Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/poamed

Original Research Article

Effect of transcranial direct current stimulation on dichotic listening test results in children with disorders of psychological development

Dmitry Y. Pinchuk [a], *Maria V. Wasserman* [a,b], *Evgeny L. Wasserman* [c,d,e,*], *Konstantin T. Sirbiladze* [a], *Nikolay K. Kartashev* [c]

[a] *City Centre of Rehabilitation Treatment for Children with Psychoneurological Disabilities, Saint Petersburg, Russia*
[b] *Saint-Petersburg State Pediatric Medical University, Saint Petersburg, Russia*
[c] *Saint Petersburg Institute for Informatics and Automation of RAS, Saint Petersburg, Russia*
[d] *Saint Petersburg State University, Saint Petersburg, Russia*
[e] *Herzen State Pedagogical University of Russia, Saint Petersburg, Russia*

ARTICLE INFO

Article history:
Received 24 February 2015
Received in revised form
23 April 2015
Accepted 4 May 2015
Available online 7 July 2015

Keywords:
Dichotic listening
tDCS
Brain asymmetry
Psychological development
Developmental disorders

ABSTRACT

Introduction: We use dichotic listening (DL) test to assess functional brain asymmetry when we treat children with disorders of psychological development (DPD) by transcranial direct current stimulation (tDCS).
Aim: In this work we carry out retrospective analysis of children with DPD and study the influence of tDCS on auditory verbal stimuli perception characteristics obtained by DL tests.
Material and methods: We analyzed the DL test results of 6–13-year-old children; 26 children with specific developmental disorders of scholastic skills (SDDSS), 31 children with specific developmental disorders of speech and language (SDDSL), and 39 healthy children were tested. Some of the children with DPD (21 children) were tested only once, 26 – before and after tDCS, and 10 – before and after the treatment without tDCS. In all cases we estimated laterality indices (LI) and the amounts of ''erroneous'' answers (ErrA).
Results and discussion: In the DPD group before the treatment the LI values were lower and the ErrA values were higher in comparison to the values of healthy children; the differences were more significant in the SDDSL than in the SDDSS subgroup. In the SDDSL subgroup after tDCS the LI values got closer to those of the healthy children, and the ErrA values decreased. The LI and ErrA values of children who had not received tDCS treatment did not change.
Conclusions: The DL test reveals the characteristics of brain asymmetry in case of DPD, and can be useful when planning tDCS treatment and estimating its effectiveness.

* *Correspondence to*: St. Petersburg Institute for Informatics and Automation of the Russian Academy of Sciences, 14 line 39, St. Petersburg 199178, Russia. Tel.: +7 8123214467.
E-mail addresses: ewasser@ev7987.spb.edu, ewasser@list.ru (E.L. Wasserman).

http://dx.doi.org/10.1016/j.poamed.2015.05.005

1. Introduction

Disorders of psychological development (DPD), such as specific developmental disorders of speech and language (SDDSL) and specific developmental disorders of scholastic skills (SDDSS), are frequent in neurologic and psychiatric practice and widely considered to be one of the main reasons of learning difficulties in children.[1] Neuropsychological methods of correction and speech therapy are time-consuming and often not effective enough.[2] Drug therapy does not allow to selectively affect the dysfunctional brain structures. Moreover, these disorders may have different etiopathogenesis, so it is impossible to claim that they have common cerebral substrate.[1]

In recent decades, the transcranial direct current stimulation (tDCS) has become increasingly and widely used in neurophysiological and clinical research as a means of directed change of excitability of brain structures in studies of the memory,[3] visual perception,[4] in treatment of depressions,[5] pain syndromes,[6] headaches,[7] etc. In tDCS method the direct electric current of low intensity is used as in traditional procedures such as brain galvanizations. However, the electric current values and densities in tDCS are lower, and tDCS is not intended for obtaining generalized nonspecific activation or inhibitory effects, but to provoke rather selective, long-lasting, specific reactions of the brain.[8] We have been successfully applying tDCS in treatment of children with cerebral palsy[9] and DPD.[10] Multiple changes and improvements have been introduced to tDCS and tDCS-based treatment;[11] a number of medical institutions have adopted this method in their practice.

