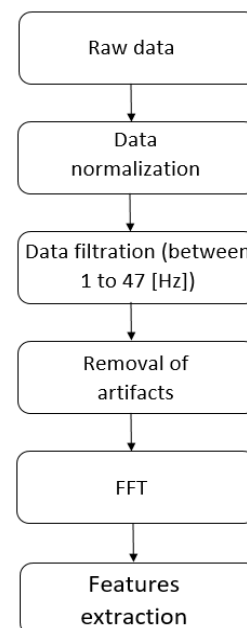


Figure 2. Block-diagram of observed data signal processing

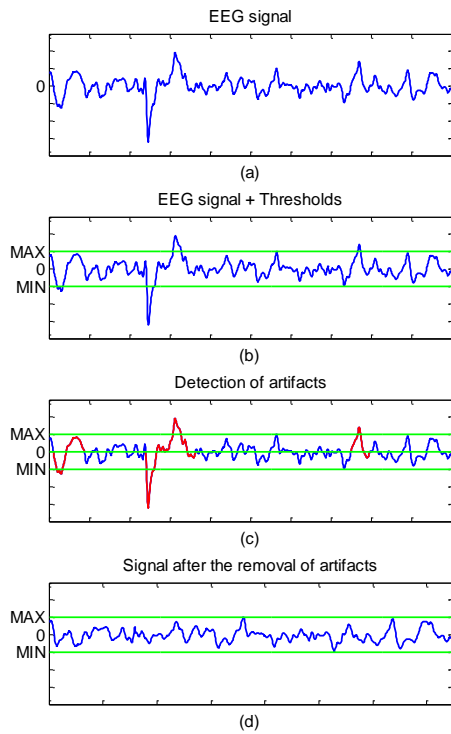


Figure 3. Removal of artifacts

1 – 4 Hz, theta (θ_f) 4 – 8 Hz, alpha (α_f) 8 – 13 Hz, low beta (β_{Lf}) 13 – 18 Hz, high beta (β_{Hf}) 18-30 Hz, gamma (γ_f) 35 – 45 Hz). For the purpose of this paper, we have divided the beta frequency range into low beta and high beta because of more detailed signal comparison within the beta frequency range. We used raw data signals of ADHD and non-ADHD participants with sampling frequency of 256 Hz. FFT was repeatedly applied on non-overlapping windows of 1 s duration. The result is the spectrum analysis with a frequency resolution of 1 Hz. Data were further averaged to obtain the mean value for 15 epochs as usually done in neurofeedback protocols.

2.2 Features

Features (power ratios, mean power value, grand mean power value, standard deviation, variance) were extracted and comparisons were made for two groups of subjects (ADHD and non-ADHD). The relative power value of each frequency band in one epoch was calculated with the formula:

$$P_{\Delta\delta} = \frac{\sum_{\Delta\delta_{band}} (f_i)^2}{\sum_{all} (f_i)^2}, \quad (1)$$

where $P_{\Delta\delta}$ is relative power of delta (δ) band per one epoch; f_i are FFT coefficients at i -th spectral component. The formula described above is also valid for other frequency bands ($\delta_f, \theta_f, \alpha_f, \beta_{Lf}, \beta_{Hf}, \gamma_f$).

3 Results and discussion

3.1 Comparing the obtained features

The results of previous studies indicate that 30-40 % of ADHD is thought to have an increased value of TBR as pattern of activity [17, 18, 35, 36]. Other studies mentioned in introduction indicate that an increased value of TBR can be used as an indicator of ADHD in comparison with non-ADHD.

We included seventeen participants, three with medically diagnosed ADHD and fourteen without the diagnosis.

The same processing procedure to detect and remove artifacts and extract TBR values was used for all participants.

In this paper, we have tried to confirm the assumption that ADHD group has higher TBR when compared to non-ADHD group of participants, which was shown in the previous researches. In addition, we have analyzed other ratios and new indicators for diagnosis of ADHD disorder have been found.

