J Appl Biomed
DOI: 10.32725/jab.2023.013

journal homepage: http://jab.zsf.jcu.cz

Journal of Applied Biomedicine

Original research article

Resting-state EEG alpha rhythm spectral power in children with specific language impairment: a cross-sectional study

Nina Stanojević [1,2] *, Saška Fatić [1,2], Ljiljana Jeličić [1,2], Vanja Nenadović [2], Miodrag Stokić [3], Ružica Bilibajkić [1], Miško Subotić [1], Tatjana Bošković Matić [4], Ljubica Konstantinović [5,6], Dragana Ćirović [5,7]

[1] *Research & Development Institute "Life Activities Advancement Institute", Cognitive Neuroscience Department, Belgrade, Serbia*
[2] *Institute for Experimental Phonetics and Speech Pathology "Đorđe Kostić", Department of Speech, Language, and Hearing Sciences, Belgrade, Serbia*
[3] *University of Belgrade, Faculty of Biology, Belgrade, Serbia*
[4] *University of Kragujevac, Faculty of Medical Sciences, University Clinical Center, Kragujevac, Serbia*
[5] *University of Belgrade, Faculty of Medicine, Belgrade, Serbia*
[6] *Clinic for Rehabilitation "Dr Miroslav Zotovic", Belgrade, Serbia*
[7] *University Children's Hospital, Physical Medicine and Rehabilitation Department, Belgrade, Serbia*

Abstract

Purpose: This study investigated EEG alpha rhythm spectral power in children with Specific Language Impairment (SLI) and compared it to typically developing children to better understand the electrophysiological characteristics of this disorder. Specifically, we explored resting-state EEG, because there are studies that point to it being linked to speech and language development.

Methods: EEG recordings of 30 children diagnosed with specific language impairment and 30 typically developing children, aged 4.0–6.11 years, were carried out under eyes closed and eyes open conditions. Differences in alpha rhythm spectral power in relation to brain topography and experimental conditions were calculated.

Results: In the eyes closed condition, alpha rhythm spectral power was statistically significantly lower in children with specific language impairment in the left temporal (T5) and occipital electrodes (O1, O2) than in typically developing children. In the eyes open condition, children with SLI showed significantly lower alpha rhythm spectral power in the left temporal (T3, T5), parietal (P3, Pz), and occipital electrodes (O1, O2). There were no statistically significant differences between the groups in relation to the relative change (the difference between average alpha rhythm spectral power during eyes closed condition and average alpha rhythm spectral power during eyes open condition divided by average alpha rhythm spectral power during eyes closed condition) in the alpha rhythm spectral power between the conditions.

Conclusion: Lower alpha rhythm spectral power in the left temporal, left, midline parietal, and occipital brain regions could be a valuable electrophysiological marker in children with SLI. Further investigation is needed to examine the connection between EEG alpha spectral power and general processing and memory deficits in patients with SLI.

Keywords: Alpha rhythm; EEG; Specific language impairment

Highlights:

- Alpha rhythm spectral power is associated with processing and memory.
- It has been previously discussed that processing and memory may be key problems in children with specific language impairment.
- We examined if alpha rhythm spectral power in the eyes open and eyes closed resting states differ between children with specific language impairment and typically developed children.
- Alpha rhythm spectral power is lower in the left temporal, left and mid parietal, and occipital regions in children with specific language impairment compared to typically developed children.

Introduction

Children with specific language impairment are characterized by delayed language development in the absence of any apparent limitations, such as hearing disorders, behavioral or emotional disorders, neurological impairments, or intellectual disability (Plante, 1998; Stark and Tallal, 1981; Tomblin et al., 1997b). Bishop (1992) emphasized that these children exhibit limited vocabulary knowledge, underdeveloped or unusual syntax, and impaired grammatical morphology. It is estimated that about 7% of all kindergarten children have this disorder

* **Corresponding author:** Nina Stanojević, Research & Development Institute "Life Activities Advancement Institute", Cognitive Neuroscience Department, Gospodar Jovanova 35, 11000, Belgrade, Serbia; e-mail: n.stanojevic@add-for-life.com
http://doi.org/10.32725/jab.2023.013

Submitted: 2023-04-10 • Accepted: 2023-09-13 • Prepublished online: 2023-09-18
J Appl Biomed 21/3: 113–120 • EISSN 1214-0287 • ISSN 1214-021X

(Tomblin et al., 1997a), which affects their social and future academic functioning. Despite the high prevalence of this disorder, its cause and biological basis are not completely understood. Some of the key problems among children with SLI that are most often considered in the literature are the storage and general processing of information (Mainela-Arnold and Evans, 2005; Montgomery, 2002).

Resting-state EEG has been studied as a baseline condition that can be conducive to understanding cognitive processes (Deco et al., 2011). Some authors have studied the changes in EEG that occur with maturation (Clarke et al., 2001; Eisermann et al., 2013; Miskovic et al., 2015; Perone et al., 2018). In resting-state EEG, the dominant frequency in the adult human brain is alpha (Klimesch, 1996, 2012; von Stein and Sarnthein, 2000). Previous studies have focused on examining the connection between EEG characteristics and specific cognitive functions (Giannitrapani, 1985; Marosi et al., 1999; Martin-Loeches et al., 2001; Schmid et al., 2002; Thatcher et al., 2005). The association between EEG spectral power and certain cognitive and speech-language abilities has been studied in typically developing (TD) children (Kwok et al., 2019; Lyakso et al., 2020; Thatcher et al., 2005) and children with SLI (Chutko et al., 2015; Fatić et al., 2022; Nenadovic et al., 2014). The spectral power of the alpha rhythm is associated with attention, memory, language ability, and articulation skills (Kwok et al., 2019; Lyakso et al., 2020; Magosso et al., 2019). According to one dominant hypothesis, the higher synchronization of alpha spectral power during the resting state shows that the cognitive system is not active but ready for perception and processing (Lyakso et al., 2020). During cognitive tasks, the alpha rhythm spectral power decreased (Klimesch, 1996). It is known that alpha rhythm spectral power desynchronizes in the eyes open condition compared to the eyes closed condition (Nunez, 1995). This phenomenon is detected across the cortex, not only in regions that process visual inputs, which was interpreted as a general cortical activity by Barry et al. (2007). Same authors pointed out that electrophysiological findings of resting state in the EC condition reflect an arousal baseline, which is explained as the current energetic level of an organism. On the other hand, investigation of EO resting states reflects an activation baseline, which is a state in which a task mobilizes the energy needed to perform it (relative to a baseline level of arousal).

