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SPECIFIC FEATURES OF BRAIN CONNECTIVITY DURING SILENT READING IN CHILDREN WITH DEVELOPMENTAL DYSLEXIA[2]

Numerous studies have used electrophysiological methods in attempts to discriminate dyslexic from non-dyslexic readers and to identify brain mechanisms underlying specific reading disability.

The aim of the present study is to apply an analysis of large-scale neuronal networks to study brain connectivity in children with developmental dyslexia during silent reading and to compare results with their peers.

EEG signal was recorded from five dyslexic and five normal readers (three female and two male) using 10-20 International system for electrode placement and mono-polar montage. Additional EOG electrodes were used in order to register horizontal and vertical eye movements. Subjects had a task to read a simple story silently. The text was presented on a computer screen with 40 cm distance from the subject's eyes. Five-second artefact free periods were analysed offline using spectral analysis (FFT algorithm). Amplitude correlations in Theta rhythm (4-7 Hz) between all 19 electrodes were calculated. Statistically significant correlations (p=0.01) were further used for neural network modelling.

We found that dyslexic children had one closed neural network that consisted of four elements (centro-parietal cortex: C3-C4-Cz-P4 electrodes) and three interhemispheric connections between homologous electrodes without complex intra- and interhemispheric connections. Non-dyslexic readers had far more, both quantitatively and qualitatively, complex large-scale neuronal networks in fronto-temporal and centro-parietal cortex.

Complex cognitive functions, such as reading, require dynamic collaboration between close and distant cortical regions in order to achieve adequate connections for parallel information processing.

Key words: *EEG, Theta Band, Neuronal Networks, Brain Connectivity, Developmental dyslexia*

INTRODUCTION

Numerous studies have used electrophysiological methods in attempts to discriminate dyslexic from normal readers and to identify brain mechanisms underlying specific reading disability. Early EEG studies of dyslexics relied on clinical interpretation of recordings from passive subjects, and a high frequency of abnormal findings was often reported (Hughes 1978). The search for electrophysiological markers in dyslexia has continued, with researchers looking for more subtle abnormalities in patterns of EEG activation. Functional neuroimaging has been used to study the neural factors of dyslexia. However, there is not much evidence with respect to developmental dyslexia since this research has focused on (young) adults (Habib, 2000). Only Shaywitz and Shaywitz (Shaywitz et al., 2002; Shaywitz et all., 2005) used children in their neuroimaging studies in order to examine the neural systems for reading during the acquisition of literacy. These reports show a failure of left hemisphere posterior brain systems to function properly during reading.

The majority of studies show increased activation in the basal surface of the temporal lobe, the posterior portion of the superior and middle temporal gyri, extending into temporoparietal areas and the inferior frontal lobe during tasks requiring reading and phonological processing (Vellutino et al., 2004). Shaywitz et al. (2005) support

these findings, however they show evidence of right hemisphere activation in the posterior temporal parietal regions. This could reflect compensatory processes or could indicate that other non-linguistic factors are related to reading disability (Shaywitz et all, 2002; Shaywitz et al., 2005; Vellutino et all. 2004).

Theta band – lexical processing and memory retrieval

Complex cognitive processes are rejected by induced EEG activity, whereas the evoked response rejects primarily stimulus driven processes (Tallon-Baudry and Bertrand, 1999). Thus, the analysis of induced Theta band power will be useful, because we expect that this type of EEG activity will be particularly large for words and may distinguish well between dyslexics and controls. In addition, in our previous research Theta band was also sensitive to recall of known information from the long term memory system during lexical processing (Stokić et all., 2011a; Djoković et al., 2010), during phonemic discrimination of auditory presented word pairs (Stokić et al., 2011b), and during processing of speech and language in children with specific language impairment (Radičević et al., 2008; Radičević et all., 2009). The theta band is the 4 - 8 Hz range of frequencies. Theta-band activity in the brain is of interest in a variety of neuroscientific settings. Theta-band amplitude and coherence measured using EEG/ MEG recordings are sensitive to a wide variety of experimental conditions and behaviours. Two broad lines of research involving the theta-band might be distinguished: those focussed on long-term memory and those focussed on working memory in general. In the theta-band, frontal amplitude and widespread coherence at the time of encoding increased as the level of recognition increased, from misses to word-only to word and colour. Relations between dimensions of stimuli may also involve the formation of cell assemblies defined by their rhythmic activity. The data reviewed here suggest that at least some such phase coding of relationships is reflected in the theta band. The integration of sensory and motor activity extends the requirement for some form of short-term relational encoding to relations between motor and sensory activity. It is the prefrontal cortex that seems to play an important role in setting up and changing short-term relations

