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Original Paper

Psychophysiological Characteristics of Children with Dyslexia

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Abstract

Dyslexia is a specific learning disorder that involves difficulty reading due to decoding problems for letters and words. Statistics shows that 5-10% of the general population has dyslexia. The aetiology of reading disorder supposes some biological causes and morphological markers useful in the classification and early identification of the problem.

The aim of this article is to find appropriate parameters, which will be useful for early diagnosis and finding the right modalities for treatment.

Our findings about QEEG characteristics are not conclusive. However, slowing of brain activity in dyslexic children appeared to be confirmed. These findings lead to the possible hypothesis of delay in neurological development of these children.

Significant theta/beta ratio suggest possible comorbidity with ADHD.

Further research with more children included is proposed.

Keywords

dyslexia, children, QEEG, Neurogame

1. Introduction

Dyslexia is a specific learning disorder that involves difficulty reading due to decoding problems for letters and words. In the fifth revision of DSM (2013) the entity "Learning disorders" was changed in "Specific learning disorder" including Dyslexia, Dyscalculia and Disorder of Written expression. For exact diagnosis of this entity some core criteria must be fulfilled: the difficulty must persist at least 6 months and failed to improve despite intervention made; it must affects academic skills below those which are age-related and expected; the start of the problem must be in school age; other disorder like

intellectual disabilities, auditory and visual problems, as well as other neurological disorder must be excluded.

Statistics shows that 5-10% of the general population has dyslexia, but this number in some region can be as high as 17%. More precisely, the real incidence varies widely by country. For example, Italy registered only a half of the incidence found in the United States, where an estimated 5 to 15 percent of the population may have dyslexia to some degree. Scientists supposed that the difference of the incidence depends on the complexity in the language used. For example, English alphabet consists of 44 different sounds which can be differently written and pronounced. Having trouble differentiating sounds (phonemes) people have problems in orthography. However, this condition was not understood worldwide until the late 20th century even today.

For the experiences in developmental neuropsychology, the acquisition of reading involves two systems: the lexical system (sight-reading) which process familial words, and phonological system, which comprises decoding unfamiliar words. Awareness of phonological structure require knowledge of the correspondence letter-sound. Developmental analysis can facilitate understanding of how reading disabled children compensate their problem. Developmental classification of reading and spelling difficulties clarify the stage where these academic skills are not completed. In this context, reading difficulties are manifested in the stage when advancing from early phase of acquisition, where reading is visually based (logographic), to the alphabetic phase, where letter-sound association are used. In the logographic stage, child lacks strategies to decode unknown words other than by visual approximation to known words. During alphabetic stage the child uses phoneme-grapheme to sound out words, and decode them from the left to right depending of the consistency between letters and sounds. The logographic stage involves instant recognition and have difficulty with nonwords, for which reason the spelling tends to be dysphonetic. The third phase established as orthographic, where features are automatic and flexible; in other words, it is needed the instant analysis into orthographic units (morphemes) without initial phonological conversion (Harris, 1998).

The aetiology of reading disorder supposes some biological causes and morphological markers useful in the classification and early identification of the problem. Post mortem studies confirmed some abnormalities in perinatal brain anatomy and physiology, as well as some neurocortical deficits that lead to disruption of cognitive processing. In some cases, cell migration abnormalities and number on chromosome 15 has been identified. Transgenerational appearance of dyslexia in some families supports possible genetic basis of transmission, but exact findings are not yet published. However, several candidate genes for dyslexia susceptibility (e.g., ROBO1, DCDC2, DYX1C1, KIAA0319) have been suggested, and all of these to play an important role in the brain development (Galaburda, LoTurco, Ramus, Fitch, & Rosen, 2006; Hannula-Jouppi, Kaminen-Ahola, Taipale, Eklund, Nopola-Hemmi, Kaariainen, & Kere, 2005; Meng, Hager, Held, Page, Olson, Pennington, & Gruen, 2005; Skiba, Landi, Wagner, & Grigorenko, 2011).

Magnetic Resonance Imaging (MRI) studies confirmed some asymmetry of the brain, using planum temporale as a marker (Rumsey, Dorwart, Vermess, Denckla, Krussi, & Rapaport, 1986). In newest studies, MRI in children and adults with dyslexia commonly demonstrate hypoactivation in left-hemispheric temporo-parietal, occipital-temporal, and inferior frontal networks. Further, reduced functional connectivity among these regions has also been demonstrated. Additionally, PET scan studies confirmed abnormalities in cerebral blood flow in the left temporoparietal region (Rumsey, 1992). An autoimmune aetiology has been proposed by Galaburda et al. (1993): some ischemic injury to the developing cortex produced by autoimmune damage to the wall of the arterial blood vessels supplying involved brain regions might results in scars and malformations and resulting as dyslexia (Galaburda & Livingstone, 1993). Having non-significant markers for dyslexia, EEG recording as a simple, cost-benefit method was largely used worldwide. The slowing of EEG is the most frequent abnormality in children with learning disabilities. In a review paper, Chabot et al. (Chabot, di Michele, Prichep, & John, 2001) showed poor EEG rhythm, low-voltage background rhythms (Hughes, 1978) and increased generalized slowing (Byring & Jarvilehto, 1985). Abnormalities in children with learning disorders included increased high amplitude atypical alpha, abnormal focal paroxysmal activity, excess focal delta, persistent delta asymmetry, and excessive EEG response to hyperventilation. EEG studies indicate that specific developmental disorders are associated with abnormal EEGs in 25% to 43.5% of these children. Neuropsychological testing is also used to establish the underlying characteristics of reading disorder. Having in mind that reading is a complex function of the nervous system, which require integration of visual and auditory processes, both central and peripheral, Boder (Boder & Jarrico, 1982; Boder, 1973) differentiated the following subtypes of dyslexia: dysphonic, dyseidetic, mixed and non-specific reading delay. For exact differentiation of the type, Bindelli and Chiarenza developed computerized Direct Test of Reading and Spelling (DTRS) for Italian language, which is a modification of original Boder test (Chabot, di Michele, Prichep, & John, 2001).