A large number of electrophysiological studies on children with SLI have focused on EEG abnormalities in light of epileptic features (Echenne et al., 1992; Levy-Rueff et al., 2012; Pal, 2011; Picard et al., 1998) and ERP investigations of speech and language processing (Epstein et al., 2014; Heim et al., 2016; Kaganovich et al., 2014). Studies on the characteristics of EEG in children with SLI, especially those concerning the resting state, are scarce. Such studies of resting-state EEG in the clinical population of children with SLI are needed to draw conclusions regarding task-dependent brain changes. This cannot be done without knowledge of the functional specifics of the brain at rest (Wang et al., 2013). To the best of our knowledge, no studies have examined the alpha rhythm in children with SLI in this light.

Empirical findings show that children with SLI have difficulties in general processing and memory (Archibald and Gathercole, 2006; Leonard et al., 2007; Montgomery, 2002). Because the alpha rhythm has been associated with these functions, investigating them in these children could provide a better understanding of the underlying processes of this impairment. The authors who studied the EEG characteristics of children with SLI revealed some specific features (Chutko et al., 2015; Nenadovic et al., 2014). Fatić et al. (2022) found that during task with word and non-word listening alpha rhythm activity differs between children with SLI and TD children. In their study of the resting state under EO and EC conditions in children aged five to seven, Chutko et al. (2015) found higher spectral power within the theta band in children with SLI compared to TD children. Nenadovic et al. (2014) compared SLI children with and without subclinical epileptiform discharge. The SLI sample with epileptiform discharges showed an increased spectral power of slower brain rhythms compared to SLI children without epileptiform discharges. Kwok et al. (2019) studied differences in alpha power between the EO and EC condition in relation to language abilities in TD children. They found no connection between the level of alpha desynchronization and language abilities. In their studies (Jausovec and Jausovec, 2001; Thatcher et al., 2005), authors confirmed that there is a connection between alpha power and the level of intelligence. Previous studies have shown an association between alpha rhythm and memory process (Klimesch, 1996; Palva and Palva, 2007; Palva et al., 2010). Farber et al. (2000) suggest that alpha rhythm is involved in general processing and memory. These functions are considered as key impairments in children with SLI. Considering the above, we can conclude that resting state can show us some specific features in clinical populations. The aim of our study was to examine the EO and EC resting state alpha rhythm in children with SLI and their typically developing peers. Therefore, the first goal was to compare the alpha rhythm spectral power separately under EO and EC conditions between children with SLI and TD children. The second goal was to investigate whether there was a difference between SLI and TD groups regarding the relative change in alpha rhythm spectral power between the two conditions.

Materials and methods

Sample

The SLI group included 30 participants diagnosed with SLI by a speech-language pathologist with > 20 years of clinical practice. The Dictionary Test for Children aged 3 to 7 years (Vasić, 1991), the Peabody Picture Vocabulary Test (Dunn and Dunn, 1981) and Token test (De Renzi and Vignolo, 1962) were used for additional confirmation of diagnosis. The inclusion criteria were IQp ≥85 (performance IQ) with a language measure of 1.25 below average (Tomblin et al., 1996). All children from the SLI group have been recruited from the Institute for Experimental Phonetics and Speech Pathology "Djordje Kostic", where they have been admitted for speech-language therapy. The TD group consisted of 30 participants, recruited from a local kindergarten. All children in the SLI and TD groups had IQp ≥85 (performance IQ), no neurological signs, normal or corrected-to-normal vision, normal hearing, and were right-handed. Performance IQ was assessed using the Brine-Lezin scale (Čuturić, 1973) and WISC (Biro, 1998). The two groups were balanced in terms of IQ, age, and sex (Table 1). All children were right-handed, according to the Edinburgh Inventory (Oldfield, 1971).

EEG recordings

During EEG recording, the children were placed in a comfortable sitting position in a sound proofed and electrically shielded room. The participants were positioned in a white box 1.7 × 1.7 m, and the distance between their eyes and the curtain was 1 m. Participants were asked to minimize their movements (blinking/head and limb movements) as much as

Table 1. Participants' characteristics

	Age*		IQp**		Gender	
	Mean	SD	Mean	SD	Male	Female
SLI group	65.70	9.80	101.00	11.27	22	8
TD group	66.60	10.15	105.90	9.66	18	12
	$p > 0.05$		$p > 0.05$		$p > 0.05$	

Note: * Age expressed in months; ** IQp is performance IQ.

possible to eliminate artifacts from the raw EEG trace. They were instructed to keep their eyes closed or open for one minute at a time, resulting in a 3-minute recording for each condition. As a way to avoid any influence caused by the fact that recoding started or ended with opened or closed eyes, the order of recording condition was arranged in two ways shown in Fig. 1. The orders of recording were randomized between subjects, with 50% recordings in each order.