One of the most important conditions of effective treatment with tDCS is the individual positioning of electrodes on the scalp which is impossible without taking into account the peculiarities of functional brain asymmetry of each patient. It is known that children with development disorders often have anomalous functional asymmetry of cerebrum and abnormality of interhemispheric interaction.[12–14] To study individual characteristics of brain asymmetry in children with DPD, tDCS-based treatment protocol traditionally includes neuropsychological tests for functional asymmetry (leading arm, leg, eye). Several years ago we appended it with dichotic listening (DL) test[15] for determination of the hemisphere that is dominant in processing of speech stimuli, and for identification of the features of asymmetry of auditory attention.

After the first works of Kimura, DL test has been used for more than 50 years in fundamental neurosciences as well as in clinical practice.[16] This sensitive, noninvasive method can be used not only to determine the lateralization of speech functions, as it was suggested by Kimura, but also to study the subject's attention and its asymmetry, interhemispheric interaction, functions of the corpus callosum, and to estimate the consequences of neurosurgical intervention and cognitive dysfunctions in case of various neuropsychiatric pathologies.[16–19]

2. Aim

Hence, the aim of this work is to carry out retrospective analysis of the data on the peculiarities of auditory verbal stimuli perception in children with DPD and to estimate the influence of tDCS on the characteristics of such perception on the basis of DL test results.

3. Material and methods

3.1. *Groups of patients*

To carry out the analysis we used the results of DL test and the data of examinations included in the protocol of tDCS treatment sessions in the City Centre of Rehabilitation Treatment for Children with Psychoneurological Disabilities. The protocol consisted of: daily reports of a patient's parents and teachers, the data of electroencephalography and neuropsychological tests.

From the archive of available medical records of patients with SDDSL and SDDSS (diagnosed in accordance with ICD-10), which were the only or prevalent in their neurological clinical picture (648 cases, 336 of them received tDCS treatment), the results of examinations and treatment of 57 children were chosen for analysis. All 57 met the following inclusion criteria.

The first criterion: the intelligence (according to WISC or Raven's Progressive Matrices for children) was at the normal level ($IQ > 85$) or corresponded to borderline intelligence functioning ($70 < IQ < 85$).

The second criterion: placement of stimulating electrodes used in tDCS. The included test results were only of those patients who had stimulating electrodes placed in the left hemisphere projection during tDCS procedure. That is because in our practice we use more than 20 different variants of stimulating electrodes positioning on a scalp; as a result clinical tDCS effects are poorly comparable. In other words, the cases when the treatment was applied to various zones of the right hemisphere or both to the right and the left hemispheres were excluded from the analysis.

The third inclusion criterion was strong right handedness, or preferable use of right hand. The preference of using either right or left hand in manipulating activity was determined by the Annett Handedness Questionnaire for children and according to parents' observations.

The results of DL test of 96 children (36 girls and 60 boys) were analyzed. The clinical group comprised 57 children, 6–13 year old, with DPD (Table 1). The healthy control (HC) group consisted of 39 apparently healthy volunteers subjected to DL test: 17 girls and 22 boys, 7–12 year old.

All 57 children of the clinical group attended the rehabilitation course (lasting 10–12 weeks) which consisted of speech therapy (10–15 sessions 45–60 min each), therapeutic physical training (10–15 sessions 45 min each), massotherapy (10 sessions 30–45 min each), and mechanotherapy (10 sessions 30–45 min each). The tDCS was administered to 47 children of this group; the other 10 children were subjected to the rehabilitation course without tDCS. The latter 10 children (3 with SDDSS and 7 with SDDSL) made up the clinical control (CC) group; all the patients in both groups were selected practically randomly from the sample of children of comparable ages and conditions. The effect of tDCS on the subjects treated by psychoactive drugs can be unpredictable. That is why we try to ensure that psychoactive

Table 1 – The distribution of children in clinical group.

	Specific developmental disorders of scholastic skills (SDDSS)					Specific developmental disorders of speech and language (SDDSL)			
	Dyslexia	Dysgraphia	Dyscalculia	Mixed disorders	Total	Disorders of impressive speech	Disorders of expressive speech	Mixed disorders	Total
Boys	3	4	2	7	16	4	9	9	22
Girls	2	3	1	4	10	1	5	3	9
Total	5	7	3	11	26	5	14	12	31

pharmacotherapy was neither prescribed nor administered to the subjects, or had been cancelled at least one month before tDCS therapy started. We ourselves do not prescribe or administer psychoactive drugs either.

