Nörogeribildirime kimin daha çok cevap vereceğini dinlenme anındaki EEG verisine bakarak öngörebilir miyiz?

Can we predict who will respond more to neurofeedback with resting state EEG?

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***Özetçe*—AutoTrainBrain, Sabancı Üniversitesi'nde disleksik çocukların bilişsel performanslarını artırmak için hazırlanmış bir nörogeribildirim ve çoklu duyu öğrenme uygulamasıdır. Bu çalışmada, AutoTrainBrain uygulamasını gönüllü olarak bir süre kullanan kişilerin verileri analiz edilerek, dinlenme anındaki EEG verileri ile nörogeribildirime kimin daha çok cevap vereceğinin tahmin edilip edilemeyeceği araştırıldı. Toplanan EEG verileri analiz edildiğinde, sol Dorsolateral Prefrontal Korteks (DLPFC) bölgesinde (FC5 elektrodu) bulunan theta dalgalarının genliklerinin AutoTrainBrain ile yapılan nörogeribildirim sonucunu önceden tahmin edebildiği ortaya konuldu (Pearson ilinti katsayısı: 0.78, P<0.001). Nörogeribildirimle, sol DLPFC alanındaki yüksek theta düşürüldüğünde, korteksin regülasyonu arttığı için nörogeribildirime daha çok yanıt alındığı düşünülmektedir.**

Anahtar Kelimeler — nörogeribildirim, AutoTrainBrain, EEG, DLPFC

***Abstract*—AutoTrainBrain is a neurofeedback and multi sensory learning-based mobile phone software application, designed at Sabancı University with the aim of improving the cognitive functions of dyslexic children. We investigated whether we can predict who will respond more to neurofeedback applied by AutoTrainBrain by analyzing the resting state EEG brain data. Based on our analysis of the EEG data collected, we observed that the power amplitudes across resting states in the theta band over the left Dorsolateral Prefrontal Cortex (DLPFC) (electrode : FC5) predicts who will respond more to neurofeedback with AutoTrainBrain (Pearson correlation coeff : 0.78, P<0.001). When we reduce the high theta brain waves with neurofeedback in this area, we hypothesize that better cortical regulation and inhibition are developed in the brain, therefore the response to neurofeedback increases.**

Keywords — neurofeedback, AutoTrainBrain, EEG, DLPFC

I. INTRODUCTION

Neurofeedback is an approved brain training methodology and is clinically proven to be effective for psychiatric conditions like ADHD (attention deficit hyperactivity disorder) and anxiety. The successful use of neurofeedback for dyslexia exists in the literature, but has not yet been approved for routine clinical use.

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Despite the success of neurofeedback treatment in many cases, the variability in the efficacy of the treatment is high, and some studies report that a significant proportion of subjects does not benefit from it. Quantifying the extent of this problem is difficult, as many studies do not report the variability among subjects. Nonetheless, the ability to identify in advance those subjects who are – or who are not – likely to benefit from neurofeedback is an important issue, which is only now starting to gain attention. In the article [3], the authors review the problem of inefficacy of neurofeedback treatment as well as possible psychological and neurophysiological predictors for successful treatment. A possible explanation for treatment ineffectiveness lies in the necessity to adapt the treatment protocol to the individual subject.

AutoTrainBrain is a neurofeedback and multisensory learning based mobile phone software application, designed at Sabancı University with the aim of improving the cognitive functions of dyslexic children (Figure 1) [1]. It reads electroencephalography (EEG) signals from 14 channels of eMotiv EPOC+ and processes these signals to provide neurofeedback to the child for improving the brain signals with visual and auditory cues in real time [2].

AutoTrainBrain neurofeedback is applied through a new, patent pending protocol (SUP133). It applies predetermined rules and personalizes the neurofeedback protocol for individual needs. Still, it would be beneficial to determine who would respond to neurofeedback more by analyzing resting state EEG before we start training.

It has been shown that AutoTrainBrain is successively used for improving entropy, coherence, and relative alpha power of a 14-year old dyslexic child as described in [1].

In this study, we investigate whether we can predict who will respond to neurofeedback applied by AutoTrainBrain beforehand by looking into the resting state EEG brain data.