	EC	EO	EC	EO	EC	EO
Order 1	1 minute	1 minute	1 minute	1 minute	1 minute	1 minute
	EO	EC	EO	EC	EO	EC
Order 2	1 minute	1 minute	1 minute	1 minute	1 minute	1 minute

Fig. 1. Scheme of the possible orders for consecutive EC and EO conditions during recording

EEG was recorded using the Nihon Kohden Corporation EEG 1200 K Neurofax apparatus with Electrocap, silver/silver-chloride (Ag/AgCl) ring electrodes that were filled with an electroconductive gel. In total, 19 EEG channels were recorded (Fp1, Fp2, F3, F4, F7, F8, Fz, C3, C4, Cz, T3, T4, T5, T6, P3, P4, Pz, O1, and O2). Electrodes were positioned according to the 10/20 international system for electrode placement. Recordings were referenced to (C3 + C4)/2, the physical reference of the NK-1200K EEG system, with the ground electrode placed on the earlobes (A1 and A2). Impedance was kept below 5 kΩ, with not more than 1 kΩ difference between the electrodes. The lower filter was set at 0.53 Hz and the upper filter at 35 Hz. The electrooculograms were recorded to detect eyeblinks and horizontal or vertical eye movements. Sensors for hand movement, heart rate, and jaw muscle activity were used for offline artifact removal. The AC filter was set to ON. The sampling rate was 200 Hz, with 16-bit resolution.

Data analysis

For EEG data analysis, the EEGLAB software packages (Delorme and Makeig, 2004) and MATLAB were used. All data were filtered using an FIR bandpass filter with a passband of 1 Hz–30 Hz. All data from each child were referenced to the average. Data segments containing obvious eyeblinks, muscle noise, and other irregular artifacts, as identified by visual examination, were removed. Independent components analysis (ICA) was subsequently used to suppress artifacts due to eye movements, eye blinks, muscle movements, and heartbeats. The ICA results were visually inspected, and the detected artifacts were removed. Then, the data were segmented into two-second epochs with a one-second overlap. After removing the data with artifacts, the final number of epochs was 40 per condition per child and 4800 in total (40 epochs × 2 conditions × 60 children). The first 40 epochs for each child and each condition were selected. The loading of the EEG data, segmentation, alpha rhythm spectral power calculation, and data storage were automated using MATLAB scripts. The power spectral density estimate was calculated on two-second segments using Welch's method in MATLAB. Since the MATLAB function used for power spectral density estimation has several options [function named pwelch()], we set the number of overlapping segments to 4 with 50% overlap. The number of discrete Fourier transform (DFT) points was set to 512. The spectral power for the EC and EO conditions was determined for alpha rhythms ranging from 8 to 12 Hz. The mean power spectral density was calculated as an average of all frequency bins greater than 8 Hz and lower than 12 Hz (all 10 frequency bins between 8 Hz and 12 Hz were equally weighted). The algorithmic description of mean power spectral density calculation for alpha rhythms is presented in Fig. 2. The average alpha rhythm spectral power was determined for three brain regions: the anterior (Fz, Fp1, Fp2, F3, and F4, F7, F8, T3, and T4), central (Cz, C3, C4), and posterior (Pz, P3, P4, T5, T6, O1, and O2). The relative change in spectral power between the EC and EO conditions was calculated using the following equation:

$$Relative\ change = \frac{SPEC - SPEO}{SPEC}$$

where SPEC represents the alpha rhythm spectral power in the EC condition, and SPEO represents the alpha rhythm spectral power in the EO condition.

Procedures

The participants' parents signed a written informed consent form for the children's participation in the EEG recording session and IQ assessment. The study was performed in accordance with the ethical standards of the Declaration of Helsinki and the protocol was approved by the Ethics Committee of the Institute for Experimental Phonetics and Speech Pathology "Djordje Kostic". The assessments were conducted in two sessions, one session per day for two days in a row. During the first session, children completed an IQ test. EEG recordings were performed separately. All participants were recorded at approximately the same time of the day (morning hours).

Statistical analysis

Statistical analysis was performed using the IBM SPSS statistical software (SPSS for Windows, version 20.0). Numerical data for all electrodes and regions were normalized using the Log10 function. All presented mean and standard deviation values are absolute and calculated before application of Log 10 function. A *t*-test was used to estimate topographic differences in alpha rhythm spectral power between groups.

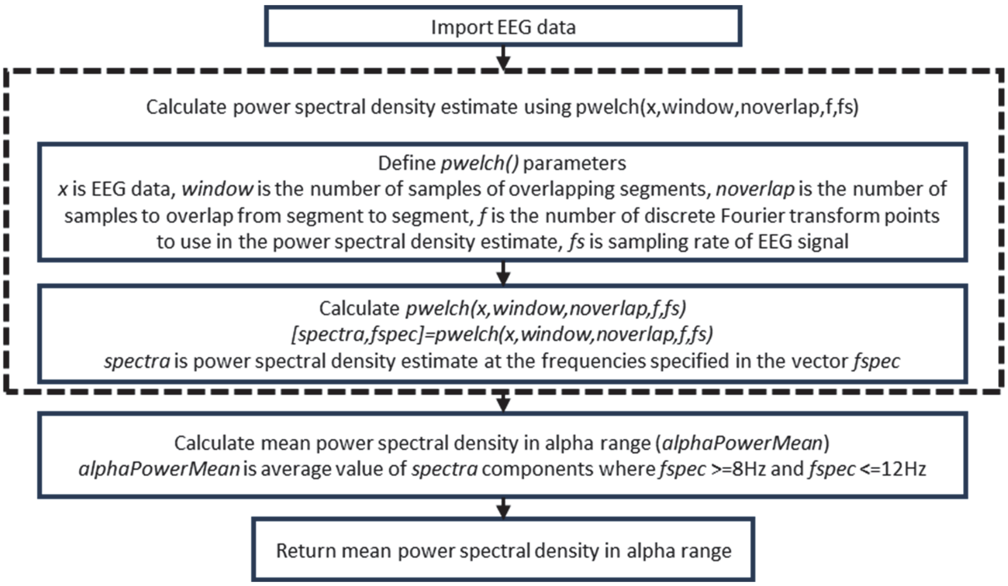

Fig. 2. Algorithmic description of mean power spectral density calculation for alpha rhythm

Results

In relation to the posterior, anterior, and central regions, our results showed that the alpha rhythm spectral power was statistically significantly lower in the posterior region in the SLI group under EO and EC conditions (Table 2). A trend of lower alpha rhythm spectral power in the anterior and central regions was observed in the SLI group. The p values for differences in anterior and central regions do not show a trend towards statistical significance, while p values in posterior region are in the range of 0.01 and 0.05 for both conditions (EC/EO).