Figures 4 and 5 show grand-mean values (GM) of magnitude spectral distributions in ADHD and non-ADHD groups through all observing electrodes.

There is no difference in GM magnitude values of alpha and delta bands on electrodes F3, Fz and F4.

The same observation is confirmed for GM on C3, Cz and C4. However, there is bigger difference on electrodes P3, Pz and P4 for the ADHD group in alpha and delta bands as opposed to non-ADHD.

Table 1 shows mean values and GM values of TLBR and ADR on the Cz. The GM values TLBR and ADR on electrode Cz are 20.15% and 122.99% higher for the ADHD group in comparison with non-ADHD. Based on the percentage of difference in GM values which are calculated for both groups of participants and all epochs we can conclude that the main differences are seen in ADR.

Figure 6 shows GM values of TLBR and ADR on C3, Cz, C4, P3, Pz and P4 electrodes. The difference of TLBR between observing groups was confirmed only on Cz [20] and P4 electrodes in comparison with previous researches.

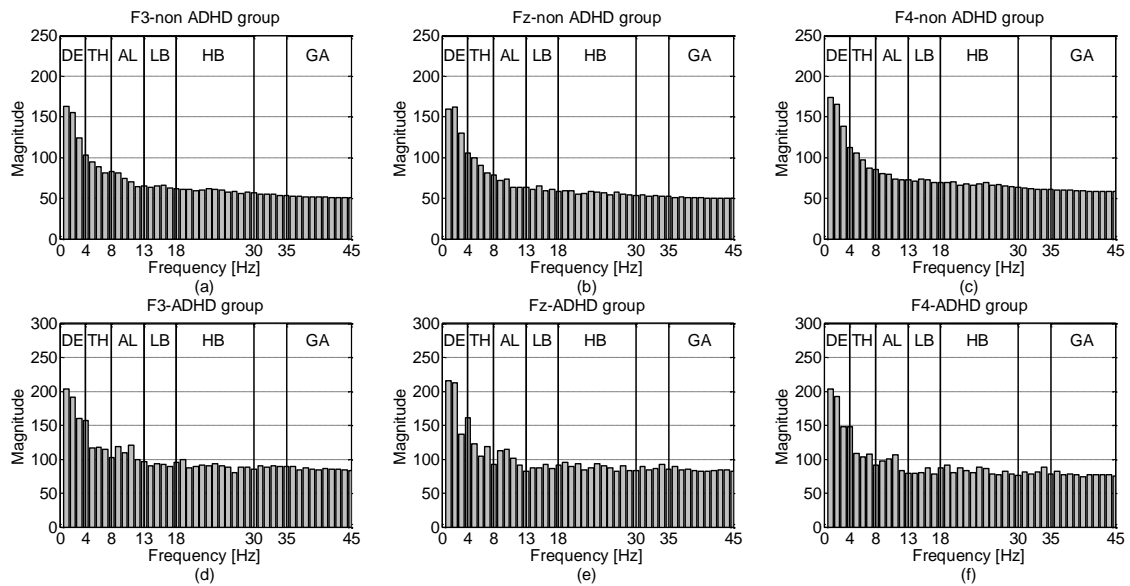


Figure 4. Grand-mean values of magnitude spectral distributions on F3, Fz and F4 electrodes)

