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The influence of the dynamics and the level of maturity of the cortical functions as a prerequisite for the development of speech in children

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SUMMARY

Introduction/Objective The development of speech is the result of interaction of different systems of the cortex, which gradually acquires the ability of phonological presentation and motor control, in the presence of a series of physical and physiological changes in the morphology of the articulation system. The objective of the study was to examine the impact of laterality and cortical responses on the development of speech in children.

Methods Research is a quasi-experimental design with two groups. The sample covered 60 children from Belgrade, of both sexes, ages 5.5–7 years, divided into two groups, experimental (30) and control (30). We used the following instruments: test for assessing laterality and ascertaining evoked potentials.

Results On the visual lateralization subtest there was a statistically significant difference ($\chi^2 = 7.56$, $p < 0.05$) between the observed groups. The visual evoked potentials on all measured parameters gave a statistically significant difference between the groups: waveform cortical responses – left ($\chi^2 = 30.00$, $df = 1$, $p < 0.05$); cortical responses – right ($\chi^2 = 6.667$, $df = 1$, $p < 0.05$); waveform amplitude – left ($\chi^2 = 13.469$, $df = 1$, $p < 0.05$); amplitude – right ($\chi^2 = 40.00$, $df = 1$, $p < 0.05$), somatosensory potentials ($\chi^2 = 18.261$, $df = 1$, $p < 0.05$); waveform amplitude ($\chi^2 = 12.000$, $df = 1$, $p < 0.05$); waveform latency ($\chi^2 = 5.455$, $df = 1$, $p < 0.05$).

Conclusion Visual laterality, as well as visual and somatosensory cortical responses to stimuli is better in children without the present articulation disorder, which could be used for timely prevention planning.

Keywords: speech; laterality; children; articulation disorder; evoked potentials

INTRODUCTION

What distinguishes people from animals is evolution of the brain. The brain is the manager of all physical and psychological activities. Due to the complex organization of the nervous system, man can produce a large number of voices with meaning and use hands to perform fine movements. Language allows man to control his behavior and behavior of others [1]. The brain is anatomically divided into two hemispheres that are approximately identical. Despite the relative similarity of brain hemispheres, they do not perform the same function. Due to the fact that the hemispheres have specialized, some skills became possible [2]. The left hemisphere plays a role in the creation of language, which is confirmed by a series of research. It has been found that in 95% of right-handed people speech is controlled by the left hemisphere, as well as in 70% of the left-handed people, while in 15% of others speech is controlled from both hemispheres [3]. The exact role of the right hemisphere is not known. It is considered to be responsible for performing visual-spatial tasks and for processing information simultaneously and holistically. In

addition, its role in controlling and processing musical abilities is indisputable [4, 5]. Neurons have to be stimulated in order to develop new synaptic connections. The development of new connections creates new opportunities for neural communication. Each new skill contributes to the new element of sensory perception and motor skills of the child. As a child's number of neural connections increases, it becomes more capable of learning [6]. Functional brain differentiation indicates that different aspects of language and speech are located in different regions of the cortex [7, 8]. This points to the genetic basis of the development, during which different aspects of language are distributed in different brain regions [9].

Laterality is determined simultaneously with the determination of the hemisphere domination. Through motor development, bilateral control is established first, followed by unilateral control. Laterality is established between the age of three and four years. It is achieved gradually during maturation and the accumulation of experience acquired by observation, kinesthesia, manipulative activity, and finally the realization that this laterality has occurred [10]. In the next phase of maturation, the dif-

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ferentiation of laterality occurs when it becomes dominant for one side and subdominant for the other side of the body – it is recognized that one extremity or sensory organ leads and thus dominates the other [11]. Harmonic laterality implies identical dominant laterality level with the arm, eye, ear, and leg. The category of disharmonic lateralization consists of subjects with complete discrepancy between the dominance of the arm, the eye, the ear, and the leg. The process of developing the ambivalence of the movement to selecting a leading right or left hand can be considered a process of maturation, because from laterality we are going to dominate the hemispheres and movements in the manipulative field, from the lower forms of organizing activities to more complex and more suitable levels, of the differentiated sensory needs and the enforcement of intelligence [12, 13]. Assessment of laterality and dominant laterality indicates the organization of the ability of senses and movements in the function of voluntary motor activity and the level of practicality of the cortex in relation to the development of the dominance of the hemisphere [14].