Table 2. Differences in alpha rhythm spectral power between EC and EO conditions across regions

Region	Condition	SLI mean ± SD	TD mean ± SD	t(58)	p-value
Posterior	EC	13.56 ± 8.55	18.69 ± 10.44	2.199	0.032
	EO	6.59 ± 5.03	11.22 ± 8.71	2.429	0.018
Anterior	EC	4.23 ± 2.22	4.42 ± 2.02	0.472	0.639
	EO	2.92 ± 1.23	3.32 ± 1.57	0.880	0.382
Central	EC	5.78 ± 5.21	6.91 ± 5.24	0.900	0.372
	EO	4.52 ± 3.54	5.58 ± 3.97	1.100	0.276

Note: TD: typical development; SLI: specific language impairment; t-value *i.e.*, a ratio of the difference between the mean of the two sample sets and the variation that exists within the sample sets; exact p-value is presented. Confidence interval was set to 95%.

When looking at separate electrodes for the EC condition, statistically significant differences were found, with lower values in the SLI group for O2: $t(58) = 2.423$; $p = 0.019$, O1: $t(58) = 2.035$; $p = 0.046$, T5: $t(58) = 2.329$; $p = 0.023$ (Fig. 3A; Appendix B). There were no statistically significant differences for the other electrodes. In the EO condition, alpha rhythm spectral power was lower for all electrodes in the SLI group (Appendix B), although statistically significant differences were found for O2: $t(58) = 2.744$, $p = 0.008$, O1: $t(58) = 2.119$, $p = 0.038$, P3: $t(58) = 2.610$, $p = 0.012$, Pz: $t(58) = 2.002$, $p = 0.050$, T5: $t(58) = 2.589$, $p = 0.012$ and T3 electrode: $t(58) = 2.372$, $p = 0.021$ (Fig. 3B).

One of the aims of our study was to examine whether a difference existed between SLI and TD groups regarding the alpha rhythm spectral power relative change between the EC and EO conditions. The results showed that there was no difference between groups regarding the relative change in alpha rhythm spectral power for specific brain regions (Appendix B) or each separate electrode (Appendix A).

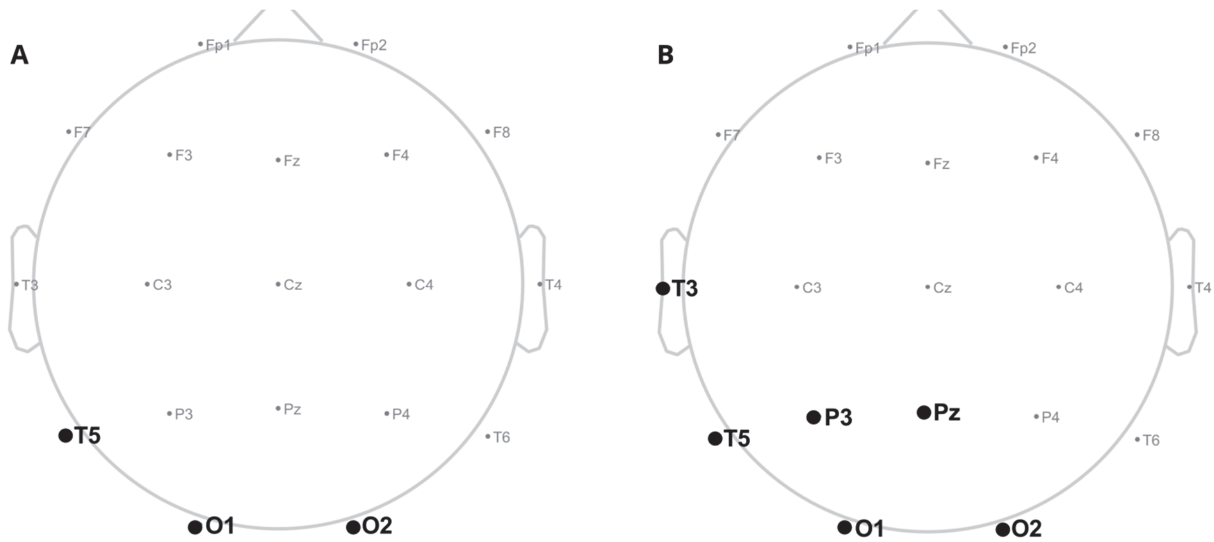

Fig. 3. Electrodes with statistically significant lower alpha rhythm spectral power in SLI group compared to TD group for (**A**) EC condition and (**B**) EO condition.

Discussion

In this study, we examined the spectral power of the alpha rhythm in children with SLI and compared it to children with typical speech-language development. The first goal was to explore whether differences existed between children with SLI and TD in alpha rhythm spectral power in the resting state – when the EC and EO conditions were examined separately. The results showed that in children with SLI, the alpha rhythm spectral power in the EC condition was lower in the left temporal (T5) and occipital electrodes (O1, O2), and in the left temporal (T3, T5), posterior (P3, Pz), and occipital electrodes (O1, O2) in the EO condition (Appendix A). The second goal was to examine relative change in alpha rhythm spectral power between different conditions (EC/EO) and groups (SLI/TD). The results showed no significant differences.