between distributed patterns of cortical activity. While there is not yet direct evidence for a prefrontal role in theta-band phase coding of motor and sensory activity, prefrontal and distributed theta-band activity are at least indirectly linked through their common collaboration. It seems, then, that theta-band activity may provide the relational encoding of cortical representations, and that this activity has two sources: first, hippocampal activity retrieving patterns from long-term memory, and possibly setting up the conditions for optimal encoding and second, prefrontal regions and anterior cingulate cortex (and possibly also the hippocampus) involved in working memory. This leads to the expectation that conflicts may arise between these two sources of phase-coding: perhaps long-term memory will exert a patterning force due to pattern recognition and completion, while working memory is stabilizing a different, more recent pattern of phase-coding. Such conflict may be the physical basis for some of the behavioural effects that resulted in the ideas of automatic and controlled processing and the supervisory attention system. If a similar end-product, in terms of influence on cortical activity, exists for prefrontal and hippocampal structures, data concerning one kind of activity may help understand the other.

In the recent study (Spironeli et all., 2008), the phonological deficit hypothesis of dyslexia was studied by analyzing language-related lateralization of theta (4–8 Hz) and beta rhythms (13–30 Hz) during various phases of word processing in a sample of 14 dyslexics and 28 controls. Compared with the controls, dyslexic children showed a delay in behavioural responses that was paralleled by sustained theta EEG peak activity. In addition, the controls showed greater theta activation at left frontal sites whereas the dyslexics showed a dysfunctional pattern. At posterior locations, and reversed with respect to controls' EEG responses, the dyslexics showed greater left lateralization during both Phonological and Orthographic tasks—a result which, in these children, indicates an altered and difficult phonological transcoding process during verbal working memory phases of word processing. Results point to a deficit, in phonological dyslexia, in recruitment of left hemisphere structures for encoding and integrating the phonological components of words, and suggest that the fundamental hierarchy within the linguistic network is disrupted.

METHOD

Subjects

Five dyslexic children (experimental group) and five peers with
normal reading abilities (control group), 2 boys and 3 girls, with average
age for experimental group – 105.6 months, and for control group –
107.8 months, participated in this experiment. All participants were
native speakers of Serbian language with no history of hearing or visual
disorders. No subjects used any medications that may influence EEG
signal. They passed standard hearing screening before the experiment
– tonal liminar audiometry, tympanometry, impendancmetry and
Otoacoustic Emission (TEOAE and DPOAE). All subjects had normal
intelligence (total IQ above 90). All subjects were right-handed.
Handedness was controlled by asking the subjects about the hand they
use in different tasks such as handwriting, throwing a ball, brushing
teeth, etc. A subject was considered right-handed if he indicated to use
the right hand for all of these different tasks. Experimental group was
selected according to DSM IV definition "reading achievement is below
the expected level for the child's age, education, and intelligence, and
the impairment significantly interferes with academic success or the
daily activities that involve reading". Clinical manifestation of dyslexic
reading: reading is very slowly and hesitant, not related to text, putting
letters in wrong order, misreading words of similar visual appearance,
omitting letters, following text with fingers, constantly losing place,
poor understanding of read paragraphs.

Procedure

During the experiment the subjects were placed in a comfortable
sitting position in a sound isolated room. Subjects were asked to
minimize their movements (eye blink, head and limbs movement)
as much as possible in order to eliminate artifacts in row EEG trace.
During the experimental procedure participants had to read a short
story silently (211 words, 1342 characters with spaces and 1131
characters without spaces). The text was presented on a computer

screen with 40 cm distance from the subject's eyes, font Times New Roman, and font size 12.

EEG recording

EEG was acquired using the Nihon Kohden Corporation, EEG 1200K Neurofax apparatus with Electrocap (model number 16 755) International, Inc., Ag/AgCl ring electrodes filled with electro-conductive gel, providing 16 EEG channels. Electrodes were positioned according to the 10/20 system in longitudinal, bipolar montage. Additional EOG electrodes were used in order to register horizontal and vertical eye movements. The reference electrode was set offline to A1 and A2 (ear lobes) creating monopolar montage. Resistance was kept below 5kΩ, lower filter was set on 0.53Hz and upper filter on 35Hz. Sampling rate was 256Hz. According to International 10/20 system of electrode positioning, the following cortical regions are covered: Fp1-Fp2 (frontopolar), F3-F4 (mid frontal), F7-F8 (inferior frontal, anterior temporal, frontal-temporal), T3-T4 (mid temporal), T5-T6 (posterior temporal), C3-C4 (central), P3-P4 (parietal), O1-O2 (occipital), Fz (frontal midline central), Cz (vertex) and Pz (parietal midline). Odd numbers represent the left hemisphere and even numbers the right hemisphere.