The processes that precede the development of proper articulation are swallowing, sucking, and chewing. Proper stimulation of these functions in the earliest age affects the good development of oral practice and, consequently, the smooth development of articulation [15, 16]. The child, by vocalization, elaborates the movements and coordination of peripheral speech organs. The speech production mechanism undergoes significant changes during growth, and the progressive maturation of motor control capabilities is the basis of this process [17]. Motor control of the articulation mechanism, as in adults, reaches the middle of childhood. More complex motor patterns require longer time for automation, and such are the patterns of articulation movements. The speed of automation is also affected by the plasticity of the nervous system. Automated articulation movements constitute the articulation base of native speakers of a language [18, 19].

The pathological articulation is a deviation in the pronunciation of the voices of the mother tongue, both on the visual and on the acoustic and the kinesthetic level [20]. Poorly placed voice organs misjudge the air current, leading to articulation disorders. Parents and the environment often find that the child speaks well of a certain voice, not knowing that the visual presentation of this voice is not good and that for this reason the pronunciation of a certain voice is considered pathological [21, 22]. This is due to ignorance of motor patterns that are necessary for the proper pronunciation of the given voice [23].

The aim of the study was to examine the impact of laterality and cortical responses on the development of speech (articulation) in children.

METHODS

The basic method of organization of research is a quasi-experimental design with two groups. The sample included 60 children, of both sexes, aged 5.5–7 years of age. The research was performed at the Children's Outpatient

Department of the Voždovac Community Health Center and University Children's Clinic in Belgrade, from 2015 to 2016. The research was carried out in accordance with the Declaration of Helsinki on Ethical Principles for Medical Research Involving Human Subjects. The Ethical Committee approved the research and, taking into account that the research subjects were children, the informed consent was obtained from their parents/guardians. The experimental group (E) consisted of 30 children with articulation disorders diagnosed with Articulation Test, who were on continuous logopedic treatment, which lasted six months on average. The control group (C) of 30 children consisted of children from the general population who did not have any articulation disorders. We used the individual testing technique for both E and C group.

The instruments used in the research included: specialized test for lateralization assessment and evaluation of evoked potential recordings. Lateralization test consists of questions and tasks classified according to the levels for the assessment of usage and gesture laterality of extremities, sight, and hearing. The tested child was supposed to ask the questions by showing certain action or complete a specific task using the appropriate equipment offered.

Evoked potentials [visually evoked potential (VEP) and somatosensory evoked potential (SSEP)]: the VEP challenge was performed by the rhythmic repetition of the light signal of a certain intensity, duration, and defined distance of the light source from the subject. Light stimuli are structured or unstructured, and the test is performed by binocular, whole field of vision, and half of the field of view. The series contains at least 128 stimuli that are analyzed and moderated by soft-technique, while responses contaminated by artifacts are rejected. Registration is done using surface electrodes at the head position determined by the 10–20 EEG system. Examined: configuration of the induced response, waveform amplitude, P100 waveform latency, and interocular latency P100 waveform.

SSEPs were tested by stimulating both *n. medianus* individually, averaging 512 stimuli of low intensity (5–15, mA), frequency of three stimuli per second, duration of 0.2 ms. Detection of the induced responses was performed above the Erb's point (brachial plexus), at C7 and C2, spinal cord segments, as well as on the scalp above the contralateral sensory cortical field. *N. medianus* is stimulated in the wrist, while the electrodes on the scalp are positioned according to the international 10–20 system. The following parameters were analyzed: absolute primary cortical response waveform latency (N20), configuration and waveform amplitude of the primary complex (N20–P25).

Statistical processing and analysis were performed in IBM SPSS Statistics, Version 20.0 (IBM Corp., Armonk, NY, USA). The measure of descriptive statistics used the arithmetic mean with the corresponding standard deviation, as well as the minimum and the maximum. Frequency and percentage were used. Chi-squared test was used to examine the relationship of two categorical variables, as well as to determine the cross-ratio of the results of the applied instruments.

RESULTS

Table 1 shows that the age of the subjects ranged 5.5–7 years. After the categorization of these variables into three categories (5.5–6 years, 6.1–6.5 years, and 6.6–7 years) we obtained the following percentile representation of respondents by category: 60% of the experimental group is 5.5–6 years old, 13.3% are 6.1–6.5 years old, and 26.7% of the group are 6.6–7 years old. Within the control group, 23.3% of the respondents belong to the group 5.5–6 years old, 46.7% belong to the group 6.1–6.5 years old, and 30% belong to the group 6.6–7 years old.