Our findings indicated that, under both conditions, the alpha rhythm spectral power was lower in the posterior region of children with SLI. It is known that alpha rhythm changes with brain maturation (Clarke et al., 2001). Its development occurs first occipitally, that is, in the posterior region, followed by the central and anterior regions (Dustman et al., 1999; Miskovic et al., 2015; Perone et al., 2018). Therefore, given that no differences were found in the anterior and central regions, this finding cannot be explained by the general immaturity of electrophysiology in children with SLI. One assumption is that there is a specific immaturity of the posterior brain region in children with SLI. Another open question is whether the differences occur at the structural or neurotransmitter level (Segalowitz et al., 2010). When looking at the results of the separate electrodes, we found that, in children with SLI, the alpha rhythm spectral power in the EO condition was lower in the left temporal electrodes, left parietal electrodes, and both left and right occipital electrodes. The temporal regions are responsible for auditory and receptive language processing (Seikel et al., 2015). The lower spectral power of the alpha rhythm, which can be ascribed to memory and general processing, can be an expected result since these aspects are considered impaired in children with SLI. Children with SLI exhibit poor auditory processing and language comprehension impairments (Tallal et al., 1993; Weismer et al., 2000). Shafer et al. (2007) found that weaker abilities of speech processing in children with SLI compared to TD children could be associated with differences in specific attention to speech. Therefore, our finding of a lower spectral power of resting-state alpha rhythm could be associated with the function of attention. The parietal region is also associated with some speech and language aspects, such as semantics, motor planning of speech, and overall integration of information from the temporal and occipital lobes (Bookheimer, 2002; Pulvermüller, 2013; Seikel et al., 2015). The lower spectral power of the alpha rhythm in children with SLI compared to TD children might reflect a general processing issue that results in impaired semantics, oral articulation, and even motor imitation. All these aspects, typical for children with SLI, can be associated with the parietal region (Halsband et al., 2001; Vukovic et al., 2010). The parietal and occipital regions also play a role in written language abilities (Shaywitz et al., 2002). The occipital region is responsible for the visual stimuli and higher visual processing (Seikel et al., 2015). Earlier studies have shown a connection between alpha rhythm spectral power in the occipital regions and written language abilities (Babiloni et al., 2012). Other studies have shown that children with SLI often have weaker visual perception and processing (Bavin et al., 2005; Menezes et al., 2007; Nicola and Watter, 2016). These functions are also impaired in children with dyslexia (Chen et al., 2019; Cheng et al., 2018; Eden et al., 1996; Ygge and Lennerstrand, 1997), and another overlap is that, compared to TD children, cortical differences were observed in the same regions (temporal, parietal, and occipital) as in our study (Babiloni et al., 2012; Klingberg et al., 2000; Shaywitz et al., 2002). Given that there is an overlap in the cognitive features of children with SLI and those with dyslexia, some studies have examined the differences between these two disorders, considering the question of whether SLI and dyslexia are distinct disorders or a different type of the same language disorder (Bishop and Snowling, 2004; Catts et al., 2005; Kamhi and Catts, 1986; Snowling et al., 2000). Our results might indicate the need for longitudinal studies to explore this issue.

The results of our study also showed no significant difference between the study groups regarding the relative change in alpha rhythm spectral power between the EC and EO conditions. Kwok et al. (2019) investigated these changes in the language ability of TD children. They found that the difference between the EC and EO conditions was smaller for children with better developed language abilities, but this association diminished when IQ and age were included in further analysis. This finding was corroborated by our study, which also has IQ, age, and sex, as a control variables. Thus, our results support the previous finding that the degree to which alpha power will decrease in the EO condition compared with the EC condition is not associated with speech and language abilities.

Due to the heterogeneity of the SLI population, studies with clearly defined SLI samples that differ in severity of impairment or even types of SLI are needed. Our study shows that a difference exists in alpha rhythm spectral power in children with SLI, and, given that similar results were found in studies on children with dyslexia, future research should focus on the longitudinal assessment of SLI children from kindergarten to school age to better examine alpha rhythm differences and/or similarities between these two disorders.

Conclusion

The study compared alpha rhythm spectral power between SLI and TD children. We have shown that children with SLI have lower alpha rhythm spectral power in the brain regions connected to speech and language processing. Because the alpha rhythm is connected to general processing and memory, higher values of this rhythm spectral power in the resting state reflect readiness for information perception and processing. Lower alpha rhythm spectral power in specific brain regions could be one of the underlying factors that lead to the difficulties in general processing and memory in children with SLI.

In contrast, children with SLI showed no difference in the relative change in alpha rhythm spectral power between the EC and EO conditions compared to TD children. Our results support the finding that the degree to which alpha power decreases in the EO condition compared with the EC condition is not associated with speech and language abilities.

The electrophysiological characteristics obtained in children with SLI may be helpful for future research on speech-language and cognitive processing in this population. Further investigation is needed to deepen our knowledge of the connection between general processing and memory deficits in SLI and their specific electrophysiology.

Data availability

The data supporting the findings of this study are available from the corresponding author, NS, upon reasonable request.

Conflict of interest

The authors declare that they have no relevant or material financial interest related to the research described in this study.

Funding

This work was partially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia within the project “Influence of psychophysiological, sociological, and cultural factors on speech and language in the child population”. The project was conducted in cooperation with the Faculty of Medical Sciences at the University of Kragujevac.

Statement of ethics

This study was approved by the Ethics Committee of the Institute for Experimental Phonetics and Speech Pathology “Djordje Kostic”. Informed written consent was obtained from parents of the participants, which was in accordance with the Declaration of Helsinki.

Authors contributions to the paper

- Nina Stanojević – Conceptualization, Data curation, formal analysis, Investigation, Methodology, Visualization, Writing – original draft
- Saška Fatić – Data curation, Formal analysis, Investigation, Writing – original draft
- Ljiljana Jeličić – Data curation, Formal analysis Writing – review & editing
- Vanja Nenadović – Formal analysis, Writing – original draft
- Miodrag Stokić – Conceptualization, Data curation, formal analysis, writing – review and editing
- Ružica Bilibajkić – Software, Formal analysis, Writing – review & editing
- Miško Subotić – Conceptualization, Funding acquisition, Writing – review & editing
- Tatjana Bošković Matić – Conceptualization, Data curation, Writing – review & editing
- Ljubica Konstantinović – Conceptualization, Methodology, Supervision, Writing – review & editing
- Dragana Ćirović – Conceptualization, Methodology, Supervision, Writing – review & editing

References

Archibald LM, Gathercole SE (2006). Short-term and working memory in specific language impairment. Int J Lang Commun Disord 41(6): 675–693. DOI: 10.1080/13682820500442602.