Signal analysis procedure

Fast Fourier Transform (FFT) was used in order to separate Theta band from the row EEG trace. First task in signal analysis was to choose artefact free epochs in duration of 5 seconds. Before computing FFT each epoch was multiplied by an appropriate windowing function (Hanning window was used) in order to avoid border problems (leakage). Then FFT was computed in order to get spectrograms of selected 5-second-epoches.
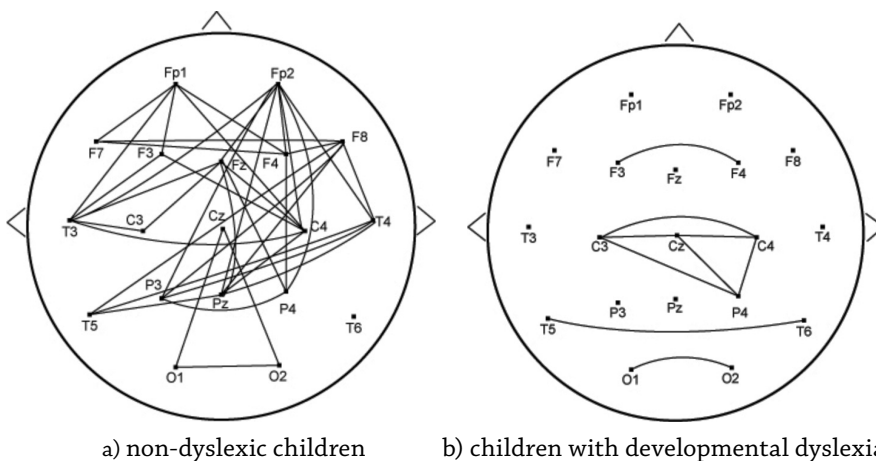
Amplitude correlations (Pearson correlation coefficient) in Theta rhythm (4-7 Hz) between all 19 electrodes were calculated. Stati-

stically significant correlations (p=0.01) were further used for neural network modelling.

RESULTS

The Picture 1a represents statistically significant correlations between amplitude values of all electrodes during silent reading in children with typical reading. By observing these results in the light of the brain connectivity in neural network model, it was emphasized that neural network is a connection of at least three regions (collaborating in the very close correlation of amplitude value, p<0.01). In qualitative analysis, we found five 3-member networks O1-O2-Cz, Fp1-F3-T3, Fp1-Fz-C4, Fp1-F7-F4, and Fz-P4-Pz), one 4-member network (T3-F3-C3-C4), one 5-member network (Fp2-F8-T4-T5-Pz), and one 6-member network (Fp2-F8-P4-P3-Pz-T5). Most of the connections made prefronto-frontal regions (Fp2 made 10 connections, F8 made 8 connections) and frontal midline Fz region made 7 connections. These findings are expected during known function of the Theta rhythm in memory recall (provided that the subjects read a story composed of familiar and frequent words). Posterior region of the brain, as well as temporal regions of both right and left hemisphere created more than five networks (Pz made 8 and P4 made 7 connections, T3 and T5 made 6 connections, T4 made 5). From the obtained results, we can see discreet leading role of the right hemisphere (even numbers represent right hemisphere electrode location and odd numbers homologous regions of the left hemisphere) in connections needed for parallel information processing in subjects with typical reading function. Involvement of parietal regions in the networks combined with temporal regions might be explained due to its role in lexical-semantic processing. These findings emphasize parallel information processing during 5-second period of silent reading in children with typical reading function. Parallel information processing leads to the ability to process phonological, lexical, semantic, and syntactic structure of written discourse.

Picture 1- EEG Theta Band Neural Networks during silent reading task

a) non-dyslexic children   b) children with developmental dyslexia

The Picture 1b represents statistically significant correlations between amplitude values of all electrodes during silent reading in children with developmental dyslexia. We can see absolute absence of prefrontal connections in a form of network, as well as absence of parietal regions involvement. Only P4 region of parietal right hemisphere cortex was involved in one 4-member network (C3-C4-Cz-P4). Except this neural network, no others were detected. In addition, present three "attempts at processing information" include two regions that are connected due to significant correlation coefficient (F3-F4, O1-O2, and T5-T6). These results indicate that there are three separated processes going on during 5-second period of silent reading, but without interconnections and intrahemispheric patterns found in children with typical reading function. These findings might be related to specific organisation of attention (also development of attention) during reading process in children with developmental dyslexia (Nenadović et al, 2011).