Dyslexia is a school problem and it frequently disappears in the adulthood. Given what we know now, many famous people may have had dyslexia, including Leonardo da Vinci, Saint Teresa, Napoleon, Winston Churchill, Carl Jung, Albert Einstein, and Thomas Edison, as well as Steven Spielberg, Muhammad Ali, Keira Knightley, Danny Glover and other in a new time. There are evidence-based treatments which are effective, even for adults with the condition (like logopaedic exercises, biofeedback, etc.).

Comorbidity with attention deficit hyperactivity disorder, anxiety and depression, disruptive problems with impulse-control, conduct disorder, and autism spectrum disorders is frequently found with learning disabilities, especially dyslexia (Hendren, Haft, Black, White, & Hoeft, 2018).

In Macedonian speaking population dyslexia has not been exactly diagnosed until the two last decades. Macedonian language comprises letter for every sound and it seems not to be so difficult for reading and writing. But, in the last time, school teachers started to differentiate a group of children with difficulty in reading and writing which not corresponded with the chronological age expectances. In this context, psychologists as well as special educators started with the diagnostics and treatment of these children.

Unfortunately, in our country the special test for dyslexia does not exists. The most used test is Macedonian translation of test developed by Kostic, Vladisavljevic and Popovic (1983) (Kostic, Vladisavljevic, Popovic, & Cudov, 1983). Some experiences in the assessment of children with dyslexia, dysgraphia and dyscalculia in our context, were published by a group of researchers from the Institute for Special Education, UKIM, Skopje in 2018 (Karovska-Ristovska, Kardaleska, Ajdinski, & Shurbanovska, 2018).

For this reason, and the scarce of data for dyslexia in our country, the aim of this research is to find appropriate parameters, which will be useful for early diagnosis and finding the right modalities for treatment. Such parameters would be possible specific abnormalities in EEG recordings, as well as the performances of these children tested with own modality we named as "Neurogame" which helps to evaluate concentration, focus attention and reaction time to some tasks. As far as we know, this is the first study that evaluates this issue in our country.

2. Method

2.1 Sample

We selected randomly 10 children diagnosed as dyslexic according to ICD-10 and DSM-V criteria, referred by the Institute for child mental health in Skopje. The diagnostic was made from the team consisted of logopaedist, psychologist, child neurologist, paediatrician as well as child psychiatrist.

Mean age of boys was 10.2±1.64 years and mean age of girls was 9.2±1.60 years. The written consent was obtained from parents. In the moment of evaluation children were in good health and without any medication 48 hours before recording.

2.2 Evaluation

EEG was recorded using a Mitsar 201 (www.mitsar-medical.com), a PC-controlled 19-channel electroencephalographic system with 19 electrodes, placed according to the international 10-20 system, referenced to linked ears (on the International 10-20 system) with 250 Hz sampling rate in 0.5-50 Hz frequency range in the following conditions: Eyes opened (EO)—5 minutes, and Eyes closed (EC)—5 minutes as well as stimuli presentation protocol (Visual Continuous Performance test—VCPT). The obtained data from VCPT, are not aimed for analysis in this paper and this data will be analysed in another paper.

The same equipment and procedures were used for children with dyslexia and controls. Subjects were tested in a quiet air-conditioned room with the experimenter and recording equipment present. During fitting of the electrodes, subjects were familiarized with the testing equipment and the procedure. Vertical Electro-Oculogram (VEOG) was recorded with 2 tin electrodes placed 1 cm above and 1 cm below the right eye. Eye-blink artifacts were corrected by zeroing the activation curves of individual ICA component score responding to eye blinks. In addition, epochs of the filtered electroencephalogram with excessive amplitude (>100 μV) and/or excessively fast (>35 μV in 20-35 Hz band) and slow (>50 μV in 0-1 Hz band) frequency activities were automatically marked and

excluded from further analysis. Finally, EEG was manually inspected to verify artifact removal. Spectral analysis of relative power using fast Fourier transform was carried out for the four frequency bands: delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), and beta (12-20 Hz). Relative power is represented by the percentage of the amplitude in a given frequency band compared with the total amplitude across all frequency bands. Also, we calculated the ratio between theta and beta absolute power in order to obtain the theta-beta ratio (TBR) at Cz.

In some article it was published that asymmetric feature for QEEG recording was typical for dyslexic children. Asymmetry is defined as a functional difference between the left and right hemispheres measured for relative power which exists between the homologous electrodes located on both hemispheres. It was calculated using the following equation:

Power (Left) – Power (Right) / Power (Left) + Power (Right)

$$\frac{\boldsymbol{Power(left) - Power\ (right)}}{\boldsymbol{Power(left) + Power\ (right)}}$$

where Power (Left) corresponds to the relative power of the electrode located on the left hemisphere, and Power (Right) to the relative power on the right hemisphere. These asymmetry data were statistically analysed.

Before the QEEG recording, "Neurogame" was applied. Our original developed application on Android operating system, named "Neurogame" is based on an open source platform to enable assessment the focus and concentration, as well as reaction time, with the ability to monitor the progress of the results over a period of time. The testing for all clients was performed in the morning period 8-12 am (Hughes, 1978). The complete evaluation of children takes around 2 hours.

2.3 Data Analysis

The Statistica StatSoft software was used to assess group differences. One-way analysis of variance (ANOVA) was carried out on relative EEG power for each band (delta, theta, alpha beta) in eyes-open condition in 5 regions (frontal [F]: (F3, F4, F7, F8); central [C]: (C3, Cz, C4); temporal [T]: (T3, T4, T5, T6), parietal [P]: (P3, Pz, P4) and occipital [O]: (O1,O2) regions. Additionally, we include and electrodes above Broca's area (F3, F7 and C3) and Wernicke's area (T3, T5 and P3). Group (dyslexia and control) was the between-subject factor. For some estimations because of the small sample size, the non-parametric Mann-Whitney U test was used to lower variability in the groups. The level of significance was set at $p < .05$.