Babiloni C, Stella G, Buffo P, Vecchio F, Onorati P, Muratori C, et al. (2012). Cortical sources of resting state EEG rhythms are abnormal in dyslexic children. Clin Neurophysiol 123(12): 2384–2391. DOI: 10.1016/j.clinph.2012.05.002.

Barry RJ, Clarke AR, Johnstone SJ, Magee CA, Rushby JA (2007). EEG differences between eyes-closed and eyes-open resting conditions. Clin Neurophysiol 118(12): 2765–2773. DOI: 10.1016/j.clinph.2007.07.028.

Bavin EL, Wilson PH, Maruff P, Sleeman F (2005). Spatio-visual memory of children with specific language impairment: evidence for generalized processing problems. Int J Lang Commun Disord 40(3): 319–332. DOI: 10.1080/13682820400027750.

Biro M (1998). REVISK manual (2nd ed.). Drustvo psihologa Srbije [Serbian Psychological Society].

Bishop, DV (1992). The underlying nature of specific language impairment. J Child Psychol Psychiatry 33(1): 3–66. DOI: 10.1111/j.1469-7610.1992.tb00858.x.

Bishop DV, Snowling MJ (2004). Developmental dyslexia and specific language impairment: Same or different? Psychol Bull 130(6): 858–886. DOI: 10.1037/0033-2909.130.6.858.

Bookheimer S (2002). Functional MRI of language: new approaches to understanding the cortical organization of semantic processing. Ann Rev Neurosci 25(1): 151–188. DOI: 10.1146/annurev.neuro.25.112701.142946.

Catts HW, Adlof SM, Hogan TP, Weismer SE (2005). Are specific language impairment and dyslexia distinct disorders? J Speech Lang Hear Res 48(6): 1378–1396. DOI: 10.1044/1092-4388(2005/096).

Chen NT, Zheng M, Ho CSH (2019). Examining the visual attention span deficit hypothesis in Chinese developmental dyslexia. Read Writ 32: 639–662. DOI: 10.1007/s11145-018-9882-1.

Cheng D, Xiao Q, Chen Q, Cui J, Zhou X (2018). Dyslexia and dyscalculia are characterized by common visual perception deficits. Dev Neuropsychol 43(6): 497–507. DOI: 10.1080/87565641.2018.1481068.

Chutko LS, Surushkina SY, Yakovenko EA, Sergeev AV, Rozhkova AV, Anosova LV, Chistyakova NP (2015). [Clinical and electroencephalographic characteristics of specific language impairment in children and an evaluation of the efficacy of cerebrolysin]. Zh Nevrol Psikhiatr Im S S Korsakova 115(7): 98–102. DOI: 10.17116/jnevro20151157198-102.

Clarke AR, Barry RJ, McCarthy R, Selikowitz M (2001). Age and sex effects in the EEG: development of the normal child. Clin Neurophysiol 112(5): 806–814. DOI: 10.1016/s1388-2457(01)00488-6.

Čuturić N (1973). Lestvica psihičkog razvoja rane dečje dobi Brunet-Lezine. Ljubljana: Zavod SR Slovenije za produktivnost dela.

De Renzi A, Vignolo L.A (1962). Token test: A sensitive test to detect receptive disturbances in aphasics. Brain 85: 665–678. DOI: 10.1093/brain/85.4.665.

Deco G, Jirsa VK, McIntosh AR (2011). Emerging concepts for the dynamical organization of resting-state activity in the brain. Nat Rev Neurosci 12(1): 43–56. DOI: 10.1038/nrn2961.

Delorme A, Makeig S (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. J Neurosci Methods 134(1): 9–21. DOI: 10.1016/j.jneumeth.2003.10.009.

Dunn LM, Dunn LM (1981). Peabody picture vocabulary test-revised. American Guidance Service, Incorporated.

Dustman RE, Shearer DE, Emmerson RY (1999). Life-span changes in EEG spectral amplitude, amplitude variability and mean frequency. Clin Neurophysiol 110(8): 1399–1409. DOI: 10.1016/s1388-2457(99)00102-9.

Echenne B, Cheminal R, Rivier F, Negre C, Touchon J, Billiard M (1992). Epileptic electroencephalographic abnormalities and developmental dysphasias: a study of 32 patients. Brain Dev 14(4): 216–225. DOI: 10.1016/s0387-7604(12)80233-6.

Eden GF, VanMeter JW, Rumsey JM, Zeffiro TA (1996). The visual deficit theory of developmental dyslexia. Neuroimage 4(3 Pt 3): S108–117. DOI: 10.1006/nimg.1996.0061.

Eisermann M, Kaminska A, Moutard ML, Soufflet C, Plouin P (2013). Normal EEG in childhood: from neonates to adolescents. Neurophysiol Clin 43(1): 35–65. DOI: 10.1016/j.neucli.2012.09.091.

Epstein B, Shafer VL, Melara RD, Schwartz RG (2014). Can children with SLI detect cognitive conflict? Behavioral and electrophysiological evidence. J Speech, Lang Hear Res 57(4): 1453–1467. DOI: 10.1044/2014_JSLHR-L-13-0234.

Farber D, Beteleva T, Gorev A, Dubrovinskaya N, Machinskaya R (2000). Functional organization of the developing brain and formation of cognitive activity. In: Farber DA, Bezrukikh MM (Eds). Fiziologiya razvitiya rebenka: teoreticheskie i prikladnye aspekty (Physiology of Child's Development: Theoretical and Applied Aspects). Moscow: Obrazovanie ot A do Ya, pp. 82–104.