Table 2 shows that the average age of the E group was $M = 6.07 \pm 0.5$ years of age, while the average age of the C group was $M = 6.34 \pm 0.46$ years of age.

Figure 1 shows that E group comprised more respondents of male sex (76.7%), while the C group comprised more female sex respondents (56.7%).

Figure 2 shows that a statistically significant difference exists only on visual laterality ($\chi^2 = 7.56, p < 0.05$). The statistical significance is below the limit of 0.05. A statistically significant difference between the experimental and the control group does not exist on other laterality tests.

Table 3 shows that when we categorize the results obtained on VEP, we obtain statistically significant differences on all measured parameters, between the experimental and the control group of the respondents.

Table 4 shows that when categorizing the results of E and C groups measured on SSEP, statistically significant differences are obtained on all measured parameters, except on the waveform cortical response – right.

Figure 3 shows that respondents with lower waveform amplitude on the left eye dominantly use the right eye (68.4%). Those who use this waveform amplitude have a regular dominant use of the left eye (54.5%). The finding of VEP (amplitude to the left) is statistically significant in relation to visual laterality ($\chi^2 = 7.56, df = 2, p = 0.023$).

Figure 4 shows that respondents with lower waveform amplitude are predominantly left-handed (50%), while subjects with a regular waveform amplitude are predominantly right-handed (70%), indicating that the finding on the SSEP (amplitude) is in a statistically significant relationship with gestural laterality ($\chi^2 = 6.72, df = 2, p = 0.035$).

DISCUSSION

The study included children 5.5–7 years of age. This age was observed because it is considered that the development of articulation should be finished at 5.5 years of age. The sample was divided into three subgroups, at the age of half the age of children (Table 1). The average age of E group was $M = 6.07 \pm 0.5$ years, while the average age of C group was $M = 6.34 \pm 0.46$ years (Table 2). All the achievements of the examinees were analyzed collectively for both subgroups and individually for each subgroup. We started from the fact that speech (articulation) and laterality, as cortical functions of the developmental category, are adopted by learning and intensively develop during the pre-school period.

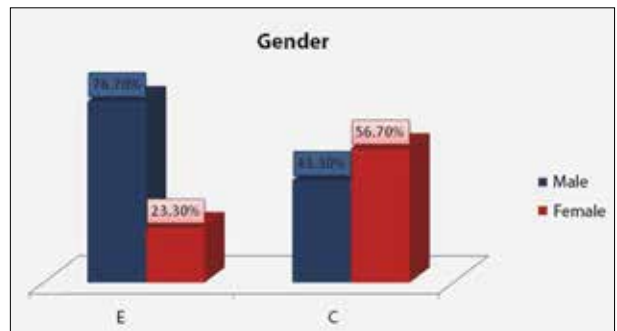


Figure 1. Sample structure according to the sex of the respondents

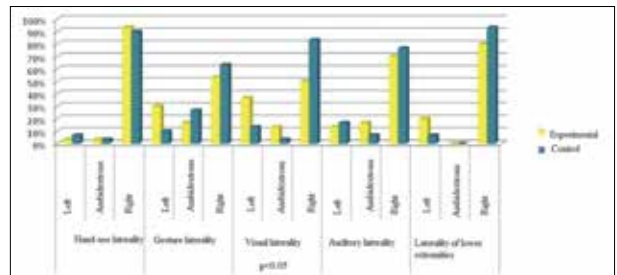


Figure 2. Test of assessment of laterality – the difference between the experimental and the control group

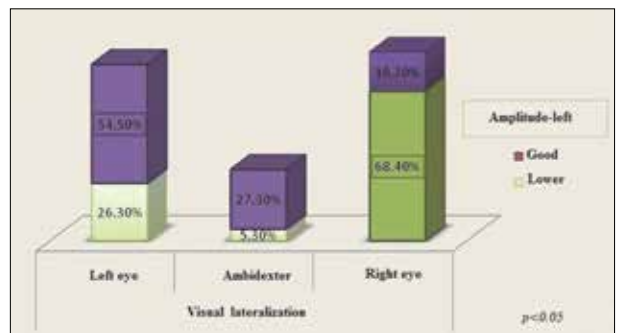


Figure 3. Cross-ratio of visually evoked potential findings (amplitude on the left) and visual laterality