The children of both clinical and control groups were subjected to the DL test which allows us to reveal the peculiarities of the auditory attention and to estimate the role of each cerebral hemisphere in the verbal stimuli perception. Some children of clinical group (26 who have received tDCS treatment and 10 who have not) were tested twice: at the beginning and at the end (1–2 weeks after finishing tDCS sessions) of the rehabilitation course. Among 26 children who have received tDCS treatment 6 were suffering from SDDSS and 20 – from SDDSL.

3.2. *Dichotic listening test*

We used the Dichotic 1.3 software[20] running on the personal computer for preliminary audiometry and DL tests. This program was designed by us to carry out audiometry and DL tests without using special acoustic equipment.[21] After audiometry we excluded from further examination children who had a difference between the hearing threshold of the right and of the left ear more than 5 dB. In DL mode the program allows us to present audio stimuli to the subject, to record his or her answers, and also to perform the basic mathematical processing of the results including the calculation of the laterality index (LI) in the following way: $LI = 100\ (R - L)/(R + L)$, where R is the number of correctly reported stimuli presented to the right ear; L is the number of correctly reported stimuli presented to the left ear. LI value was expressed in percentages.

As a stimulus material in our study we used 36 pairs of consonant-vowel syllables (*ba*, *da*, *ga*, *pa*, *ta*, *ka*) pronounced in a natural male voice and stored to disc. Six identical pairs were not counted when LI had been calculated, but they were taken into account when percentage of erroneous answers in total number of answers (ErrA) was calculated. As an erroneous answer we consider an answer not containing any of the presented syllables. If the subject pronounces two syllables, the first of them is taken as an answer. After presenting a synchronous pair of stimuli and collecting subject's answer, a 4-second delay countdown starts, then the next pair is automatically presented, etc. Pairs of stimuli used for the presentation are being taken randomly and without replacement from the pool of stimuli. Thus the full set of 36 pairs of syllables is being presented.

One of the features of the Dichotic 1.3 software is that at each step of the test it computes not only the estimated parameter (LI), but also its confidence interval.[21] Confidence interval is calculated assuming that each iteration of the DL algorithm is an independent test of a subject. To determine boundaries of the confidence interval, a modified Wald interval is used.[22,23] If the confidence interval does not include 0 and $LI > 0$ the right ear advantage is stated, if $LI < 0$ the left ear advantage is stated, and if the confidence interval of LI includes 0 the ear preference is considered insignificant.

Further in this paper we analyze the obtained LI and ErrA values.

3.3. *tDCS procedures*

The children of the clinical group went through the tDCS treatment course. The treatment was performed in compliance with all conventional standards of medical ethics. In this study we analyze the results of treatment which was carried out in the municipal outpatient rehabilitation clinic, and therefore for ethical reasons the sham stimulation had not been conducted.

In the group under analysis the stimulating electrodes were placed using two different schemes, but in both cases only the left hemisphere was stimulated. In the first scheme the anode was placed in Brodmann areas 44, 45 of the left hemisphere (Broca's area), and the cathode was placed 2–2.5 cm above the ipsilateral mastoid. In the second scheme the anode was placed in the left temporo-parieto-occipital area and the cathode was over the left mastoid. The paper of Homan et al.[24] on correspondence between Brodmann areas and International 10–20 system was taken into account when stimulating electrodes were placed.

To carry out the procedures we utilized certified and approved for use in Russia drug iontophoresis apparatuses Potok1, Elfor-Prof (Russia), and NeuroConn (Germany). The duration of stimulation was 25 min for children aged 6–7 years, 30 min for children aged 8–9 years, and 35 min for children aged 10–12 years; electric current was 0.06–0.09 mA. All electrodes were of the same size of 6.25 cm^2. Thus, the used current density was 0.0096–0.014 mA/cm^2, that did not exceed Russian safety standards for direct current in child treatment (0.01–0.2 mA/cm^2), nor the current density used in tDCS-related clinical researches in other countries (0.029–0.066 mA/cm^2).[25] The prolongation of exposure time leads to transfer of a greater amount of electricity; however, surface charge density does not exceed values which are used in tDCS (0.017–0.048 C/cm^2),[26] where 1 C is the amount of electric charge transported in 1 s by a constant current of 1 A. In our case, surface charge density ranged 0.0144–0.0302 C/cm^2, although some specialists use values that exceed ones used by us. For

example, in the work of Schlaug and Renga[27] maximum surface charge density was 2.4 C/cm^2. However, even in their case surface charge density values were much lower than safe level (200 C/cm^2).[28] Thus, we used exposure parameters which meet all Russian medical safety requirements to procedures that use direct current to effect human brain.[29]