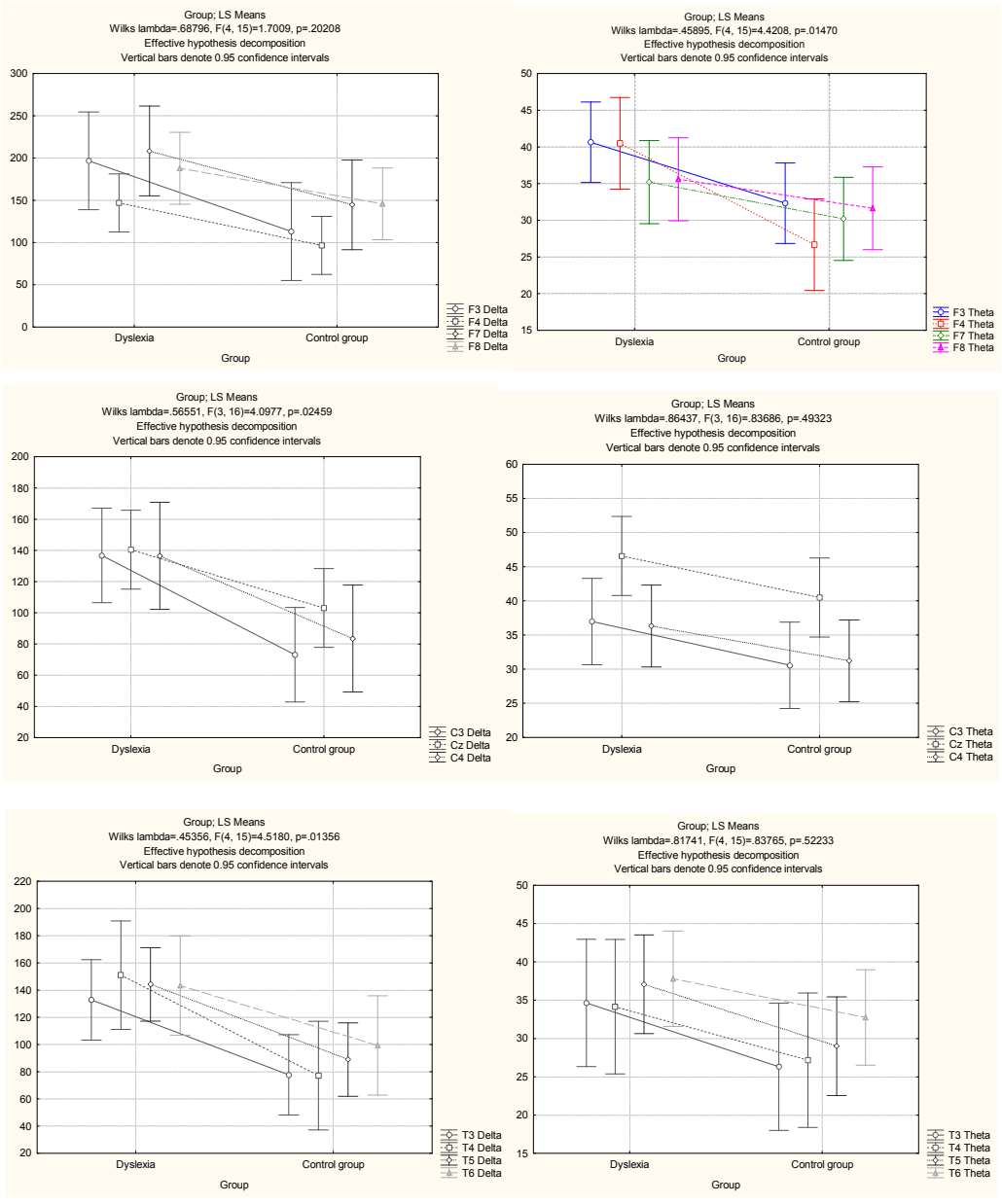
3. Results

As mentioned before, the evaluated sample is small, consisting of 10 children, where mean age of boys was 10.2±1.64 years and mean age of girls was 9.2±1.60 years. The results are compared with matched control group consisting of 10 children with normo-typical development without any learning problems or neurodevelopmental delay. Mean age of boys in the control group was 10.4±1.84 years and mean

age of girls 9.8±1.30 years. They are paired with the examined group according to the age and gender without any significant difference (Current effect: F (1, 18) = .19240, p = .66615).

Relative EEG power was estimated in eyes open condition, because in eyes closed condition alpha power usually prevails the other frequencies.

Results obtained for Delta and Theta waves in frontal, central and temporal position are presented on Figure 1. As can be seen central, temporal, parietal and occipital slow waves are significantly greater in dyslexic children in comparison to control group (see graphs for p values).



