

Electroencephalographic Identifiers of Reading Abilities in Turkish Language

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Abstract—Fluent reading requires learning the print knowledge of alphabet symbols (letters), rapid automatic naming and phonological awareness skills. In this study, electroencephalographic brain signals of 17 subjects were measured with an eMotiv EPOC+ headset before, during and after a computer-based training session. For the training, distorted letter prints were created by rotating Turkish letters 180 degrees along the y-axis. Using these distorted letters two different texts, each 150 words in length, were created. Subjects were asked to read these texts before and after the training session. We investigated whether there is an improvement in reading speed and a decrease in number of errors due to the computer-based training and whether we can correlate the success of training with any characteristic of any EEG brain signals. 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 Broca Area (F7 and FC5) predicts individual reading performance measures. Even though there exist a variety of studies indicating a relation of Theta band power and learning performance, EEG measurements with eMotiv EPOC+ had not been previously reported with a Turkish alphabet learning task.

Keywords—EEG signal processing, multi sensory learning.

I. INTRODUCTION

Reading, writing and arithmetic abilities are important for academic success. University students pass many exams throughout their school lives by the time they reach university education. However, in spite of the fact that their IQ is normal or above normal, some of these students, suffer from specific learning disabilities. If the Wechsler Intelligence Scale for Children (WISC-R) test shows there is a big discrepancy between verbal IQ and performance IQ, this may point to specific learning disability (SLD). However, there are many specific learning disability cases which cannot be shown by such tests

alone [11]. The findings in the article suggest that IQ tests are not particularly useful for determining learning disabilities. Instead achievement (reading, arithmetic, writing) test scores are more useful diagnostic tools. Learning to read starts with learning the names of the alphabet symbols (rapid automatic naming) and their related sounds (phonological awareness) [1]. The relation between an alphabet symbol and its sound should be unique in order to retrieve the information correctly later on when needed during reading. Reading speed is based on how a person easily retrieves the information about the symbol and its sound(phonics). This reading process involves both short-term and long-term memory. Both rapid automatic naming and phonological awareness skills have been strongly predictive of individual differences in reading. The performance measure for good reading is, therefore, the reading speed (number of words read in a minute) and the number of errors made during reading. Reading comprehension (which is to understand what is read) develops in the brain after the reading speed reaches a certain level and the vocabulary is extended enough, which requires a variety of oral-language skills [2], [3]. Although IQ is normal or above normal, 5% of people in many societies may not perform well in reading, writing and/or arithmetic, and/or in learning in general [4], [7]. There is a great deal of research about specific learning disabilities in the literature which show that specific learning disabilities are mostly developmental [12], [13], [24]. The research conducted in this area suggests an abnormal lateralization of prefrontal attentional control processes [22]. This finding is in accordance with the (scarce) evidence that reading disabilities involve a deviant structural asymmetry of the frontal lobe [23]. The recent fMRI studies in neurotypical adults implicate corticostriatal and hippocampal systems in language learning [27]. In the literature, it has been further shown that higher levels of slow brain waves in the Broca area (F7 and FC5) in the left hemisphere have a high correlation with linguistic learning disabilities [5], [6], [10], [21], [25], [26]. These studies have been completed

using laboratory EEG equipment with 32 or 64 electrodes. In our study, we measured the EEG signals of subjects with a lightweight eMotiv EPOC+ headset with 14 electrodes before, during and after a learning task. The Emotiv EPOC+ headset (<http://emotiv.com/>) has become one of the leading pieces of BCI equipments available today as a result of its low cost and features, including 14 EEG channels plus two references, inertial sensors, wireless connectivity, the ability to provide raw EEG data as well as averaged EEG data, ease of use and attractiveness for children and adolescents. Although its use for research purposes is being questioned by many researchers, several researches have demonstrated that eMotiv EPOC+ headset captures the EEG data quite accurately [?], [8], [19], [20]. In order to collect data from many children, eMotiv EPOC+ provides a user friendly and ergonomic interface and can integrate with both desktop and mobile phone applications and be used at home. In the near future, with this new technology, it can be possible to apply neurofeedback to young children at home without disturbing them much and without lowering their self-esteem. Turkish is an ortographic language, meaning that the words are read as they are written. This makes the reading easier for many people, yet there are learning disabilities in Turkey. There has been little research [14]–[18] conducted about specific learning disabilities in Turkey and to our knowledge, there is no research conducted about Turkish language which correlates learning disabilities with EEG data. The contribution of this paper is an experimental study that explores neural correlates of reading abilities in Turkish based on EEG data collected by an eMotiv EPOC+ headset. Our experimental analysis of the collected data show that higher slow brain waves in the Broca area (F7 and FC5) in the left hemisphere have a high correlation with linguistic learning disabilities.