DISCUSSION

Developmental dyslexia is much more than a reading impairment - it is a different pattern of *brain* organization and *information processing.* Functional brain imaging studies have identified a distributed network of brain regions located in both left and right hemispheres as being involved in skilled reading. In particular, decoding words is associated with three brain regions: (a) the juncture of the posterior temporal and anterior occipital lobes, (b) the juncture of the superior temporal and inferior parietal lobes, and (c) a region of the inferior frontal lobe. When they read, typically developing children engage both frontal and posterior regions of this network (Hoeft et al., 2007; Shaywitz et al., 2002). In contrast, individuals with dyslexia do not engage the posterior portions of it (Hoeft et al., 2007; Shaywitz & Shaywitz, 2004). Our results confirm these findings.

Given the importance of left hemisphere cortical regions for skilled reading, Klingberg et al. (2000) hypothesized that individuals with dyslexia would demonstrate less integrity along the left superior longitudinal fasciculus, a white matter tract that connects the anterior and posterior components of the left hemisphere in the reading network. They provided initial support for this hypothesis by observing a decrease in bilateral temporo-parietal white matter signal transduction in a group of adults with reading difficulties when compared to non-impaired readers. Our findings showed different brain organisation in children with dyslexia. They had connections between homologous regions of left and right hemisphere without clear lateralisation of the reading function (with only one network that included C4 region of the right hemisphere). In addition, regarding frontal, temporal, and occipital 2-member connections that might be named as an "attempt at processing information", and one central 4-member network we might conclude that all "necessary" processes for adequate reading function are present. Nevertheless, main deficit is in absence of cortical connections of three and more regions providing parallel information processing at the same time without complex intra- and inter-hemispheric connections.

Nonetheless, further research will be needed for a better understanding of the functional meaning of EEG frequencies in different developmental stages as well as cortical connectivity during reading process.

CONCLUSIONS

a) non-dyslexic children form complex inter- and intra-hemispheric connections between close and distant brain regions during silent reading

b) children with developmental dyslexia form "attempts at processing information" - including two regions that are connected, without complex intra- and inter-hemispheric connections

c) children with developmental dyslexia had connections between homologous regions of left and right hemisphere without clear lateralisation of the reading function

d) in children with developmental dyslexia we found lack of prefronto-frontal connections

e) in children with developmental dyslexia main deficit might be in the absence of cortical connections of three and more regions providing parallel information processing

REFERENCES

1. Djoković, S., Stokić, M., Nenadović, V., Milosavljević, Z., Maksimović, S. (2010). Spectral analysis of EEG signal in verbal information processing task. *Disabilities and Disorders: Phenomenology, Prevention and Treatment part II*, Editors: Jasmina Kovačević, Vesna Vučinić, pp. 63-82.

2. Habib, M. (2000). The neurological basis of developmental dyslexia. An overview and working hypothesis, *Brain 123*, 2373–2399.

3. Hoeft, F., Meyler, A., Hernandex, A., Juel, C., Taylor-Hill, H., Martindale, J. L., et al. (2007). Functional and morphometric brain dissociation between dyslexia and reading ability. *Proceedings of the National Academy of Sciences of the United States of America*, *104*, 4234–4239.

4. Hughes, J. R.(1978). EEG and neurophysiological studies in dyslexia. In: A.L. Benton and D. Pearl (Eds.), *Dyslexia: an Appraisal of Current Knowledge.* Oxford University Press, New York, 251-261.

5. Klingberg, T., Hedehus, M., Temple, E., Salz, T., Gabrieli, J. D. E., Moseley, M. E., et al. (2000). Microstructure of temporo-parietal white matter as a basis for reading ability: Evidence from diffusion tensor magnetic resonance imaging. *Neuron*, *25*, 493–500.

6. Nenadović, V., Djoković, S., & Pečenica, D. (2011). Developmental changes in auditory attention. *Specijalna edukacija i rehabilitacija, 10* (1), ISSN 1452-7367, pp. 77-92.