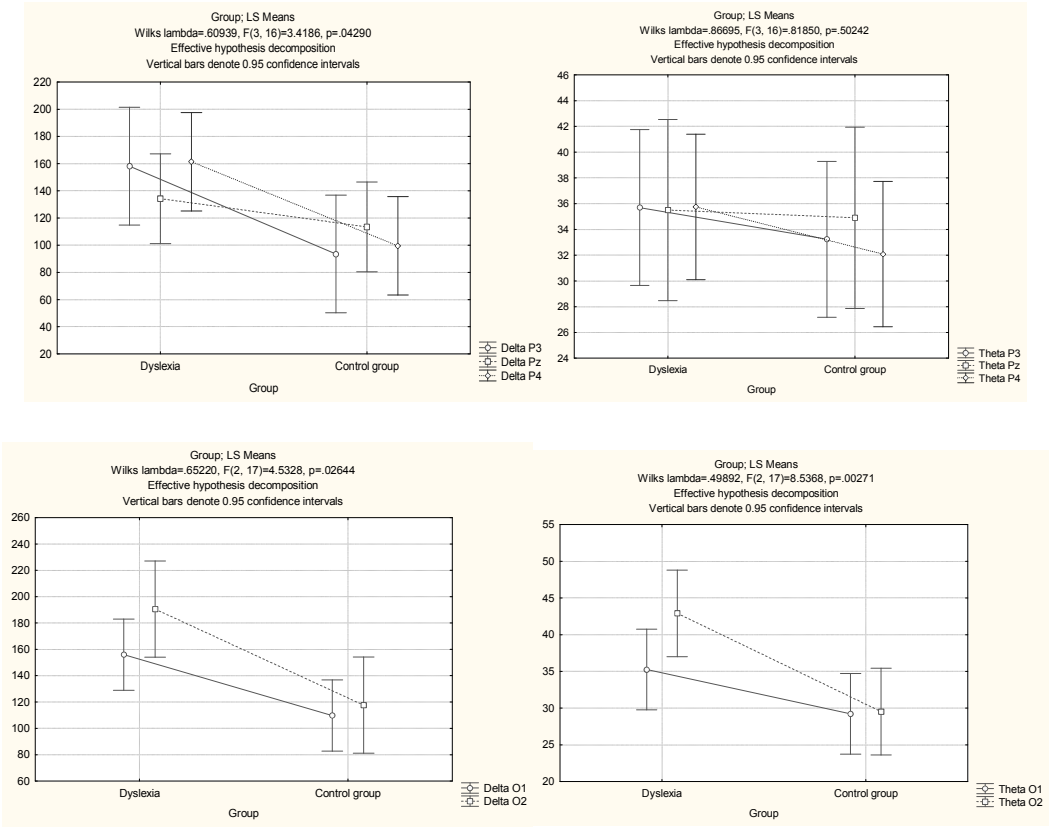
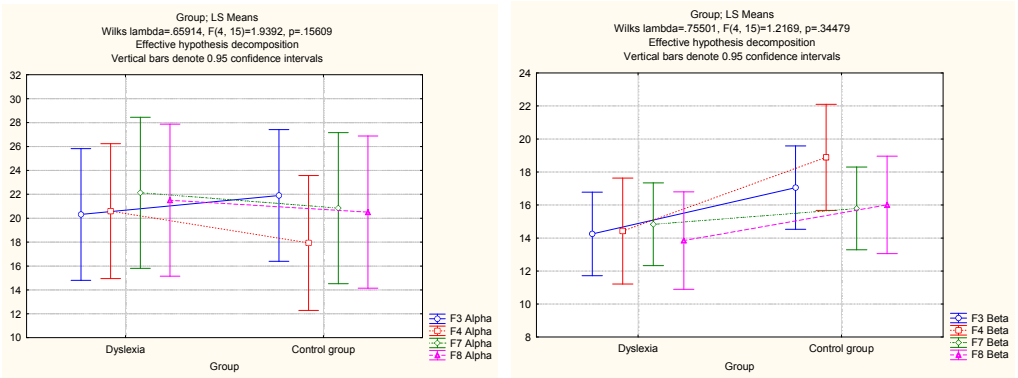


Figure 1. Relative Power for Delta and Theta in Eyes Open Condition for Compared Groups in Frontal, Central, Temporal, Parietal and Occipital Positions

For alpha (frontal, central and temporal) and beta we obtained almost the same results for both groups without any significance (Figure 2).



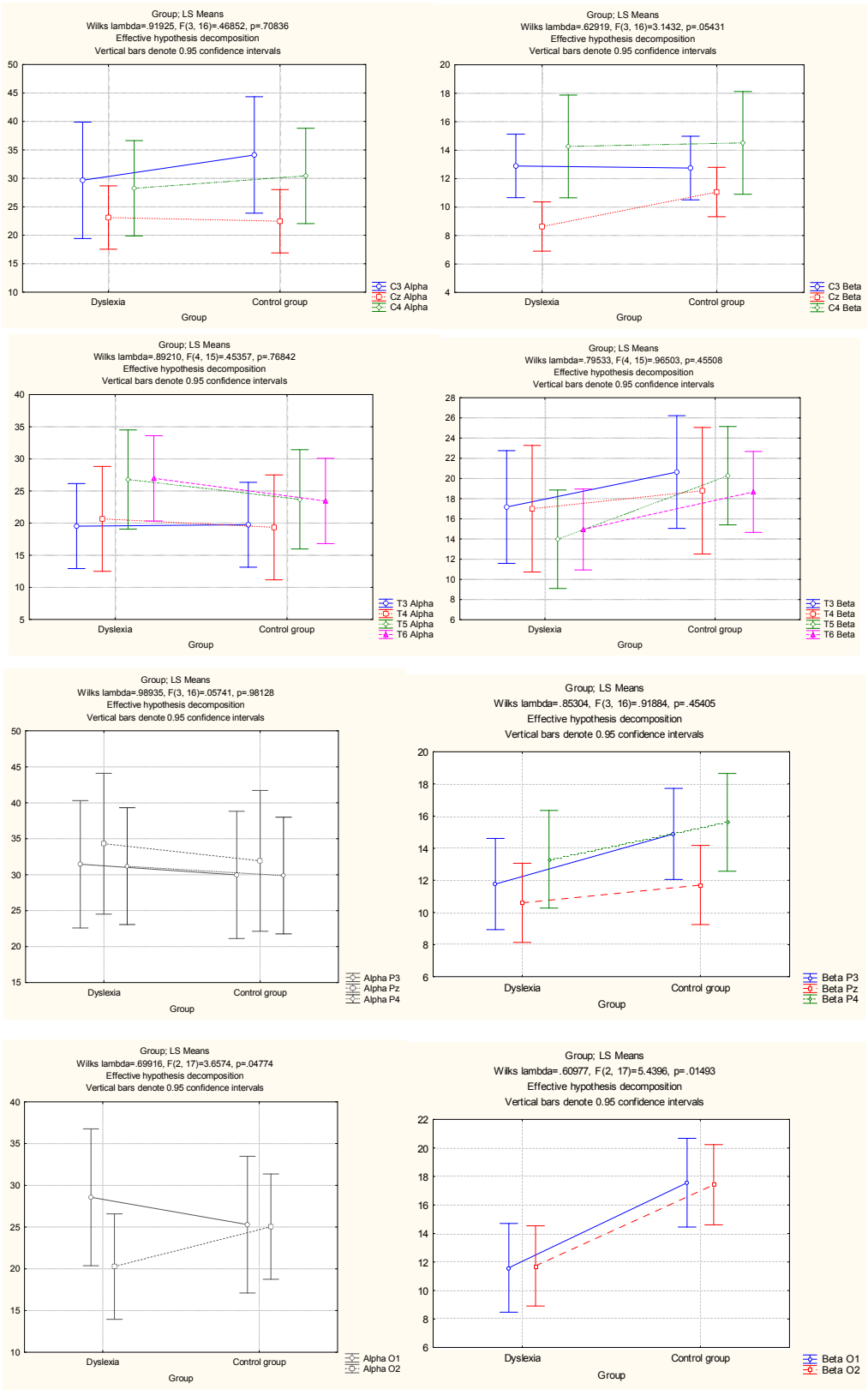


Figure 2. Comparison of Alpha and Beta Power between Dyslexic and Normal Control Groups

Table 1. Significant Differences between Groups

Delta	In central, temporal, parietal and occipital region relative power of delta in Dyslexia group>Control group
Theta	In frontal region and occipital region relative power of theta in Dyslexia group>Control group
Alpha	In occipital region relative power of alpha in Dyslexia group<Control group
Beta	In occipital region relative power of beta in Dyslexia group<Control group

For F (1,18) = 5.7346, p = 0.02702 Delta in Broca'a area is significantly higher in dyslexia group compared to controls (Figure 3).