Fatić S, Stanojević N, Stokić M, Nenadović V, Jeličić L, Bilibajkić R, et al. (2022). Electroen cephalography correlates of word and non-word listening in children with specific language impairment: An observational study20F0. Medicine 101(46): e31840. DOI: 10.1097/MD.0000000000031840.

Giannitrapani D (1985). The electrophysiology of intellectual functions. Kargere Press, 247 p.

Halsband U, Schmitt J, Weyers M, Binkofski F, Grützner G, Freund HJ (2001). Recognition and imitation of pantomimed motor acts after unilateral parietal and premotor lesions: a perspective on apraxia. Neuropsychologia 39(2): 200–216. DOI: 10.1016/s0028-3932(00)00088-9.

Heim S, Choudhury N, Benasich AA (2016). Electrocortical dynamics in children with a language-learning impairment before and after audiovisual training. Brain Topogr 29(3): 459–476. DOI: 10.1007/s10548-015-0466-y.

Jausovec N, Jausovec K (2001). Differences in EEG current density related to intelligence. Brain Res Cogn Brain Res 12(1): 55–60. DOI: 10.1016/s0926-6410(01)00029-5.

Kaganovich N, Schumaker J, Leonard LB, Gustafson D, Macias D (2014). Children with a history of SLI show reduced sensitivity to audiovisual temporal asynchrony: An ERP study. J Speec Lang Hear Res 57(4): 1480–1502. DOI: 10.1044/2014_JSLHR-L-13-0192.

Kamhi AG, Catts HW (1986). Toward an understanding of developmental language and reading disorders. J Speech Hear Disord 51(4): 337–347. DOI: 10.1044/jshd.5104.337.

Klimesch W (1996). Memory processes, brain oscillations and EEG synchronization. Int J Psychophysiol 24(1–2): 61–100. DOI: 10.1016/s0167-8760(96)00057-8.

Klimesch W (2012). Alpha-band oscillations, attention, and controlled access to stored information. Trends Cogn Sci 16(12): 606–617. DOI: 10.1016/j.tics.2012.10.007.

Klingberg T, Hedehus M, Temple E, Salz T, Gabrieli JD, Moseley ME, Poldrack RA (2000). Microstructure of temporo-parietal white matter as a basis for reading ability: evidence from diffusion tensor magnetic resonance imaging. Neuron 25(2): 493–500. DOI: 10.1016/s0896-6273(00)80911-3.

Kwok EYL, Cardy JO, Allman BL, Allen P, Herrmann B (2019). Dynamics of spontaneous alpha activity correlate with language ability in young children. Behav Brain Res 359: 56–65. DOI: 10.1016/j.bbr.2018.10.024.

Leonard LB, Ellis Weismer S, Miller CA, Francis DJ, Tomblin JB, Kail RV (2007). Speed of processing, working memory, and language impairment in children. J Speech Lang Hear Res 50(2): 408–428. DOI: 10.1044/1092-4388(2007/029).

Levy-Rueff M, Bourgeois M, Assous A, Beauquier-Maccota B, Boucheron E, Clouard C, et al. (2012). Abnormal electroencephalography results and specific language impairment: towards a theoretical neurodevelopmental model? Encephale 38(4): 318–328. DOI: 10.1016/j.encep.2011.12.008.

Lyakso E, Frolova O, Matveev Y (2020). Speech Features and Electroencephalogram Parameters in 4- to 11-Year-Old Children. Front Behav Neurosci 14: 30. DOI: 10.3389/fnbeh.2020.00030.

Magosso E, De Crescenzio F, Ricci G, Piastra S, Ursino M (2019). EEG Alpha Power Is Modulated by Attentional Changes during Cognitive Tasks and Virtual Reality Immersion. Comput Intell Neurosci 2019: 7051079. DOI: 10.1155/2019/7051079.

Mainela-Arnold E, Evans JL (2005). Beyond capacity limitations: determinants of word recall performance on verbal working memory span tasks in children with SLI. J Speech Lang Hear Res 48(4): 897–909. DOI: 10.1044/1092-4388(2005/062).

Marosi E, Rodriguez H, Harmony T, Yanez G, Rodriguez M, Bernal J, et al. (1999). Broad band spectral EEG parameters correlated with different IQ measurements. Int J Neurosci 97(1–2): 17–27. DOI: 10.3109/00207459908994300.

Martin-Loeches M, Muñoz-Ruata J, Martinez-Lebrusant L, Gómez-Jarabo G (2001). Electrophysiology and intelligence: the electrophysiology of intellectual functions in intellectual disability. J Intellect Disabil Res 45(Pt 1): 63–75. DOI: 10.1046/j.1365-2788.2001.00292.x.

Menezes CG, Takiuchi N, Befi-Lopes DM (2007). [Visual short-term memory in children with specific language impairment]. Pro Fono 19(4): 363–369. DOI: 10.1590/s0104-56872007000400007.

Miskovic V, Ma X, Chou CA, Fan M, Owens M, Sayama H, Gibb BE (2015). Developmental changes in spontaneous electrocortical activity and network organization from early to late childhood. Neuroimage 118: 237–247. DOI: 10.1016/j.neuroimage.2015.06.013.

Montgomery JW (2002). Understanding the language difficulties of children with specific language impairments. Am J Speech Lang Pathol 11(1): 77–91. DOI: 10.1044/1058-0360(2002/009).

Nenadovic V, Stokic M, Vukovic M, Dokovic S, Subotic M (2014). Cognitive and electrophysiological characteristics of children with specific language impairment and subclinical epileptiform electroencephalogram. J Clin Exp Neuropsychol 36(9): 981–991. DOI: 10.1080/13803395.2014.958438.

Nicola K, Watter P (2016). Visual-motor integration performance in children with severe specific language impairment. Child Care Health Dev 42(5): 742–749. DOI: 10.1111/cch.12365.