7. Radicevic, Z., Jelicic-Dobrijevic, Lj., Sovilj M., & Barlov I. (2009). Comparison of mapping quantitative theta encephalograms during directed and required visual-verbal activity and passive period in children with different disorders of speech-language functioning. *Experimental Brain Research, 195* (4), pp. 569-574.

8. Radicevic, Z., Vujovic, M., Jelicic, Lj., & Sovilj M. (2008). Comparative findings of voice and speech: language processing at an early ontogenetic age in quantitative EEG mapping. *Experimental Brain Research*, *vol. 184* (4), pp. 529 -532.

9. Shaywitz, B. A., Shaywitz, S. E., Pugh, K. R., Mencl, W. E., Fullbright, R. K., Skudlarski, P., et al. (2002). Disruption of posterior brain systems for reading in children with developmental dyslexia, *Biological Psychiatry 52*, 101–110.

10. Shaywitz, S. E., & Shaywitz, B. A. (2005). Dyslexia (Specific Reading Disability), *Biological Psychiatry 57,* 1301–1309.

11. Shaywitz, S. E., & Shaywitz, B. A. (2004). Neurobiological basis for reading and reading disability. In P. McCardle & V. Chhabra (Eds.), *The voice of evidence in reading research* (pp. 417–442). Baltimore, MD: Brookes.

12. Spironelli, C., Penolazzi, B., & Angrilli A. (2008). Dysfunctional hemispheric asymmetry of theta and beta EEG activity during linguistic tasks in developmental dyslexia. *Biological Psychology*, 77 (2), 123-131.

13. Stokić, M., Milosavljević, Z., & Maksimović, S. (2011a). Oscilatory brain dynamics during lexical processing. *Specijalna edukacija i rehabilitacija 10* (1), 141-152

14. Stokić, M., Milosavljević, Z., & Marković, D. (2011b). Quantitative EEG correlates of verbal information processing in four-years-old child with severe auditory phoneme adiscrimination. *Proceedings of The Third European Congress on Early Prevention, Detection and Diagnostics of Verbal Communication Disorders,* Ancient Olympia, Greece, *21-23. October 2010.* pp. 67-71.

15. Tallon-Baudry, C., & Bertrand, O. (1999). Oscillatory gamma activity in humans and its role in object representation. *Trends in Cognitive Sciences, 3* (4). 151-162.

16. Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry, 45*, 2–40.

SPECIFIČNOSTI POVEZIVANJA MOŽDANIH REGIJA TOKOM ČITANJA U SEBI KOD DECE SA RAZVOJNOM DISLEKSIJOM

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Rezime

Brojne studije koristile su elektrofiziološke metode u pokušaju da diferenciraju decu sa razvojnom disleksijom od tipičnih čitača kao i da identifikuju mehanizme koji su u osnovi razvojne disleksije.

Cilj ove studije bio je da se ispitaju karakteristike povezivanja moždanih regija u lokalne i široko-distribuirane neuralne mreže kod dece sa razvojnom disleksijom tokom čitanja u sebi i da se rezultati uporede sa rezultatima dece urednih čitača.

EEG signal je snimljen kod petoro dece sa razvojnom disleksijom (2 dečaka i 3 devojčice) i pet urednih čitača iste polne i uzrasne strukture, koristeći 10-20 Internacionalni sistem za pozicioniranje elektroda uz monopolarnu montažu. Dodatne elektrode su korišćene kako bi se registrovali pokreti očiju. Ispitanici su imali zadatak da u sebi čitaju jednostavan tekst. Tekst je prezentovan na monitoru računara na udaljenosti od 40cm od očiju ispitanika. Periodi od 5 sekundi bez artefakata analizirani su spektralnom analizom (FFT-Fast Fourier Transform algoritam). Statistički značajne (p<0.01) korelacije u amplitudi teta ritma (4-7 Hz) između svih 19 elektroda korišćene su za dalje modeliranje neuralnih mreža.

Ustanovljeno je da su deca sa razvojnom disleksijom formirala jednu četvoročlanu neuralnu mrežu (centro-parijetalni korteks: C3-C4-Cz-P4) kao i tri interhemisferne konekcije između homolognih elektroda leve i desne hemisfere bez kompleksnih intra ili interhemisfernih konekcija. Deca sa tipičnom funkcijom čitanja su ostvarila daleko veći broj tročlanih, četvoročlanih i petočlanih zatvorenih mreža u odnosu na decu sa razvojnom disleksijom. Kognitivna funkcija kao što

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je čitanje zahteva dinamičku saradnju bliskih i udaljenih kortikalnih regiona u cilju postizanja paralelnog procesiranja informacije.