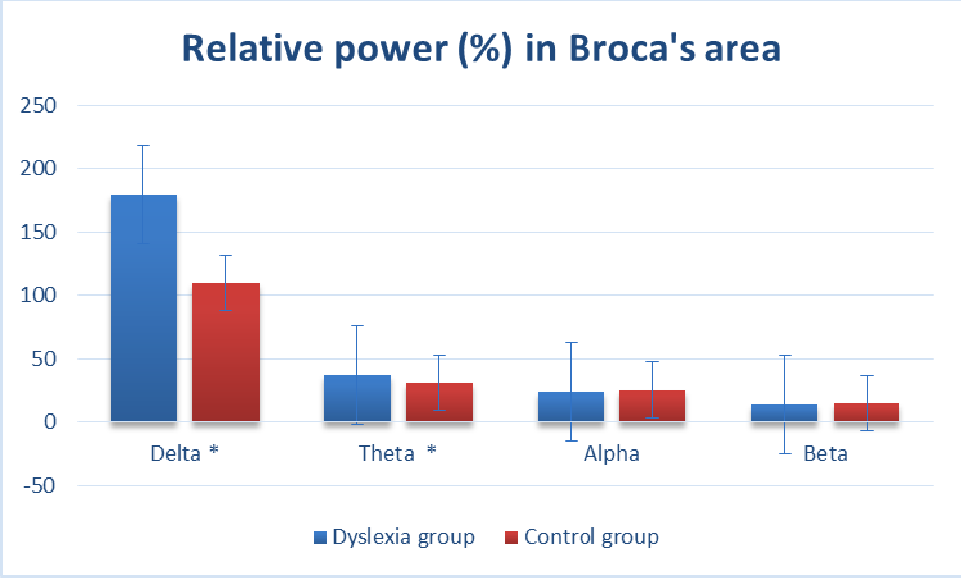


Figure 3. Relative Power in Broca's Area

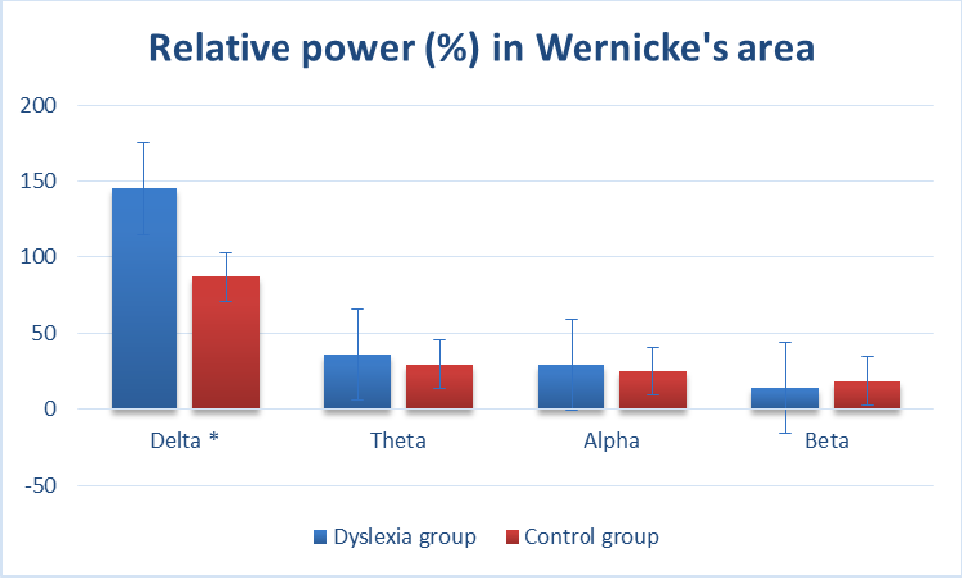


Figure 4. Relative Power in Wernicke's Area

As can be seen, slow waves are higher in dyslexic group; results for beta values are higher in all topographies of control children but without statistical significance.

Peak frequencies of brain waves showed no significant differences between the groups (Wilks lambda = .75259, F (4, 15) = 1.2328, p = .33875) (Figure 5).

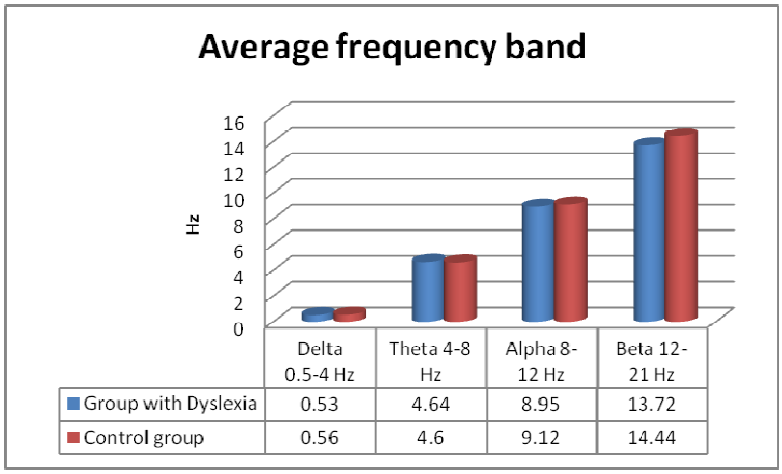


Figure 5. Average Peak Frequency Bands for Two Compared Samples

Mann-Whitney U Test (Dyslexia sheet)
By variable Group
Marked tests are significant at p <.05000

variable	Rank Sum Dyslexia	Rank Sum Control group	U	Z	p-level	Z adjusted	p-level	Valid N Dyslexia	Valid N Control group	2*1sided exact p
Delta in Broca's area	134.0000	76.0000	21.00000	2.192194	0.028366	2.192194	0.028366	10	10	0.028806
Theta in Broca's area	134.0000	76.0000	21.00000	2.192194	0.028366	2.192194	0.028366	10	10	0.028806
Alpha in Broca's area	101.0000	109.0000	46.00000	-0.302372	0.762369	-0.302372	0.762369	10	10	0.795936
Beta in Broca's area	94.5000	115.5000	39.50000	-0.793725	0.427356	-0.794024	0.427182	10	10	0.435872

