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Effects of EEG-Neurofeedback in children with Down syndrome

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ABSTRACT

Background. Down syndrome (DS) is a genetic disorder characterized by varying degrees of mental retardation and neurological complications. Children with DS often experience difficulties with attention, concentration, learning, memory, speech, language, behavior, and physical balance.

Methods. This study included 11 children with DS and 10 children with ADHD, aged 6 to 10 years who received treatment at the private clinic "Neyromed Servis" in Tashkent, Uzbekistan. Cognitive functions were analyzed by using Electroencephalography-neurofeedback (EEG-NFB) and the Forbrain headsets. The Wechsler Preschool and Primary Scale of Intelligence and Schulte table were used to assess the effectiveness of non-drug treatment.

Results. The utilization of Forbrain headsets enhanced children's attentiveness as listeners and improved the quality of their voice and speaking. Positive changes in EEG parameters were also registered: theta wave amplitude and theta-to-beta ratio in the frontal lobes decreased significantly.

Conclusion. EEG-NFB treatment significantly improved cognitive function, particularly attention, without any side effects in observed children. Moreover, impulsivity as well as hyperactivity decreased gradually. Additionally, after using of the Forbrain method, vocabulary in children improved by 20-40% across all groups.

Keywords: Down syndrome, ADHD, EEG-Neurofeedback, Wechsler Preschool and Primary Scale of Intelligence, Schulte table, cognitive impairment, trisomy 21, children

INTRODUCTION

Down syndrome (DS), also known as trisomy 21, is a genetic disorder that causes learning disabilities and delayed development [1]. The most prevalent identified factor leading to cognitive impairment, occurring in around one out of every 1000 births [1,2].

Individuals with DS typically display physical traits such as reduced muscle tone, a flattened facial profile, a depressed nasal bridge [3], a small nose, upward-slanting eyes, an enlarged tongue relative to the size of the mouth [4], and abnormal ear shape [5]. In addition to these features, children with DS are more susceptible to various medical issues [6]. They may also exhibit varying degrees of intellectual disability ranging from mild to severe [1,5,7].

Physical characteristics observed in individuals with DS include short stature, short fingers, low muscle tone, and atlantoaxial instability (unstable upper neck joint) [8]. Facial features commonly seen include epicanthic folds, flat nasal bridge and occiput, small mouth and ears, and upward-slanting palpebral fissures [9]. Moreover, congenital heart anomalies—particularly atrioventricular septal defects-are frequently present among individuals with DS [10]. Additionally, they are at increased risk for health conditions such as hypothyroidism, epilepsy, early-onset Alzheimer's disease, hematological disor-

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ders, recurrent infections, and hearing/vision problems [11-13].

Children with DS often face difficulties related to attention, memory concentration, behavior language, and speech [14]. Language challenges can include difficulties in expression [15], articulation fluency, and social changes [16].

While individuals born with DS can acquire cognitive and social skills, mild to moderate intellectual disabilities are common alongside additional neurological deficits, such as sleep issues, memory problems, and symptoms associated ADHD [2,17]. Using various strategies to address these problems is crucial.

EEG-Neurofeedback (EEG-NFB) has been identified as an effective treatment option for individuals with DS by helping to improve brain regulation through self-regulation training using brainwaves [18].

Behavioral problems such as aggression and hyperactivity can also be addressed through EEG-NFB therapy which focuses on enhancing attention, focus, cognition, and behavior in individuals with DS [19].

In recent years, EEG-NFB has been extensively utilized as a primary therapeutic approach for psychiatric and neurological disorders. EEG-NFB utilizes the patients' capacity to acquire the skill of regulating and harmonizing their cerebral functions by manipulating brain waves in specific regions of focus [20, 21].

Individuals with DS typically have symptoms of comorbidities associated with cerebral dysregulation. EEG-NFB can effectively mitigate these symptoms by harnessing the brain's inherent capacity for self-regulation, thereby enhancing its functionality and alleviating the associated manifestations [22-24].