II. MATERIALS & METHODS

A. Subjects and Experimental data

Seventeen University students (mean age: 20.58, stddev: 2.39 ; 10 men, 7 women) are voluntarily participated in this study. All subjects' native language were Turkish. They learned reading without any problem in the elementary school, however they were naive to the alphabet formed with distorted Turkish letters and the computer based training task. Before the experiment, all participants gave their informed consent after the experimental procedure was explained to them in accordance with guidelines set by the research ethics committee. Throughout the experiments, eMotiv EPOC+ headset is used. Internal sampling rate in the headset is 2048 per secs per channel. The data are filtered to remove mains artefacts then down-sampled to 128 per secs per channel. There are 14 EEG channels plus two references. Electrodes were placed according to the 10-20 system. Before the experiments, the calibration of the eMotiv Headset on the subject's scalp is done with the Xavier Control panel of eMotiv, each electrode is made sure to transfer EEG data with high quality (see Figure 1).

B. Study Design

Participating subjects performed a letter print learning task under simultaneous EEG recordings. The goal of the task was learning the name of new letters which are distorted 180

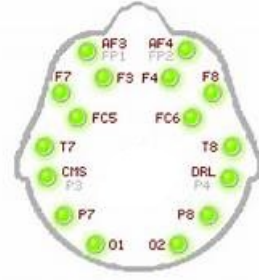


Figure 1: The 10-20 numbering system of eMotiv EPOC electrodes.

degrees in the y-axis (See Figure 1). Before the experiments, the EEG signals in the resting, eyes open state are measured for each subjects for five minutes and the data is stored in .csv files. During these recordings, subjects were placed approximately 0.5 meters in front of a computer screen and instructed to relax with eyes open, looking at a fixation point in the middle of the screen. The programs are written with Python and uses the Community SDK provided by eMotiv to communicate with eMotiv EPOC+ headset. Artefact removal and conversion from Analog to Digital signal is done by the eMotiv standard procedures. libEDK.IEE_GetAverageBandPowers routine is used. During the experiments EEG is recorded, and after the experiment, another five minutes of resting, "eyes open" state EEG signals are recorded.

C. Letter print learning task

The task involved showing distorted letters on the screen together with a picture which starts with the letter shown and the phonics of letter (See Figure 2). Throughout the experiments, subjects are shown 29 distorted Turkish letters, repeated three times. In each repetition, there are slight differences in the order of pictures and sounds which are shown on the screen. In the first round, the picture and sound are shown at the same time, in the second round, the picture is shown one second before the sound, in the third round, the picture is shown one second after the sound. This is done for addressing differences in the cross modal attention shift characteristics of different subjects.

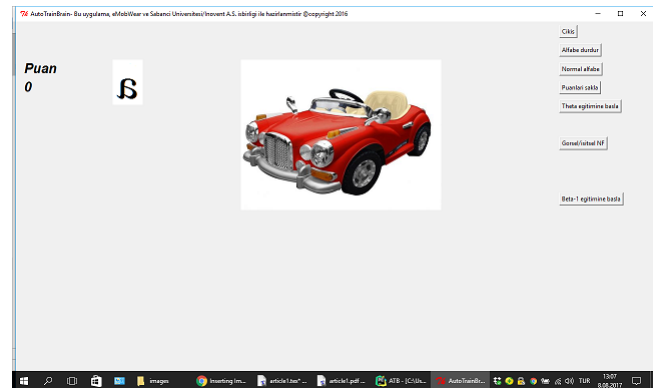


Figure 2: The computer based training program to teach distorted letters.

D. Resting-State EEG processing

For all analyses in this study, all of the 14-channel EEG data are recorded during the experiments in 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 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.

E. Measuring performance of reading speed and number of errors

Before the experiments, subjects are asked to read a text written with distorted letters and their voices are recorded (See Figure 1). The following measures are calculated:

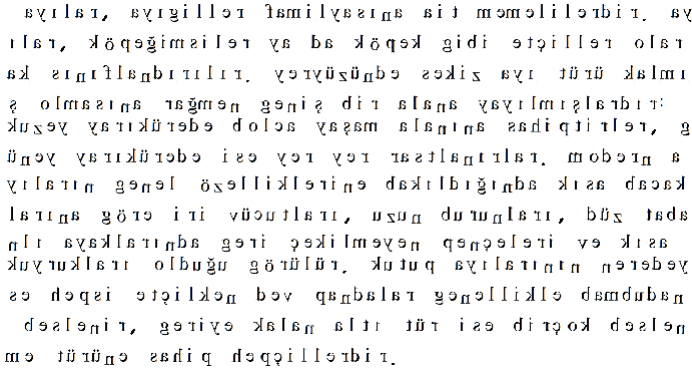


Figure 3: The text written with distorted Turkish letters.