Mann-Whitney U Test (Dyslexia sheet)
By variable Group
Marked tests are significant at p <.05000

variable	Rank Sum Dyslexia	Rank Sum Control group	U	Z	p-level	Z adjusted	p-level	Valid N Dyslexia	Valid N Control group	2*1sided exact p
Delta in Wernicke's area	139.0000	71.0000	16.00000	2.57016	0.010166	2.57016	0.010166	10	10	0.008931
Theta in Wernicke's area	123.0000	87.0000	32.00000	1.36067	0.173618	1.36067	0.173618	10	10	0.190316
Alpha in Wernicke's area	112.0000	98.0000	43.00000	0.52915	0.596702	0.52915	0.596702	10	10	0.630529
Beta in Wernicke's area	85.0000	125.0000	30.00000	-1.51186	0.130571	-1.51186	0.130571	10	10	0.143140

Figure 6. Nonparametric Mann-Whitney U Test for Delta and Theta Waves in Broca's and Wernicke's Areas

From Figure 6 it is clear that significant differences in dyslexic group was found for delta and theta waves in Broca's area, bur only for delta in Wernicke's area.

Additionally, we have calculated theta/beta ratio for dyslexic and control group of children. Obtained results showed that there is significant higher theta/beta ratio in the group of dyslexic children in comparison to control group $p < 0.05$ (Figure 7). Following previous experience, these corresponds to ADHD marker even in dyslexic group.

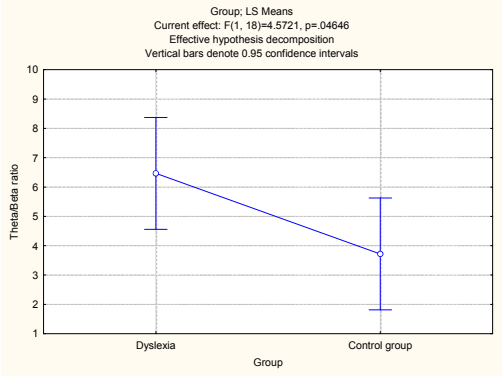
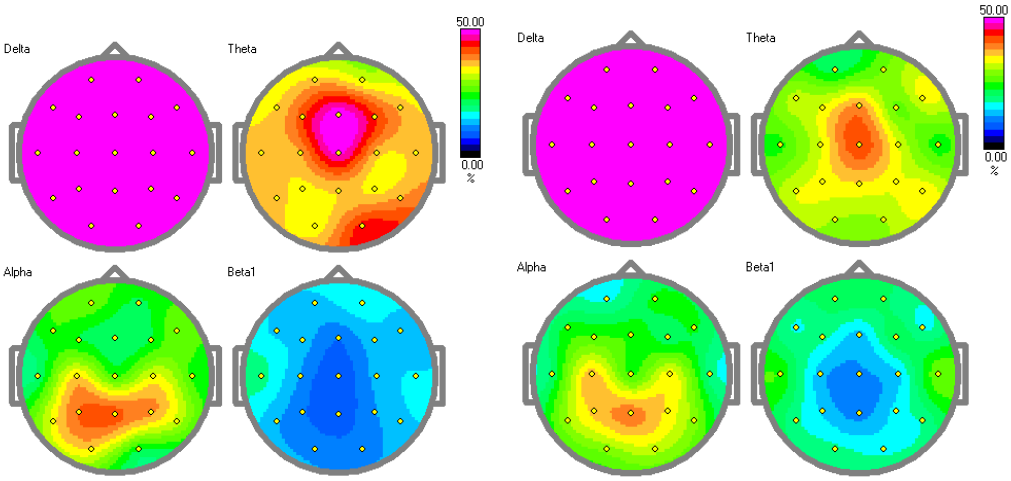


Figure 7. Theta/Beta Ratio in Dyslexic and Control Group

Topographic maps of brain waves for both evaluated groups are presented in Figure 8.



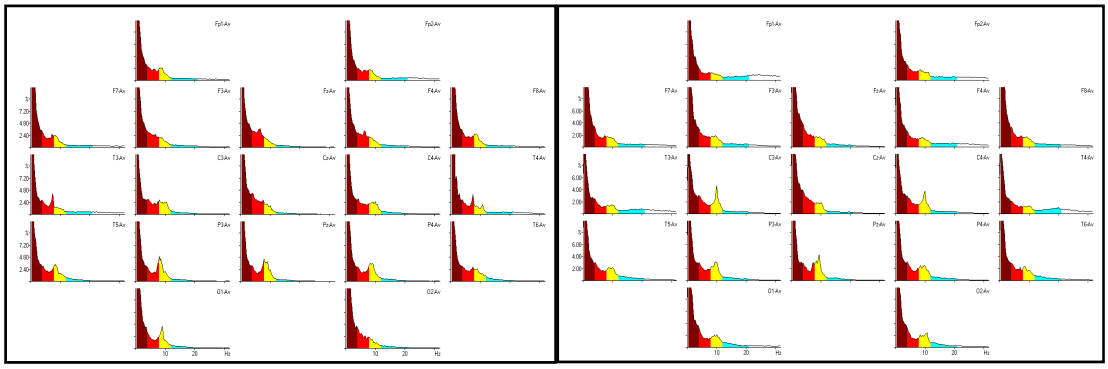
Children with dyslexia Control group

Figure 8. Topographic Maps of Brain Waves for Dyslexic Versus Control Group

Topographic maps confirmed that in dyslexic children (left) there is more theta and alpha and less beta compared to children with normal typical development (right).