Nunez PL (1995). Neocortical dynamics and human EEG rhythms. Oxford University Press, 708 p.

Oldfield RC (1971). The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia 9(1): 97–113. DOI: 10.1016/0028-3932(71)90067-4.

Pal DK (2011). Epilepsy and neurodevelopmental disorders of language. Curr Opin Neurol 24(2): 126–131. DOI: 10.1097/WCO.0b013e328344634a.

Palva JM, Monto S, Kulashekhar S, Palva S (2010). Neuronal synchrony reveals working memory networks and predicts individual memory capacity. Proc Natl Acad Sci 107(16): 7580–7585. DOI: 10.1073/pnas.0913113107.

Palva S, Palva JM (2007). New vistas for α-frequency band oscillations. Trends Neurosci 30(4): 150–158. DOI: 10.1016/j.tins.2007.02.001.

Perone S, Palanisamy J, Carlson SM (2018). Age-related change in brain rhythms from early to middle childhood: Links to executive function. Dev Sci 21(6): e12691. DOI: 10.1111/desc.12691.

Picard A, Cheliout Heraut F, Bouskraoui M, Lemoine M, Lacert P, Delattre J (1998). Sleep EEG and developmental dysphasia. Dev Med Child Neurol 40(9): 595–599. DOI: 10.1111/j.1469-8749.1998.tb15424.x.

Plante E (1998). Criteria for SLI: the Stark and Tallal legacy and beyond. J Speech Lang Hear Res 41(4): 951–957. DOI: 10.1044/jslhr.4104.951.

Pulvermüller F (2013). How neurons make meaning: brain mechanisms for embodied and abstract-symbolic semantics. Trends Cogn Sci 17(9): 458–470. DOI: 10.1016/j.tics.2013.06.004.

Schmid RG, Tirsch WS, Scherb H (2002). Correlation between spectral EEG parameters and intelligence test variables in school-age children. Clin Neurophysiol 113(10): 1647–1656. DOI: 10.1016/s1388-2457(02)00212-2.

Segalowitz SJ, Santesso DL, Jetha MK (2010). Electrophysiological changes during adolescence: a review. Brain Cogn 72(1): 86–100. DOI: 10.1016/j.bandc.2009.10.003.

Seikel JA, Drumright DG, King DW (2015). Anatomy & physiology for speech, language, and hearing. Nelson Education, 912 p.

Shafer VL, Ponton C, Datta H, Morr ML, Schwartz RG (2007). Neurophysiological indices of attention to speech in children with specific language impairment. Clin Neurophysiol 118(6): 1230–1243. DOI: 10.1016/j.clinph.2007.02.023.

Shaywitz BA, Shaywitz SE, Pugh KR, Mencl WE, Fulbrigh RK, Skudlarski P, et al. (2002). Disruption of posterior brain systems for reading in children with developmental dyslexia. Biol Psychiatry 52(2): 101–110. DOI: 10.1016/s0006-3223(02)01365-3.

Snowling M, Bishop DVM, Stothard SE (2000). Is preschool language impairment a risk factor for dyslexia in adolescence? J Child Psychol Psychiatry 41(5): 587–600. DOI: 10.1111/1469-7610.00651.

Stark RE, Tallal P (1981). Selection of children with specific language deficits. J Speech Hear Disord 46(2): 114–122. DOI: 10.1044/jshd.4602.114.

Tallal P, Miller S, Fitch RH (1993). Neurobiological basis of speech: a case for the preeminence of temporal processing. Ann N Y Acad Sci 682: 27–47. DOI: 10.1111/j.1749-6632.1993.tb22957.x.

Thatcher RW, North D, Biver C (2005). EEG and intelligence: relations between EEG coherence, EEG phase delay and power. Clin Neurophysiol 116(9): 2129–2141. DOI: 10.1016/j.clinph.2005.04.026.

Tomblin JB, Records NL, Buckwalter P, Zhang X, Smith E, O'Brien M (1997a). Prevalence of specific language impairment in kindergarten children. J Speech Lang Hear Res 40(6): 1245–1260. DOI: 10.1044/jslhr.4006.1245.

Tomblin JB, Records NL, Zhang X (1996). A system for the diagnosis of specific language impairment in kindergarten children. J Speech Lang Hear Res 39(6): 1284–1294. DOI: 10.1044/jshr.3906.1284.

Tomblin JB, Smith E, Zhang X (1997b). Epidemiology of specific language impairment: prenatal and perinatal risk factors. J Commun Disord 30(4) 325–343; quiz 343–324. DOI: 10.1016/s0021-9924(97)00015-4.

Vasić S (1991). Veština govorenja: Vežbe i testovi za decu i odrasle. Pedagoška akademija za obrazovanje učitelja, 206 p.

von Stein A, Sarnthein J (2000). Different frequencies for different scales of cortical integration: from local gamma to long range alpha/theta synchronization. Int J Psychophysiol 38(3): 301–313. DOI: 10.1016/s0167-8760(00)00172-0.

Vukovic M, Vukovic I, Stojanovik V (2010). Investigation of language and motor skills in Serbian speaking children with specific language impairment and in typically developing children. Res Dev Disabil 31(6): 1633–1644. DOI: 10.1016/j.ridd.2010.04.020.

Wang J, Barstein J, Ethridge LE, Mosconi MW, Takarae Y, Sweeney JA (2013). Resting state EEG abnormalities in autism spectrum disorders. J Neurodev Disord 5(1): 24. DOI: 10.1186/1866-1955-5-24.

Weismer SE, Tomblin JB, Zhang X, Buckwalter P, Chynoweth JG, Jones M (2000). Nonword repetition performance in school-age children with and without language impairment. J Speech Lang Hear Res 43(4): 865–878. DOI: 10.1044/jslhr.4304.865.

Ygge J, Lennerstrand G (1997). Visual impairment and dyslexia in childhood. Curr Opin Ophthalmol 8(5): 40–44. DOI: 10.1097/00055735-199710000-00008.