Treatment course consisted of 5–9 procedures performed 3–4 days apart (twice a week). The stability of improved clinical state (when a kind of a *plateau* is reached) was ascertained by daily reports of a patient's parents and teachers and served as a criterion for finishing the course.[8]

3.4. *Statistics*

The statistical analyses of the results were performed in STATISTICA 6.1 (StatSoft Inc.). Due to the small number of patients in groups we used non-parametric Mann–Whitney *U*-test to estimate the differences between groups and Wilcoxon matched pairs W-test to estimate the changes within one group. Significance was determined at $P < 0.05$.

4. Results

Before the treatment the LI values of children with DPD were different from the LI values of healthy children from HC group (*U*-test: $P = 0.000001$). The difference was more significant between HC and SDDSL subgroup (*U*-test: $P < 0.0000001$), rather than between HC and SDDSS subgroup (*U*-test: $P = 0.04$) or between HC and CC group (*U*-test: $P = 0.003$). The distribution of the LI1 values (before the treatment) is shown in Fig. 1.

The ErrA values of children with DPD were higher than of healthy children from HC group. Like in case of LI, parameter

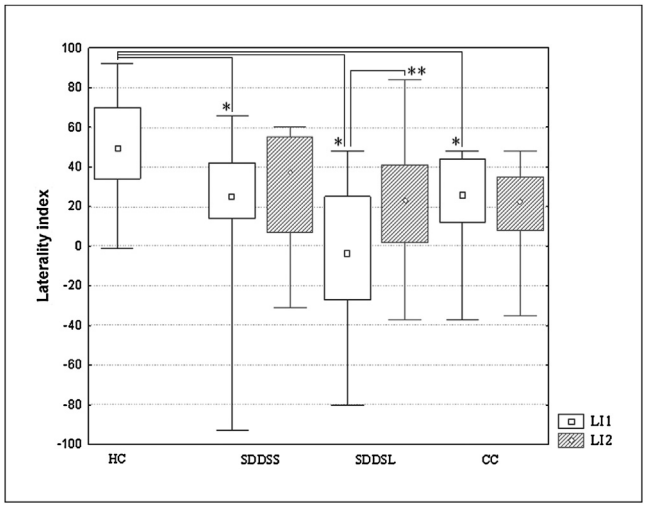

Fig. 1 – The distribution of the LI values in groups of children. Comments: boxes – 25%–75%; dots in boxes – medians; whiskers – minimums and maximums; * – significant difference from healthy control; ** – significant difference from the results of dichotic listening test obtained before treatment.

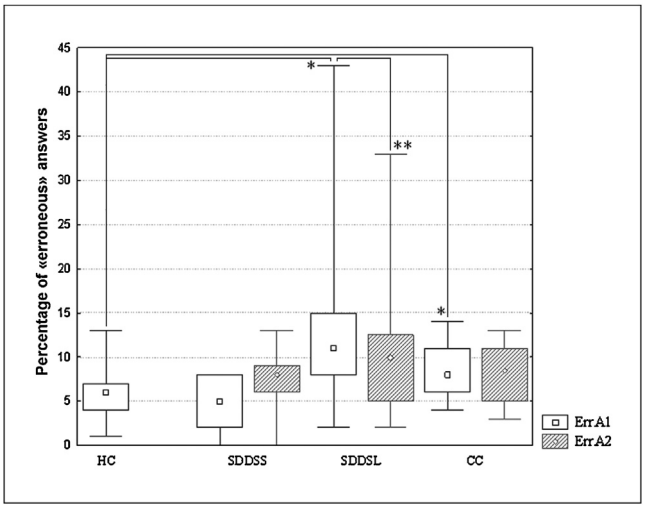

Fig. 2 – The distribution of the percentage of ErrA in groups. Comments: boxes – 25%–75%; dots in boxes – medians; whiskers – minimums and maximums; * – significant difference from healthy control; ** – significant difference from the results of dichotic listening test obtained before treatment.