Children with dyslexia have higher theta of 6.35Hz frontally and in temporal areas of 7.57Hz. There is less alpha (10Hz) and beta (14.88Hz). Also, the alpha as a sign of maturation is not well differentiated from theta in dyslexic group.

Results for graphs of EEG power spectra are presented on Figure 9.



dyslexia control group

Figure 9. Spectra Power Comparison

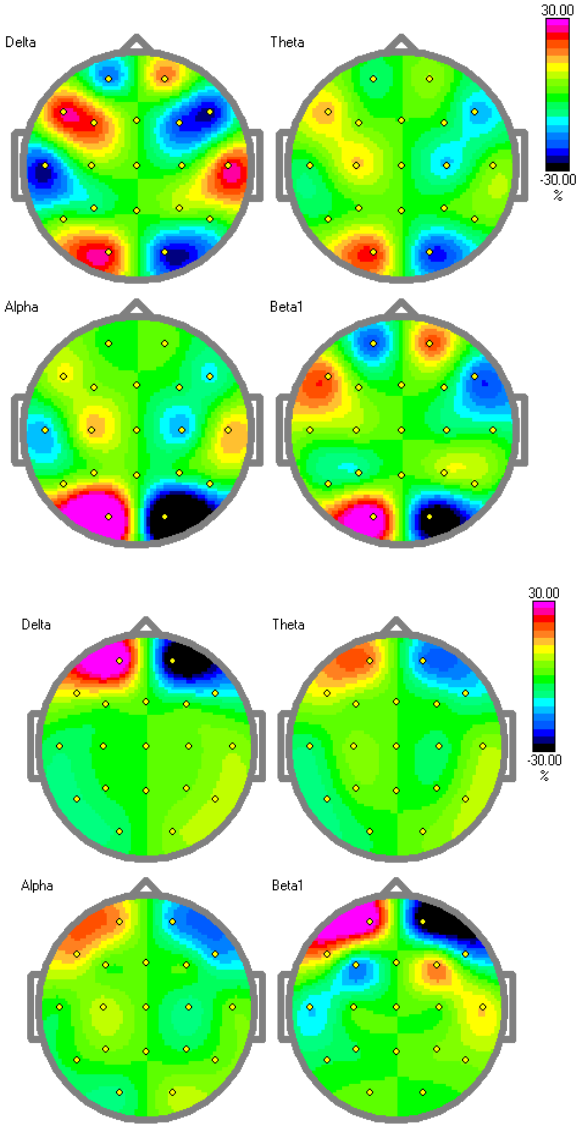


Figure 10. Topographic Maps for Asymmetry

(Left-Group with dyslexia; Right-Control group)

Even without statistical difference for asymmetry, the topographic maps show that there is more asymmetry between hemispheres for dyslexic group compared to control group, especially for temporal and parietal areas.

The testing with "Neurogame" was applied in children with dyslexia and results were compared with sample of school healthy children (Table 2)

Table 2. Descriptive Statistics Dyslexia vs. Healthy

Variable	Mean	Minimum	Maximum	Stand. Dev	
t T	182	141	214	20.07	healthy
	128	0	336	102.77	dyslexic
t H	47.16	8	80	26.99	healthy
	14.4	0	39	15.5	dyslexic
t M	134.83	94	189	26.93	healthy
	113.66	0	299	91.412	dyslexic
t h	328.33	189	422	78.88	healthy
	329.88	0	578	207.64	dyslexic

t T = max. tries; t H = max. hits; t M = max misses; t h = max time).

Calculated Student t-test for parameters between groups is presented on Figure 11. It is clear that only time for maximum hits is statistically significant; all other parameters are similar for both groups.

	T-test for Independent Samples (Dyslexia vs Healthy) Note: Variables were treated as independent samples								
Group 1 vs. Group 2	Mean Group 1	Mean Group 2	t-value	df	p	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	p Variances
t T vs. t T	128.1111	182.0000	-1.7862	19	0.090035	102.7782	20.07260	26.2177	0.000008
t H vs. t H	14.4444	47.1667	-3.2447	19	0.004264	15.5009	26.99439	3.0327	0.126178
t M vs. t M	113.6667	134.8333	-0.7649	19	0.453750	91.4166	26.93033	11.5230	0.000468
t h vs. t h	329.8889	328.3333	0.0239	19	0.981169	207.6454	78.88926	6.9280	0.004460

Figure 11. T-test for Independent Samples (Dyslexia vs Healthy)

Generally, results obtained with "Neurogame" are similar for dyslexic children and matched control healthy school children.

4. Discussion

A wide range of research has investigated what people understand about dyslexia. In this context, electrophysiological measures of brain function are used as effective tools to understand neurocognitive phenomena and as sensitive indicators of pathophysiological processes of this disorder.

The aim of the present study was to examine group differences in spontaneous oscillatory brain activity during a resting (eyes opened) condition. EEG power was examined across all frequency bands in children with dyslexia and contrasted to neurotypical children.

As presented, our group of dyslexic children did not differ significantly for results obtained by QEEG. It is obvious that the only difference is general slowing in brain activity and significantly higher theta/beta ratio found in dyslexic group.

Long time ago, the QEEG parameters were used to differentiated between children with learning Disorders (LD) and those with good academic achievement (Hendren, Haft, Black, White, & Hoeft, 2018; Harmony et al., 1990; Jäncke & Alahmadi, 2016; John, Prichep, Ahn, Easton, Fridman, & Kaye, 1983; Karovska-Ristovska, Kardaleska, Ajdinski, & Shurbanovska, 2018). LD children are characterized by more power in the theta band and less amount of power in the range of alpha frequencies (Kostic, Vladisavljevic, Popovic, & Cudov, 1983; Knight, 2018; Loleski, Loleska, & Pop-Jordanova, 2017; Lubar, Bianchini, Calhoun, Lambert, Brody, & Shabsin, 1985; Marosi, 1992; Marosi, 1997; Marosi et al., 1992; Meng, Hager, Held, Page, Olson, Pennington, & Gruen, 2005). Even increases in power in the delta band have also been observed in cases with severe difficulties (Harmony et al., 1990).