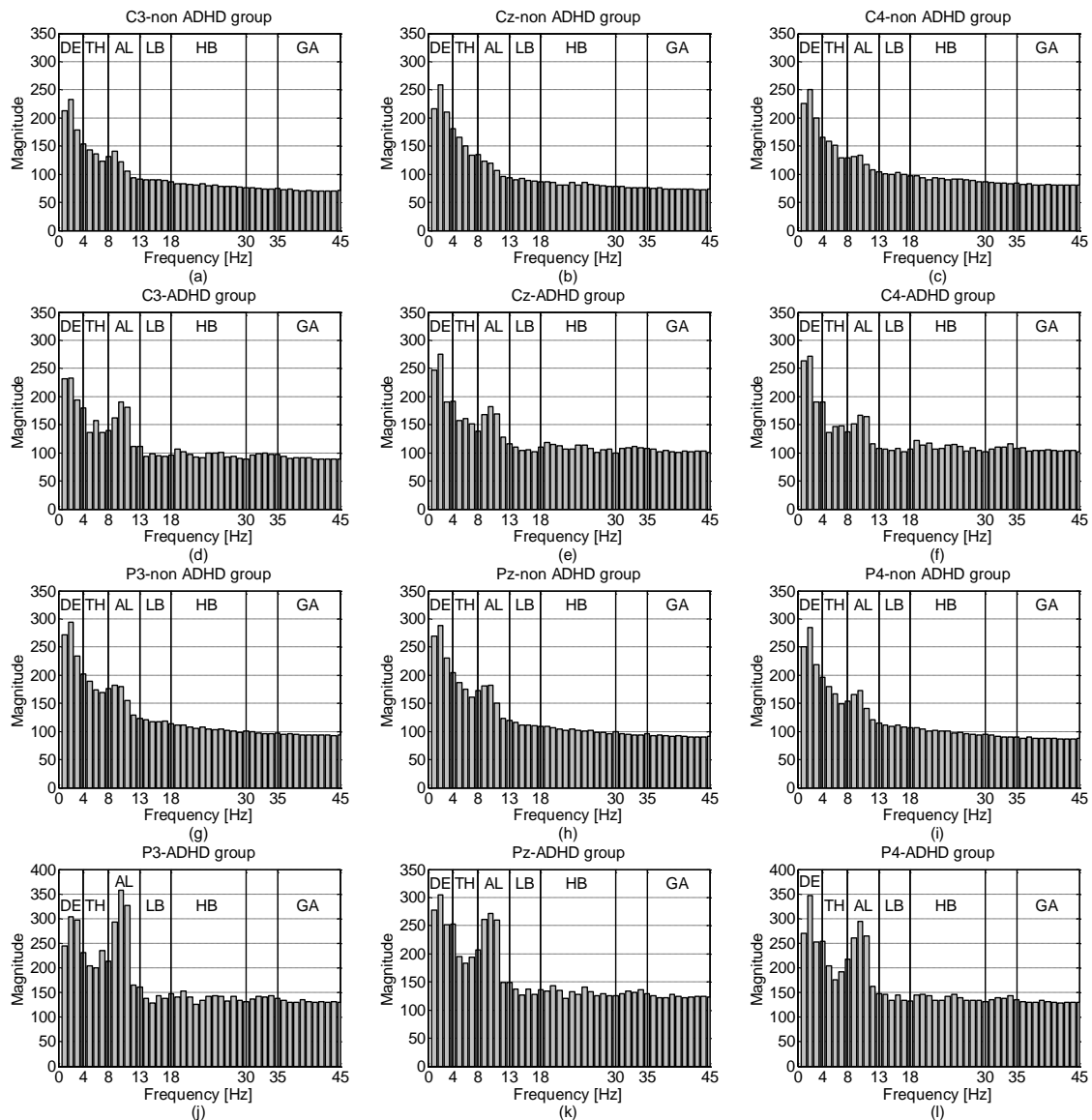


Figure 5. Grand-mean values of magnitude spectral distributions on C3, Cz, C4, P3, Pz and P4 electrodes, for ADHD and non-ADHD participants (DE - delta, TH - theta, AL - alpha, LB - low-beta, HB - high-beta, GA - gamma)

Table 1. Mean values and grand-mean values of power TLBR and ADR on Cz (N-number)

Group	N	TLBR	ADR
ADHD	1	4.75778	1.31432
	2	9.96931	0.50149
	3	2.15027	1.57408
GM ADHD		5.62579	1.12996
non-ADHD	1	5.56906	0.541204
	2	6.67911	0.548517
	3	2.48677	0.677761
	4	2.13537	0.683455
	5	4.75630	0.302550
	6	2.84018	0.296510
	7	2.16688	0.910122
	8	7.54455	0.255433
	9	3.65058	0.765094
	10	9.76422	0.659966
	11	4.75630	0.302550
	12	6.71936	0.428446
	13	2.83285	0.472008
	14	3.65279	0.250629
GM non-ADHD		4.68245	0.50673