- The number of words read in the first minute (pre-training)
- The number of errors done (pre-training)

After the experiments, subjects also read another text written with distorted letters and their voices are recorded.

The following measures are calculated.

- The number of words read in the first minute (post-training)
- The number of errors done (post-training)

The final performance score is calculated by taking the difference between the post training performance and the pre-training performance.

F. Relation of Resting state Broca Area slow waves with Letter Print learning performance

Resting state absolute value of Theta brain waves before the experiment have high correlation with the level of letter print learning performance.

G. Analysis of EEG data

During the EEG recordings , we have excluded the EEG data which exceeded three standard deviatons of the median, as an outlier rejection criterion as onine real time. So the data only had the accepted data as a result of that exclusion. The

analysis of data is done with SPSS, and a linear regression model is created. The independent variable is the average of Theta absolute powers at F7 and FC5, the dependent variable is the difference between the correctly read words in one minute after-training and that before training.

III. RESULTS

In this research, we investigated whether there is an improvement in reading speed and a decrease in number of errors due to the computer-based training and whether we can correlate the success of training with any characteristic of any EEG brain signals. 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 Broca Area (F7 and FC5) predicts individual reading performance measures. The resting state absolute Theta brain powers at the Broca area (F7 and FC5) before the experiment demonstrated a high correlation (0.66) with the measured learning performance (P<0.05) (see Figure 4). In order to conclude that a linear regression model is created (the independent variable is the average of Theta absolute powers at F7 and FC5, the dependent variable is the difference between the correctly read words in one minute after-training and that before training) in SPSS. The output of regression model is compared with the actual data using ANOVA. The result is statistically significant (P<0.05) and the correlation coefficient is 0.66 (see table 1 and table 2).

In other words, the slower the brain waves measured in the Broca area (F7 and FC5) at resting state, the less useful the computer based training of distorted letters is for learning performance.

IV. CONCLUSION

In this research, we have confirmed using eMotiv EPOC+ headset that the resting state absolute Theta brain powers at the Broca area (F7 and FC5) determines the reading abilities. In our future research, we will be using the results found in this research in order to create a specific neurofeedback protocol for enhancing reading abilities of dyslexic people who have learning disability and we will plan to apply this specific neurofeedback protocol on dyslexic subjects more than 20 times to see whether there will be any improvement in their reading abilities.

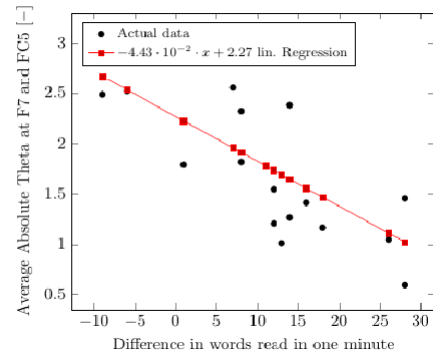


Figure 4: Words read versus Absolute Theta at Broca before the experiment

TABLE I: Learning performance measures

ID	Age	Sex	error pre-training	error post training	Oneminute-pre	Oneminute-post	Words read one minute
307	19	Male	3	1	14	40	28
304	19	Female	3	2	49	75	28
5000	20	Male	4	1	42	65	26
5005	18	Female	7	1	18	31	18
5002	20	Female	6	5	31	46	16
302	22	Female	4	2	24	36	14
5006	20	Male	0	2	0	16	14
5004	19	Male	4	2	25	36	13
2002	20	Male	4	1	31	40	12
5009	20	Male	3	0	31	40	12
5001	20	Female	7	5	42	51	11
308	18	Male	0	0	30	38	8
303	27	Female	3	2	49	56	8
5003	20	Male	3	3	45	52	7
2001	25	Male	1	0	37	40	1
306	20	Male	1	0	50	43	-6
301	23	Female	2	2	43	32	-9

TABLE II: Theta powers at Broca area

ID	Words read in one minute	Avg Theta (F7)	Avg Theta(FC5)	Average of Theta at F7 and FC5
307	28	1,346621	1,564475	1,455548
304	28	0,821042	0,352808	0,586925
5000	26	1,233911	0,860058	1,0469845
5005	18	0,75083	1,582611	1,1667205
5002	16	2,077955	0,746231	1,412093
302	14	0,440884	2,090648	1,265766
5006	14	2,873486	1,878642	2,376064
5004	13	1,463205	0,562709	1,012957
2002	12	1,038742	1,374948	1,206845
5009	12	2,15392	0,934102	1,544011
5001	11	3,144928	2,957646	3,051287
308	8	1,571115	2,060929	1,816022
303	8	2,549321	2,086834	2,3180775
5003	7	3,630647	1,467857	2,549252
2001	1	0,915747	2,660747	1,788247
306	-6	3,537321	1,495707	2,516514
301	-9	2,6577	2,307136	2,482418

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