ErrA reveals difference of HC group from SDDSL subgroup (*U*-test: $P = 0.00005$) and from CC group (*U*-test: $P = 0.04$), but no statistically significant difference from SDDSS subgroup (*U*-test: $P = 0.8$). The distribution of the ErrA1 values in groups (before treatment) is shown in Fig. 2; it is noticeable that the parameter spread is very wide in SDDSL subgroup (4–48%). The greatest number of mistakes was made by several children with SDDSL whose LI was close to zero (Fig. 3).

Neither LI nor ErrA values showed statistically significant changes between boys and girls in either group.

The results of DL test retaken in 7–14 days after the treatment showed the changes in characteristics of verbal stimuli perception of patients with DPD who had undergone

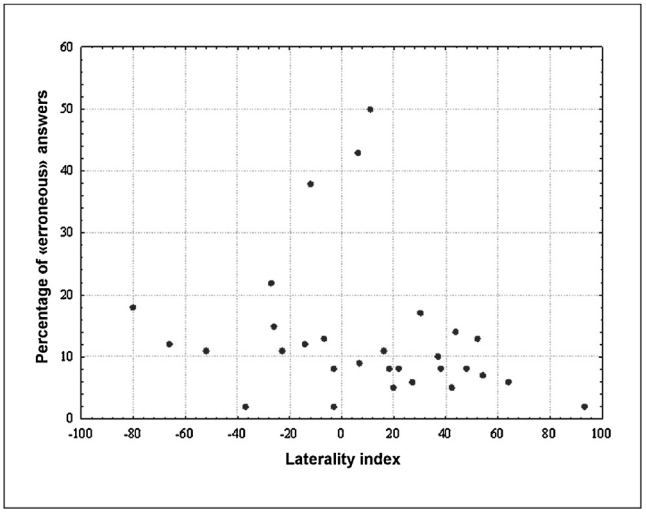

Fig. 3 – The percentage of ErrA vs. LI in SDDSL subgroups of clinical group.

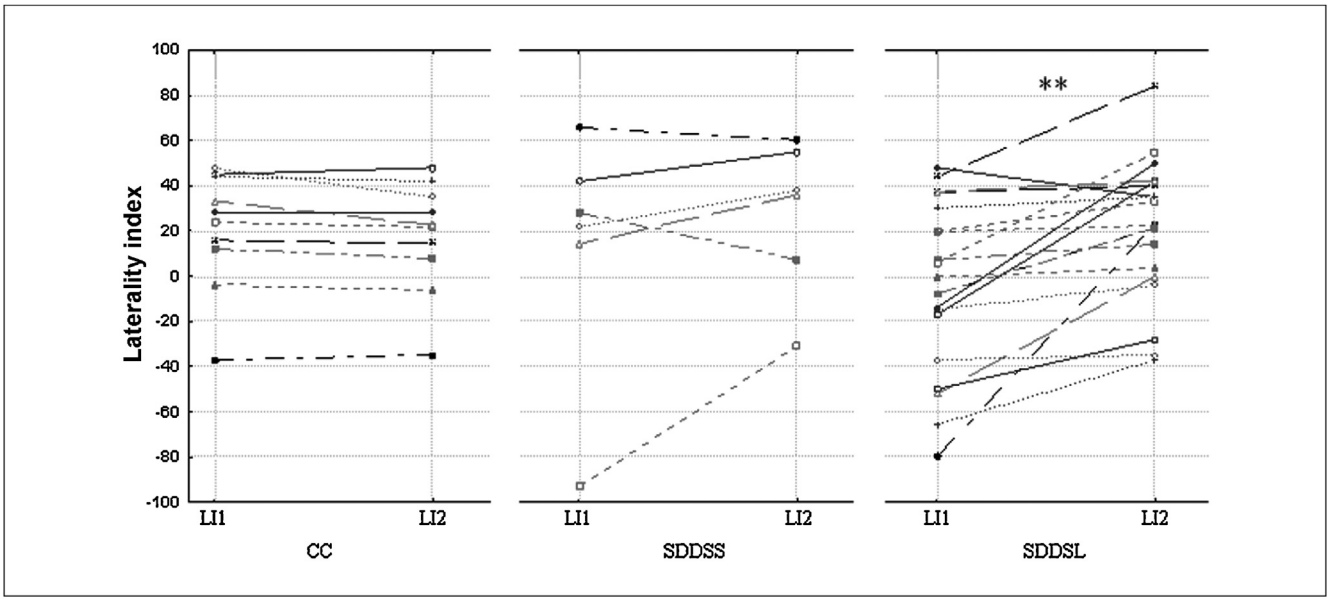

Fig. 4 – The individual LI values of patients obtained before (LI1) and after (LI2) the treatment. Comments: ** – significant difference between LI1 and LI2.