II. MATERIALS & METHODS

A. *Subjects and Data*

21 subjects have voluntarily participated in this experiment. 6 participants were healthy, 15 of them were diagnosed patients (8 of them were dyslexics, 6 of them had ADHD, 1 of them was autistic).

Their ages range from 8(eight) to 81 (eighty one). 8 of them are males, 5 of them are females. ADHD, dyslexia, and autism are developmental brain conditions and they have the same root causes, and are mostly comorbid. Therefore subjects who have ADHD and autism participated voluntarily in our experiment.

The subjects have used AutoTrainBrain many times (4-163 times) in order to improve their cognitive abilities (Figure 1).

Before the experiment, all participants gave their informed consent after the experimental procedure was explained to them in accordance with guidelines set by the Sabancı University and Yeditepe University research ethics committees. Throughout the experiments, eMotiv EPOC+ headset is used. Internal sampling rate in the headset is 2048 samples per second per channel. The data are filtered to remove main artefacts and then down-sampled to 128 samples per second per channel. There are 14 EEG channels plus two references. Electrodes were placed according to the 10-20 system. Before the experiment, the calibration of the eMotiv Headset on the subject’s scalp is done with the Xavier Control panel of eMotiv, through which each electrode is made sure to transfer EEG data with high quality.

B. *Study Design*

Each participant has used AutoTrainBrain many times. Their brain waves are read using eMotiv EPOC+ from 14 channels and visual and auditory feedback is given for 20 minutes.

Their EEG is recorded and sent to a database. For all analyses in this study, all of the 14-channel EEG data are recorded during the experiments and decomposed into theta (4-8 Hz), alpha (8-12 Hz), beta-1 (12-16 Hz), beta-2 (16-25 Hz), gamma (25-45 Hz) bands. As we have used the libEDK.IEE_GetAverageBandPowers routine, we have collected averaged and cleaned data from eMotiv EPOC+ headset and used the session average band powers in our calculations. Emotiv EPOC+ headset can not measure delta band power values correctly. Therefore, all calculations and neurofeedback are applied using theta band powers.

The feature set consists of 155 variables including the gender, age, the EEG band power values before neurofeedback from 14 channels (theta, alpha, beta-1, beta-2, gamma), the EEG band power values after neurofeedback from 14 channels (theta, alpha, beta-1, beta-2, gamma), and average EEG band power values in all channels before neurofeedback and after neurofeedback (Table 1).

C. **Measuring performance**

The performance of neurofeedback applied by AutoTrainBrain is measured by the amount of average theta band power reduced before and after AutoTrainBrain neurofeedback sessions.

Measuring : the difference between the average theta band power measured before neurofeedback and the average theta band power measured after neurofeedback session.

Average theta band power means that we read N numbers of theta band powers measured from scalp in a session and sum these numbers and divide by N.

average theta band powers = sum(theta band powers read)/ N

TABLE 1- DLPFC THETA VERSUS MEASURE

Subjects versus theta	Theta Values		
	FC5 Theta	***FC6 Theta***	***Measure***
User1	6.45	17.05	7.06
User2	6.82	12.59	6.62
User3	4.43	5.76	4.47
User4	8.80	13.42	4.15
User5	7.06	13.62	3.82
User6	5.29	6.85	3.63
User7	3.28	14.48	3.60
User8	3.07	3.63	2.99
User9	2.10	10.89	2.30
User10	1.78	10.81	2.27
User11	5.84	7.57	2.20
User12	3.05	4.43	1.99
User13	1.60	4.48	1.33
User14	0.83	2.10	1.03
User15	2.27	7.26	0.98
User16	1.00	1.88	0.84
User17	2.09	3.69	0.84
User18	0.69	2.22	0.71
User19	2.43	5.13	0.46
User20	1.24	0.64	0.46
User21	3.18	0.90	0.46

Figure 1: AutoTrainBrain.

Final Cluster Centers

	Cluster	
	1	2
FC5	2,0	6,4
Measure	1,4421428571	4,5571428571

Number of Cases in each Cluster

Cluster	1	14
	2	7
Valid		21

Figure 2: Clustering of patients in terms of their responses to neurofeedback.