Forbrain, a learning device equipped with an electronic filter that uses sound waves, blocking environmental sounds in order to improve cognitive processes. It has shown to be proficient at enhancing voice quality sound discrimination, stuttering, cognition, and reading ability in subjects including children with DS according to existing studies [25]. Furthermore, a significant number of individuals with DS encounter challenges in speech and language, which can result in compromised communication abilities [26]. So, the Forbrain headsets help the brain process sensory information more effectively for these children [27].

Forbrain is used for both adults and children who want to improve verbal and short-term memory, focus, communication, etc. [28]. Constant use of the Forbrain headsets might help to improve various skills like: attention, concentration, focus; verbal and short-term memory; ability to stay on task; writing, reading, and learning skills; fluency, pronunciation, and speech; communication skills; social interaction skills; motor (vestibular) production; self-regulation, etc. [16, 25, 27, 29, 30]. The aim of the present study is to perform rehabilitation methods for children with Down syndrome.

METHODS

This research investigated the effects of EEG-NFB training on attention and Forbrain techniques on speech skill development in children with DS. Eleven children with DS and 10 children diagnosed with ADHD, aged 6 to10, participated in the EEG-NFB training over a period of seven weeks. Additionally, a speech therapist utilized Forbrain techniques during this time. The EEG-NFB training sessions involved 10 sessions lasting 5-30 minutes each, following the β-rhythm program by using Neyron-Spektr-1/NFB equipment from Neurosoft, Russia.

Cognitive functioning was assessed using the Wechsler Preschool and Primary Scale of Intelligence (WPPSI) as well as the Schulte table before and after completing all training sessions. The WPPSI evaluates verbal and performance intelligence quotient (IQ) scores, along with a comprehensive IQ score derived from 15 subtests categorized into core, supplemental, and optional sections. The mean of the quotient and composite scores is 100, with a standard deviation of 15 [31].

Schulte tables are known for enhancing peripheral vision, attention, memory skills needed for rapid reading comprehension, efficient information retrieval, and cognitive resilience against external distractions during tasks. The tables consist of randomly arranged numbers or letters in varying colors corresponding to different levels of difficulty [26,32].

Exclusion criteria included severe mental retardation, profound hearing or vision impairment, and epilepsy.

Statistical analysis was conducted using variation statistics techniques in Microsoft Office Excel to calculate measures such as standard deviation (s), median error (M ± m), mode error along with interquartile range. Student's criterion (t) was then used to assess statistical significance at a confidence level of 95% ($P < 0.05$) for data that followed normal distribution patterns.

RESULTS

A questionnaire prepared by a neurologist regarding concentration, speech capabilities and language skills, attention, learning ability, and behaviors was given to parents of each child. All sessions were medication-free throughout the entirety of treatment.

According to the medication history of the patients, height-weight parameters, 4 (36.4%) children with DS were diagnosed with intrauterine develop-

mental delay. Retrospective neurosonographic (NSG) examination revealed signs of cerebral ischemia in 8 (72.7%) children with DS of the main group and in 4 children (40%) of the comparison group. Additionally, immaturity of cerebral structures on NSG was detected in 2 (18.2%) children. There were also noted disorders of the liquor system with first- and second-degree ventricular dilatation, widening of the interhemispheric gap and increased vascular pulsation in 3 (27.3%) children of the main group.

The lag in motor development in children with DS and the age of formation of such motor skills as the ability to sit, crawl and walk independently were significantly different from those of healthy children. In the main group of children with DS, the skill of sitting was formed on average by 9-10 months of age. The skill of crawling was formed by 1 year of age and was preserved for a long time. The skills of independent walking were started on average after 2 years of age. Separately, we would like to mention the delay in the development of fine motor skills, which also accompanied children with DS. Such motor acts as holding a toy and the ability to hold a spoon were also formed with a noticeable delay, which corresponds to the literature data on delayed psycho-motor development in children with DS. In addition, retrospective analysis of medical records showed that these children had weak inadequate manifestations of emotional reactions (reaction of revival at the sight of familiar adults, joy from a favorite toy), late humming, which was associated with late speech formation and, as a consequence, underdevelopment of speech functions (dysarthric speech, lack of vocabulary, late emergence of connected speech). It should be noted that all examined children with DS had difficulties with swallowing and speech of varying degrees due to a high arched palate, small upper jaw, as well as low muscle tone in the tongue and weak oral muscles. Against the background of preserved phonemic hearing, the productivity of expressive speech was depressed. Communication took place through simple words and gestures. Children did not always name the object correctly, but they could show what they were doing with movements and gestures.