the tDCS treatment course. The LI values of children with DPD after tDCS procedures changed closer to the normal level (Fig. 1). But such changes were only observed in SDDSL subgroup (W-test: $P = 0.0004$), while in SDDSS subgroup (6 children) there were no statistically significant changes (W-test: $P = 0.24$). At the same time, children who had not received tDCS treatment (CC group) did not show any significant changes in LI values before and after the rehabilitation course (W-test: $P = 0.12$) (Fig. 1).

The individual LI values of patients after the first and the second tests are presented in Fig. 4. Despite the considerable variability it is easy to notice the bidirectional character of changes in SDDSS subgroup and, on the opposite, the one-directional character (with a single exception) of changes in SDDSL subgroup.

The ErrA values after tDCS treatment in the whole clinical group did not change, but, comparing the subgroups, one can see the slight decrease of the ErrA values in SDDSL subgroup (W-test, $P = 0.03$) (Fig. 2). In CC group (children who had not been treated with tDCS) no significant differences in the ErrA values before and after the rehabilitation course were observed (W-test, $P = 0.83$).

5. Discussion

The results obtained in this study indicate that the role of the left hemisphere in speech functions in children with DPD belonging to the clinical group in many cases is significantly lesser than in healthy children belonging to the control group. These results coincide with data obtained by other researchers.[12–14] This means that patterns of functional asymmetry of the cerebral hemispheres and interhemispheric interaction in children with such disorders are formed in a special way. The perception and processing of auditory verbal stimuli (syllables, concerning our study) are not carried out with a strong predominance of the left hemisphere, as it occurs in normal child development, but with a significant contribution of the right hemisphere; sometimes this contribution is even greater than one of the left hemisphere. At that, LI more often approaches extremal negative values (left ear advantage) in children with SDDSL who have dominating disorder of impressive component of speech. In our opinion, and according to a number of evidences,[1,30,31] such an anomalous asymmetry in the perception of speech stimuli can be explained by a shift of these functions from the left hemisphere into the right hemisphere due to some adverse factors that caused functional deficiency of the left hemisphere. Dysgenesis of corpus callosum is also considered as a possible cause.[1,2,32]

The number of errors made during the perception of verbal stimuli by children with SDDSL is much greater than the number of errors made by healthy children. These data may indicate the dysfunction of the temporal lobe in the left hemisphere which implements auditory verbal perception, and particularly phonemic hearing during DL.[16,32,33] Since the maximum number of errors (50%) was characteristic of children with the LI values close to zero, we can assume that in these cases the shift of the speech stimuli processing into the right hemisphere did not happen for some reasons. Seemingly, the deficiency of the left hemisphere in the speech stimuli processing and the absence of the shift of this function into the right hemisphere led to a large number of errors in DL test.

For each patient we compared the obtained results of DL test with the data of clinical, paraclinical, neuropsychological tests to choose tactics of tDCS treatment. In the group of children with DPD the stimulation was aimed at the activation

of the left hemisphere systems, whose dysfunction had been discovered during the preliminary tests. Most probably, the left hemisphere activation and related adjustment of auditory attention to the right ear is the very reason why the LI values grew much higher after the treatment, i.e. the number of the speech stimuli perceived by the left hemisphere increased.

The absence of statistically significant differences between the LI values before and after the treatment in the SDDSS subgroup is possibly caused by the small number of patients in this subgroup (6 persons), and by the greater heterogeneity of the observed disorders (despite the common deficiency of the left hemisphere which had been supposed). Apparently, the effect of the left hemisphere activation by tDCS in this group of children was not sufficient also because of the strong tonic reciprocal influences from the side of the right hemisphere systems. This assumption is evidenced by the results of the combined application of tDCS, which we have used for patients with SDDSS more frequently in recent years. According to this approach we firstly conduct the preliminary tDCS of the right hemisphere systems with inhibitory techniques, and then we conduct tDCS of the left hemisphere systems with activation techniques.[8,11] However, in this paper we did not analyze the results of this way of applying tDCS because it would make much more difficult both the comparison of DL tests results and the comparison of treatment results.