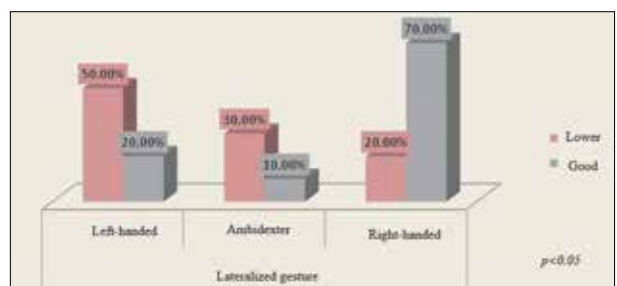


Figure 4. Cross-sectional relationship between somatosensory evoked potential (amplitude) and gestural laterality

The analysis of the results in relation to sexes (Figure 1) showed that there were more boys (76.7%) than girls (23.3%) in E group, while the number of girls in C group was larger (56.7%) compared to the number of boys (43.3%). As a prospective section study, the sample structure by sex reflects the numerical representation of groups in the population. The results of the laterality test show that a statistically significant difference exists on the visual laterality subtest ($\chi^2 = 7.56, p < 0.05$). By analyzing

Table 1. Structure of the sample according to the age categories of the respondents

| Parameter | | Age of respondents (years) | | | Total | |
|-----------|--------------|----------------------------|---------|-------|-------|-----|
| | | 5.5–6 | 6.1–6.5 | 6.6–7 | | |
| Group | Experimental | Total (n) | 18 | 4 | 8 | 30 |
| | | % | 60 | 13.3% | 26.7% | 100 |
| Group | Control | Total (n) | 7 | 14 | 9 | 30 |
| | | % | 23.3 | 46.7% | 30.0% | 100 |
| Total | | Total (n) | 25 | 18 | 17 | 60 |
| | | % | 41.7 | 30.0% | 28.3% | 100 |

Table 2. Sample structure according to average age of the respondents

| Group | n | Min. | Max. | M | SD |
|--------------|----|------|------|--------|---------|
| Experimental | 30 | 5.50 | 7 | 6.0700 | 0.50729 |
| Control | 30 | 5.50 | 7 | 6.3433 | 0.46065 |
| Total | 60 | 5.50 | 7 | 6.2067 | 0.49979 |

Min. – sample minimum variable value; Max. – sample maximum variable value; M – sample arithmetic mean (sample average variable value); SD – standard deviation (average deviation of individual sample variable values)

the percentage representation of certain categories, we can see that both groups are predominantly right lateralized. The analysis shows that there were more left-handed individuals in E group (36.7%) than in C group (13.3%). The number of ambidextrous respondents was higher in E group (13.3%) compared to C group (3.3%), which shows

the existence of a larger number of respondents with undifferentiated lateralization within E group (Figure 2). This indicates the existence of disharmonic laterality and slow maturation of certain functions in these subjects. The category of disharmonic laterality consists of subjects with complete discrepancy between the dominance of the arm, the eye, the ear, and the leg. In addition, we registered the presence of undifferentiated lateralization, i.e. the presence of an ambient, within the group [24–27]. The results of evoked potentials show that both groups of subjects are at the physiological age limits, but that certain differences within these values exist. The results of VEP show that waveform cortical responses to the left were less formed in 66.7% of the subjects in E group, and 33.3% were well formed; in C group, 100% of the respondents were well formed, which gave statistically significant difference ($\chi^2 = 30$, $df = 1$, $p < 0.05$). A better waveform cortical response to the left was present in the subjects in C group. Waveform cortical responses to the right were less formed in 20% of the examinees of E group, and they were well formed in 80% of the respondents; within C group, cortical responses were 100% well-formed, and there was a statistically significant difference ($\chi^2 = 6.667$, $df = 1$, $p < 0.05$). The waveform amplitude was on the right in 20% of E group examinees, while it was regular in 80% of the subjects.

Table 3. Visually evoked potential – the difference between the experimental and the control group on the measured parameters