Furthermore, Jäncke and Alahmadi (2016) (Jäncke & Alahmadi, 2016), showed significant QEEG differences between children with LD-NOS (not otherwise specified), those with learning disabilities with verbal disabilities (LD-Verbal), and healthy controls. The features were selected by using a group independent component analysis (gICA) model. Finally, in the study by Roca-Stappung et al. (2017) (Turker, Reiterer, Preisler, & Schneider, 2017) it was shown that QEEG parameters differed between subtypes of LD-NOS in which group dyslexic children belong.

Bosch-Bayard J. and all (Bosch-Bayard et al., 2018; Bosch-Bayard, Peluso, Galan, Valdes Sosa, & Chiarenza, 2018) applied specific methodology to find an optimal predictor of LD-NOS disability severity based on a reduced set of QEEG variables that may be of use in real world screening settings. They divided nonspecific learning disabilities in three subgroups each with EEG characteristics related to the cognitive scores.

In a very large and significant study of Bosch-Bayard J. et all. Chiarenza (Bosch-Bayard, Peluso, Galan, Valdes Sosa, & Chiarenza, 2018), children with dysphonetic dyslexia showed significant excess in delta band in the middle line (Fz, Cz and Pz), as well as Fp2 and the occipital leads bilaterally (O1 and O2). A significant excess in high theta (6-7.5 Hz) and low alpha (7.5-8.5 Hz) bands was also present in the Fz, Cz and Fp2. Fz, Cz and Pz also showed significant excess of activity in the dyslexic group. However, a significant reduction of high alpha (11-12.5 Hz) activity was present in the dyslexic group bilaterally in F3, C3, C4 and in P3 but more pronounced in the left leads. Additionally, significant reduction was also present in the left leads F7, F3, C3, P3 and T5.

Having in mind the work of Broca and Wernicke and more recently those of language production as well as specific aspects of syntactic processing which are primarily localized in the left hemisphere, the left hemispheric localisation of abnormalities are expected. Papagiannopoulou and Lagopoulos (Papagiannopoulou & Lagopoulos, 2016) find a presence of an atypical linguistic network in dyslexic children where dominance of theta activity in the left frontal region implicated delayed maturation and abnormal hypoarousal mechanisms.

The results of these analyses revealed significantly increased theta power for the dyslexia group (when compared to controls) in frontal brain regions, the scalp topography corresponding to Broca's area and greater theta power in the left hemisphere. Children with dyslexia also had significantly increased slow

wave activity (for both delta and theta), in Broca's compared to Wernicke's area, which was in direct contrast to the control children who did not exhibit any asymmetry across these two areas. Children with dyslexia also had significantly decreased EEG power on the left for alpha2 and beta frequency bands, but had significantly increased EEG power in the left hemisphere for the theta band.

Our analysis for asymmetry of relative power did not confirmed any hemispheric asymmetry in dyslexic children.

Oscillatory dynamics of brain activity during processing of words and non-words was analysed thought analysis of EEG signals. Starting from the knowledge that reading is a complex cognitive skill sub served by a distributed network of visual and language-related regions, Žarić G. et al. (Žarić, 2017) investigated whether directed connectivity during reading scales with the level of dysfluency in dyslexic children exist. Obtained results of this study suggest disrupted visual processing of words in both dyslexic groups, together with a compensatory recruitment of right posterior brain regions. Functional connectivity in the brain's reading network may thus depend on the level of reading dysfluency beyond group differences between dyslexic and typical readers.

The finding that the functional connectivity pattern in dyslexic children is related to their reading level, may in part explain the mixed results obtained in previous functional connectivity studies of dyslexia.

Recent research has shown that the morphology of certain brain regions may correlate with a number of cognitive skills such as musicality or language ability. In a study of Turker S. et al. (Skiba, Landi, Wagner, & Grigorenko, 2011) the aim was to explore the extent to which foreign language aptitude, in particular phonetic coding ability, is influenced by the morphology of Heschl's gyrus (auditory cortex), working memory capacity, and musical ability. Study showed the importance of the right hemisphere for language processing, especially when linked or common resources are involved, such as the inter-dependency between phonetic and musical aptitude. Although there is no doubt that numerous external variables influence the development of language and musical skills, authors of this study supported the claim that there are strong innate and/or prenatally determined neurological factors that remain to be uncovered in the next decades.

Given that reported rates range for dyslexia are from of 4% to 20%, it is of great importance that teachers have an accurate understanding of what dyslexia is and how it effects their students. In the study of Cathryn Knight (Knight, 2018) it was demonstrated that teachers held only a basic understanding of dyslexia, based on the behavioral issues that it is associated with. Teachers lacked the knowledge of the biological (i.e., neurological) and cognitive (i.e., processing) aspects of dyslexia. Additionally, teacher training, which informs teachers of the up-to-date research on the biological, cognitive, and behavioral aspects of dyslexia, is essential to combat misconceptions and ensure that teachers have more nuanced and informed understandings of dyslexia.

There is emerging evidence that neuroimaging measures, combined with key behavioral measures, can enhance the accuracy of identification of dyslexia risk in prereading children but its sensitivity, specificity, and cost-efficiency is still unclear. Early identification of dyslexia risk carries important

implications for dyslexia remediation and the amelioration of the psychosocial consequences commonly associated with reading failure.

Structural MRI studies have demonstrated atypicality within the dorsal and ventral reading networks and functional MRI studies have shown reduced neural processing of phonological, rapid auditory, and orthographic information in these networks.

Despite the progress in studies for reading difficulties we are still far from having reliable biomarkers of dyslexia. Comorbidity make dyslexia very difficult for many treatment procedures. In our study, we also confirmed possible comorbidity with ADHD obtaining significantly higher theta/beta ratio in a group diagnosed as dyslexia.

5. Conclusion

Studies devoted to dyslexia are enormous and gives different interpretation about the aetiology. Not yet uniform conclusions about specific neurophysiological aspect exist.

Our finding about QEEG characteristics are not conclusive. However, slowing of brain activity in dyslexic children appeared to be confirmed. This finding lead to the possible hypothesis of delay in neurological development of these children.

Significant theta/beta ratio suggest comorbidity with ADHD.

The small sample size that we have evaluated must stimulate further research with more sophisticated analyses of the results.

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