In most cases the left hemisphere activation resulted in a distinctive reduction of erroneous answers percentage during the DL test, which might indicate an improvement in the verbal stimuli processing implemented by the left temporal lobe systems.

Changes in the auditory perception characteristics were accompanied by the improvement of patients' clinical state according to the neurological and neuropsychological examinations and parents' questioning. For example, the treatment improved motor, sensory and communicative functions of speech, reduced specific disorders of counting, reading and writing. Non-specific improvements of the attention and memory functions were also noticed. In general, significant improvements were observed in 11% of children, moderate improvements – in 61%, and slight improvements – in 13%; 5% of children showed no improvements. The detailed assessment of clinical efficacy of tDCS procedures had been described in previous papers.[8]

6. Conclusions

Thus, the DL tests results, allowing to determine reliably enough the peculiarities of functional hemispheric asymmetry with respect to the verbal stimuli perception, significantly complement data of clinical and paraclinical tests. This is practically useful when planning the tDCS treatment tactics, and also enables us to estimate quickly and easily the efficacy of polarization exposure aimed at modifying of the cerebral hemispheres activity.

Conflict of interest

None declared.

REFERENCES

1. Njiokiktjien C. *Pediatric Behavioural Neurology*. vol. 2. Moscow: Terevinf; 2010 [in Russian].
2. Teeter PA, Semrud-Clikeman M. *Child Neuropsychology: Assessment and Interventions for Neurodevelopmental Disorders*. Boston: Allyn and Bacon; 1997.
3. Fregni F, Boggio PS, Nitsche M, et al. Anodal transcranial direct current stimulation of prefrontal cortex enhances working memory. *Exp Brain Res*. 2005;166(1):23–30.
4. Antal A, Paulus W. Transcranial direct current stimulation and visual perception. *Perception*. 2008;37(3):367–374.
5. Palm U, Schiller C, Fintescu Z, et al. Transcranial direct current stimulation in treatment resistant depression: a randomized double-blind, placebo-controlled study. *Brain Stimul*. 2012;5(3):242–251.
6. Zaghi S, Heine N, Fregni F. Brain stimulation for the treatment of pain: a review of costs, clinical effects, and mechanisms of treatment for three different central neuromodulatory approaches. *J Pain Manag*. 2009; 2(3):339–352.
7. Pinchuk D, Pinchuk O, Sirbiladze K, Shugar O. Clinical effectiveness of primary and secondary headache treatment by transcranial direct current stimulation. *Front Neurol*. 2013;4:25. http://dx.doi.org/10.3389/fneur.2013.00025.
8. Pinchuk D, Vasserman M, Sirbiladze K, Pinchuk O. Changes of electrophysiological parameters and neuropsychological characteristics in children with psychic development disorders after transcranial direct current stimulation (tDCS). *Pol Ann Med*. 2012;19(1):9–14.
9. Bogdanov OV, Pinchuk DY, Pisar'kova EV, Shelyakin AM, Sirbiladze KT. The use of the method of transcranial micropolarization to decrease the severity hyperkineses in patients with infantile cerebral palsy. *Neurosci Behav Physiol*. 1994;24(5):442–445.
10. Pinchuk D, Katisheva M, Sidorenko G, Yurieva R. Investigation of brain plasticity in children with minimal brain disfunctions during directed transcranial stimulations. In: *10-th World Congress of International Association for the Scientific Study of Intellectual Disabilities*. Helsinki, Finland, July 8–13, 19961996.136–137.
11. Pinchuk DY. *Transcranial Micropolarization of Brain. Clinical Picture. Physiology. 20 Years of Clinical Experience*. St. Petersburg: Chelovek; 2007 [in Russian].
12. Johnson BW, McArthur G, Hautus M, et al. Lateralized auditory brain function in children with normal reading ability and in children with dyslexia. *Neuropsychologia*. 2013;51(4):633–641.
13. Obrzut JE, Mahoney EB. Use of the dichotic listening technique with learning disabilities. *Brain Cogn*. 2011;76 (2):323–331.
14. Pinheiro FH, Oliveira AM, Cardoso AC, Capellini SA. Dichotic listening tests in students with learning disabilities. *Braz J Otorhinolaryngol*. 2010;76(2):257–262.
15. Bless JJ, Westerhausen R, Arciuli J, Kompus K, Gudmundsen M, Hugdahl K. ''Right on all occasions?'' – on the feasibility of laterality research using a smartphone dichotic listening application. *Front Psychol*. 2013;4:42. http://dx.doi.org/10.3389/fpsyg.2013.00042.
16. Hugdahl K. Fifty years of dichotic listening research – still going and going and. . .. *Brain Cogn*. 2011;76(2):211–213.
17. Andersson M, Ystad M, Lundervold A, Lundervold AJ. Correlations between measures of executive attention and cortical thickness of left posterior middle frontal gyrus – a dichotic listening study. *Behav Brain Funct*. 2009;5:41. http://dx.doi.org/10.1186/1744-9081-5-41.