Table 2. Mean values and grand-mean values of power ADR on C3, Cz, C4, P3, Pz and P4 (N-number, GM-grand mean)

	C3	Cz	C4	P3	Pz	P4
ADHD						
1	1.02	1.31	1.18	2.37	3.02	2.01
2	0.50	0.50	0.40	1.13	0.51	0.67
3	2.21	1.57	1.08	2.23	1.36	1.87
GM	1.24	1.13	0.89	1.91	1.63	1.52
non-ADHD						
1	0.67	0.54	0.99	1.08	1.91	1.51
2	0.61	0.55	0.71	0.85	1.31	1.55
3	0.73	0.68	0.73	1.16	1.07	0.99
4	0.78	0.68	0.68	0.69	0.65	0.72
5	0.53	0.30	0.46	0.45	0.38	0.33
6	0.36	0.29	0.43	0.59	0.55	0.62
7	1.35	0.91	1.23	1.86	1.69	1.27
8	0.42	0.26	0.38	0.25	0.26	0.32
9	0.89	0.77	0.87	0.90	1.23	1.05
10	0.75	0.66	0.68	0.92	0.83	0.86
11	0.53	0.30	0.46	0.45	0.38	0.33
12	0.44	0.43	0.37	0.48	0.46	0.39
13	0.45	0.47	0.61	1.41	2.06	2.72
14	0.43	0.25	0.34	0.43	0.35	0.33
GM	0.64	0.51	0.64	0.82	0.94	0.93

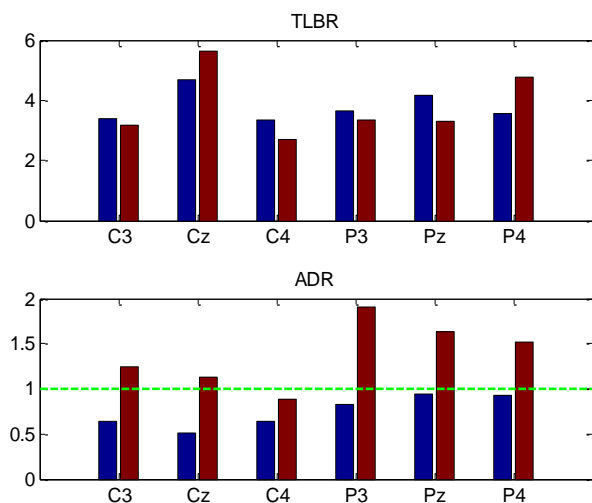


Figure 6. Grand-mean values of power TLBR and ADR on C3, Cz, C4, P3, Pz and P4 electrodes (blue – non-ADHD, red - ADHD)

Table 2 shows that GM values of power ADR of ADHD participants are higher than 1 on all observing electrodes (except on C4 electrode) compared with non-ADHD participants whose values are lower than 1. Even if C4 electrode GM value of power ADR is lower than 1, it was higher for ADHD in comparison with non-ADHD subjects. Comparison of GM values for TLBR and ADR are presented in Figure 6.

4 Conclusion

In this article, a study was conducted to investigate differences between the EEG signals of participants with and without medically diagnosed ADHD. In addition, we have given a brief overview of previous studies on this topic. Given the results of this study, it can be mentioned that the increase in grand mean values of power TLBR on a Cz electrode was confirmed when comparing ADHD participants and

non-ADHD participants, which was mentioned as conclusion in previous studies. ADR on C3, Cz, P3, Pz and P4 is consistently higher for ADHD subjects. We propose that the ADR parameter should also be included in diagnostic procedures, but this needs to be verified or revised because of the small number of participants and lack of statistical analysis caused by a small number of participants.

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