| Parameter | | Experimental | | Control | | χ^2 | Df | p |
|---------------------------|-----------------------------------------|--------------|-------|-----------|-------|----------|----|-------|
| | | Total (n) | % | Total (n) | % | | | |
| Cortical response – left | Well formed | 10 | 33.3% | 30 | 100% | 30.000 | 1 | 0.000 |
| | Less formed | 20 | 66.7% | 0 | 0% | | | |
| | No response | 0 | 0% | 0 | 0% | | | |
| Cortical response – right | Well formed | 24 | 80% | 30 | 100% | 6.667 | 1 | 0.010 |
| | Less formed | 6 | 20% | 0 | 0% | | | |
| | No response | 0 | 0% | 0 | 0% | | | |
| Amplitude – right | Lower | 6 | 20% | 30 | 100% | 40.000 | 1 | 0.000 |
| | Good | 24 | 80% | 0 | 0% | | | |
| Amplitude – left | Lower | 19 | 63.3% | 30 | 100% | 13.469 | 1 | 0.000 |
| | Good | 11 | 36.7% | 0 | 0% | | | |
| Latency | Within physiological limits | 30 | 100% | 30 | 100% | / | / | / |
| Interocular difference | Equal | 0 | 0% | 4 | 13.3% | 5.795 | 2 | 0.050 |
| | Prolonged at the cost of the left side | 24 | 80% | 17 | 56.7% | | | |
| | Prolonged at the cost of the right side | 6 | 20% | 9 | 30% | | | |

Df – degrees of freedom

Table 4. Somatosensory evoked potential – the difference between the experimental and the control group on the measured parameters

| Parameter | | Experimental | | Control | | χ^2 | Df | p |
|---------------------------|-----------------------------|--------------|-------|-----------|------|----------|----|-------|
| | | Total (n) | % | Total (n) | % | | | |
| Cortical response – left | Well formed | 16 | 53.3% | 30 | 100% | 18.261 | 1 | 0.000 |
| | Less formed | 14 | 46.7% | 0 | 0% | | | |
| | No response | 0 | 0% | 0 | 0% | | | |
| Cortical response – right | Well formed | 29 | 96.7% | 30 | 100% | 1.017 | 1 | 0.313 |
| | Less formed | 1 | 3.3% | 0 | 0% | | | |
| | No response | 0 | 0% | 0 | 0% | | | |
| Amplitude | Lower | 10 | 33.3% | 0 | 0% | 12.000 | 1 | 0.001 |
| | Good | 20 | 66.7% | 30 | 100% | | | |
| Latency | Within physiological limits | 25 | 83.3% | 30 | 100% | 5.455 | 1 | 0.020 |
| | Prolonged latency | 0 | 0% | 0 | 0% | | | |

Df – degrees of freedom

In 100% of C group, waveform amplitude on the right is regular ($\chi^2 = 40.000$, $df = 1$, $p < 0.05$). Waveform amplitude on the left 63.3% of the examinees in E group is lower, and in 36.7% of the examinees it is regular, while in 100% of the C patients it is regular ($\chi^2 = 13.469$, $df = 1$, $p < 0.05$) (Figure 3). Waveform latency is within the physiological limits of the examinees of both groups. In the assessment of the waveform cortical response of the left eye, the results showed that the cortical response was worse in 43.3% of the subjects of E group, while 56.7% of the subjects were without clear lateralization (equal to the left and right eye); there was a statistically significant difference between the groups ($\chi^2 = 16.596$, $df = 1$, $p < 0.05$), as in 100% of patients in group C the response was without clear laterality – equable.

The distribution of the results for interocular difference shows that 80% of the examinees in E group had poorer results on the left eye and 20% of them had poorer results on the right eye. In C group, in 13.3% of the examinees there was no interocular difference, 56.7% of the examinees confirmed poorer result on the left eye, while 30% of them had poorer result on the right eye. In the final analysis of the results, the difference would be reflected in the larger number of subjects with a balanced interocular latency of 13.3% within C group, which is a better result. This result can be observed through the functional localization of parts of the body in the cerebral cortex (eye, mouth-tongue, arm, leg) [28].

The SSEP results show that waveform cortical responses on the left side were less formed in 46.7% of the respondents in E group, and in 53.3% they were well formed; in C group, 100% of the respondents had well-formed waveform cortical responses on the left side ($\chi^2 = 18.261$, $df = 1$, $p < 0.05$) (Figure 4). A better waveform cortical response on the left is present in C group subjects. Waveform cortical responses on the right were less formed in 3.3% of the respondents in E group, and 96.7% of respondents were well formed; within C group, waveform cortical responses on the right side were 100% well-formed ($\chi^2 = 1.017$, $df = 1$, $p > 0.05$). Sophisticated and coordinated movements of the hands affect the sensorimotor development of the central nervous system and, by doing so, the development of speech, which requires a higher level of sensorimotor coordination [26].