18. Hiscock M, Kinsbourne M. Attention and the right-ear advantage: what is the connection? *Brain Cogn*. 2011; 76(2):263–275.
19. Westerhausen R, Woerner W, Kreuder F, Schweiger E, Hugdahl K, Wittling W. The role of the corpus callosum in dichotic listening: a combined morphological and diffusion tensor imaging study. *Neuropsychology*. 2006;20(3):272–279.
20. Wasserman EL, Kartashev NK. *Dichotic [Computer Program], Version 1.3*. St. Petersburg, Russia: St. Petersburg Institute for Informatics and Automation of RAS; 2008.
21. Wasserman E, Kartashev N. Dichotic listening: computer implementation, methodical problems, and modeling prospects. In: *The Third International Conference «Problems of Cybernetics and Informatics» (PCI'2010), vol. 1*. Baku, Azerbaijan, 2010 September 6–9, 2010Baku: Elm; 2010:106–109.
22. Agresti A, Coull B. Approximate is better than ''exact'' for interval estimation of binomial proportions. *Am Statist*. 1998;52(2):119–126.
23. Brown LD, Cai TT, DasGupta A. Interval estimation for a binomial proportion. *Statist Sci*. 2001;16(2):101–133.
24. Homan RW, Herman J, Purdy P. Cerebral location of international 10–20 system electrode placement. *Electroencephalogr Clin Neurophysiol*. 1987;66(4):376–382.
25. Bastani A, Jaberzadeh S. Does anodal transcranial direct current stimulation enhance excitability of the motor cortex and motor function in healthy individuals and subjects with stroke: a systematic review and meta-analysis. *Clin Neurophysiol*. 2012;123(4):644–657.
26. Liebetanz D, Koch R, Mayenfels S, König F, Paulus W, Nitsche MA. Safety limits of cathodal transcranial direct current stimulation in rats. *Clin Neurophysiol*. 2009; 120(6):1161–1167.
27. Schlaug G, Renga V. Transcranial direct current stimulation: a noninvasive tool to facilitate stroke recovery. *Expert Rev Med Devices*. 2008;5(6):759–768.
28. Yuen TG, Agnew WF, Bullara LA, Jacques S, McCreery DB. Histological evaluation of neural damage from electrical stimulation: considerations for the selection of parameters for clinical application. *Neurosurgery*. 1981;9(3):292–299.
29. Obrosov AN, Karachevtseva TV, eds. In: *Handbook of Physiotherapy and Physioprophylaxis of Childhood Diseases*. Moscow: Meditsina; 1987 [in Russian].
30. Carlsson G, Hugdahl K, Uvebrant P, Wiklund LM, von Wendt L. Pathological left-handedness revisited: dichotic listening in children with left vs right congenital hemiplegia. *Neuropsychology*. 1992;30(5):471–481.
31. Rasmussen T, Milner B. The role of early left-brain injury in determining lateralization of cerebral speech functions. *Ann N Y Acad Sci*. 1977;299:355–369.
32. Hugdahl K. What can be learned about brain function from dichotic listening? *Rev Esp Neuropsicol*. 2000;2(3):62–84.
33. Hirnstein M, Westerhausen R, Hugdahl K. The right planum temporale is involved in stimulus-driven, auditory attention – evidence from transcranial magnetic stimulation. *PLoS ONE*. 2013;8(2):e57316. http://dx.doi.org/10.1371/journal.pone.0057316.