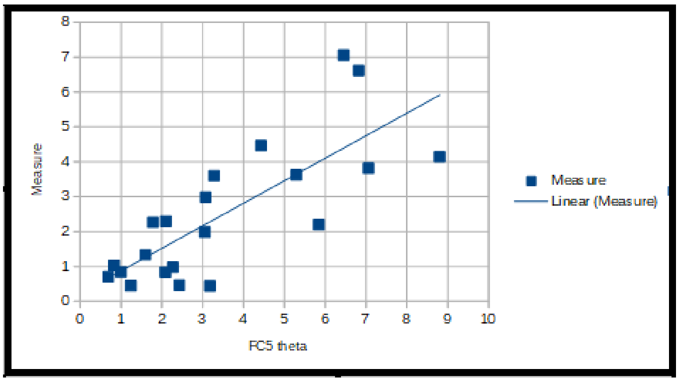

Figure 3: Relationship between Theta at DLPFC and measure.

III. RESULTS

In this research, we investigated whether we can infer who would respond more to neurofeedback by looking into the resting state EEG brain data. Based on our analysis of the EEG data collected throughout the experiment, we observed that the frequency modulation across resting states in the theta at the left Dorsolateral Prefrontal Cortex (left DLPFC, electrode FC5) predicts who will respond to neurofeedback with AutoTrainBrain (Table 1). The resting state absolute theta brain powers at the left DLPFC before the experiment demonstrated a high Pearson correlation (0.78) with the measure ($P<0.001$). We have checked whether the data has a normal distribution first. The data are normalized by taking logarithm of both independent (ThetaFC5) and dependent variables (measure) and a linear regression model is created (the independent variable is the ln(avgThetaFC5), the dependent variable is the logarithm of the difference of average theta powers before and after neurofeedback. The output of the regression model is compared with the actual data using ANOVA. The result is statistically significant ($P<0.001$) (Figure 3). Non-parametric tests are also applied: Two related samples (Wilcoxon test) are applied to pairs (theta_FC5, measure), and the two tailed significance is 0.014.

In other words, the higher the amplitude of the theta brain waves measured at the left Dorsolateral Prefrontal Cortex (electrode FC5) at resting state, the more effective AutoTrainBrain for reducing the slow brain waves with neurofeedback.

The data are clustered using K-Means algorithm to see who has responded more to neurofeedback (Figure 2) and observed that the clusters 2, where theta power at FC5 is greater than 3.60 are the ones who will respond to neurofeedback more. It means 7/21 people respond to neurofeedback significantly more than the others. The clinical and psychometric tests have not been applied to subjects after the experiment.

The theta power at the right Dorsolateral Prefrontal Cortex (electrode FC6) during resting state is the second most important area which can be used to predict who will respond more to neurofeedback (Pearson correlation coefficient: 0.79, P<0.001). The relationship between the measure and the other electrode theta band powers at resting state are not statistically significant.

Age and gender do not have high correlation with responding to neurofeedback.

IV. DISCUSSION

The higher the amplitude of the theta brain waves measured at the left Dorsolateral Prefrontal Cortex (electrode FC5) at resting state, the more effective is AutoTrainBrain for reducing the slow brain waves with neurofeedback. DLPFC is a region of the frontal lobes that is most typically associated with executive functions including working memory and selective attention [4]. The activity in this area is controlled by the hippocampus and shows the level of cortical regulation. The higher the theta band powers are in this area, the less cortical regulation, the less memory and the less attention functions exist [5]. Moreover, high theta power in this area points to brain maturation delay. When we reduce the theta brain waves with neurofeedback in this area, we hypothesize that more cortical regulation and inhibition are developed in the brain, hence the response to neurofeedback increases.

In this paper the measure of response to neurofeedback was simply the difference in the power of an EEG band within the range of bands targeted by the neurofeedback protocol. In the future, we plan to use other measures of success, that are either indirectly related to the neurofeedback protocol, or more importantly are related to the behavioral performance of the subjects. Some of these measures may include: increase in healthiness measures (entropy, coherence, relative alpha power), increase in number of words read, decrease in number of errors during reading, decrease in fear, anxiety.

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