The waveform amplitude is lower in 33.3% of E group of examinees, while it is regular in 66.7% of the subjects. In 100% of group C respondents, the amplitude is regular, which gives a statistically significant difference ($\chi^2 = 12$, $df = 1$, $p < 0.05$). Waveform latency is in 83.3% of the experimental group in the physiological limits, while in 16.7% of the subjects, latency is at the limit value (which implies latency at the physiological limit for the age); in 100% of examinees of C group, latency is at physiological limits ($\chi^2 = 5.455$, $df = 1$, $p < 0.05$). After evaluation of the waveform cortical response, the left *n. medianus* results of 46.7% of subjects in E

group were inferior, and in 53.3% of the subjects the results showed no clear laterality (equal), in the control group, the waveform cortical response was equal ($\chi^2 = 18.261$, $df = 1$, $p < 0.05$). These results suggest that there was mild dysfunction of the central afferents on the left hand in some patients of E group, within the physiological limits. We tested with the χ^2 test whether the results of the applied tests were statistically significant. Connection testing was done in E group. The reason for this is that C group generally had unified results so that is no point in doing comparison (numbers are constants). VEP (amplitude of waves of the left eye) is statistically significant with visual laterality ($\chi^2 = 7.56$, $df = 2$, $p = 0.023$) (Figure 3). Respondents with lower waveform amplitude on the left side dominantly use the right eye (68.4%). Those with a regular amplitude have a regular dominant use of the left eye (54.5%). SSEP (*n. medianus*, cortical wave amplitude) is in a statistically significant connection with gestural laterality ($\chi^2 = 6.72$, $df = 2$, $p = 0.035$). Respondents with a lower amplitude were predominantly left-handed (50%), while subjects with a regular amplitude were predominantly right-handed (70%) (Figure 4). Considering that gestural lateralization of the hand is seen here, we can conclude that laterality did not succumb to sociocultural pressure and reflects spontaneous, individual maturation, which is precisely the reason for this result [29].

CONCLUSION

Articulation disorders are manifested more often in boys than it is in girls. Diffusion of visual lateralization is more pronounced in children with articulation disorders than in children with normally developed speech. Results of visual and somatosensory waveform cortical test responses, which are within the physiological values for the respective age, represent better results for children with well-developed articulation than for children with articulation impairment in mutual comparison. Consequently, neuropsychological and neurophysiological indicators give us the possibility of detecting risks in speech development in pre-school children. This result suggests that further monitoring of findings could provide data that could be used to timely plan prevention.

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Утицај динамике и нивоа зрелости кортикалних функција као предуслов за развој говора код деце

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САЖЕТАК

Увод/Циљ Развој говора од рођења до одраслог доба је резултат интеракције различитих система коре великог мозга, помоћу којих се постепено стичу способности фонолошке презентације и моторне контроле, уз присуство низа физичких и физиолошких промена у морфологији артикулационог система.

Циљ истраживања је био испитати утицај латерализованости и кортикалних одговора на развој говора код деце.

Метод Истраживање је квазиекспериментални дизајн са две групе. Узроком је обухваћено 60 деце (30 у експерименталној и 30 у контролној групи) из Београда, оба пола, узраста од пет и по до седам година. Од инструмената смо користили тест за процену латерализованости и налаз евоцираних потенцијала.

Резултати На суптесту визуелна латерализованост постоји статистички значајна разлика ($\chi^2 = 7,56, p < 0,05$) између пос-

матраних група. Визуелни евоцирани потенцијали на свим мереним параметрима су дали статистички значајну разлику између експерименталне и контролне групе кортикалних одговора – лево ($\chi^2 = 30,00, df = 1, p < 0,05$); кортикални одговори – десно ($\chi^2 = 6,667, df = 1, p < 0,05$); амплитуда – лево ($\chi^2 = 13,469, df = 1, p < 0,05$); амплитуда – десно ($\chi^2 = 40,00, df = 1, p < 0,05$). Соматосензорни потенцијали су дали статистички значајну разлику код кортикалних одговора – лево ($\chi^2 = 18,261, df = 1, p < 0,05$), амплитуде ($\chi^2 = 12,000, df = 1, p < 0,05$), латенција ($\chi^2 = 5,455, df = 1, p < 0,05$).

Закључак Визуелна латерализованост, као и визуелни и соматосензорни кортикални одговори на стимулусе су бољи код деце без присутног поремећаја артикулације, што би се могло искористити за благовремено планирање превенције.

Кључне речи: говор; латерализованост; деца; артикулациони поремећаји; евоцирани потенцијали