Children initially had a vocabulary range between 15–30 words. All participants in the main group exhibited difficulties in articulation (prevailed substitution type), limited sentence formation abilities were registered in 9 children (81.8%), noncompliance with rules, stubbornness, and challenges in retaining acquired knowledge (100%). Communication was primarily achieved through finger pointing, indicating a lack of verbal expression. Additionally, the children displayed poor attention span and concentration, impulsivity, behavioral issues, and problems with balance. Overall, there was a notable lack of awareness regarding their surrounding environment.

Participants underwent pre- and post-training assessments utilizing WPPSI and Schulte tables. The study was conducted uniformly across both groups over a duration of two months.

Initially, individuals with DS exhibited a deficit in literacy and numerical competence. However, subsequent intervention yielded promising outcomes as they displayed an emerging aptitude for reading comprehension, numerical counting, and basic addition. Moreover, their initial inability to generate written content was ameliorated, evidenced by their capacity to write both their names and sentences of substantive meaning.

DISCUSSION

When the cognitive performance of the two groups was evaluated according to the WPPSI, it was 63.38 ± 11.3 and 84.0 ± 5.91 points, respectively. The children in the first group had the lowest overall score on this scale, and a statistically significant difference was observed when compared to the ADHD groups ($p = 0.018$ and $p = 0.009$).

After the EEG-NFB treatment, cognitive activity was re-evaluated according to the Wechsler scale intended for children. According to the test results, a total 70.8 ± 5.8 points were obtained in the representatives of the 1st group and 95.1 ± 2.2 points in the members of the 2nd group.

TABLE 1. Indicators of cognitive function

Scale and table	Main group (n=11)		Control group (n=10)	
	Before training	After training	Before training	After training
WPPSI (score)	63.38±11.3	70.8±5.8	84.0±5.91	95.1±2.2*
Schulte (second) "3×3"	115.7±8.8	92.1±5.4	94±5.7	82±3.9*

*Note: * the reliability of the main and control group indicators is P <0.05.*

According to the results of the verbal test, children with DS had a dominant deficit in the ability to understand words, speaking sentences, paying attention to details, perceiving information, and connecting elementary emotions. When evaluating according to this scale, as well as during EEG-NFB therapy, rapid distraction, inattention, irritability, signs of fatigue and refusal to perform prescribed activities were observed in DS children. Nevertheless, during this activity, children were treated professionally: in order to ease the children's adaptation, the training was initially conducted for a minimum time, and the treatments were organized in the form of games. Then the duration of the training was gradually increased to the target minutes, which allowed to obtain the maximum response results.

In the representatives of the second group, attention deficit, disorganization, hyperactivity and systematic errors in training prevailed.

Based on the results of the Schulte table, before the first training, DS children completed "3 × 3", "4 × 4" tables with difficulty with a certain number of errors. This group failed to complete the "5 × 5" tables. For example, in the first training, the time it took to find numbers from 1 to 10 in a sequence (when a total of 5 tables "3 × 3" were performed in a row) was 115.7 ± 8.8 seconds, and the number of errors was 3.5 ± 1.0. At the end of the 10th training, this indicator became 92.1±5.4 seconds and 1.5±0.5 mistakes, which means that children's ability to find numbers in the correct sequence is much faster and more efficient.

The control group diagnosed with ADHD, before treatment, the 1st EEG–NFB, these parameters were 94±5.7 seconds, the number of errors was 2.0±1.0, after training it was 82±3.9 seconds, the number of mistakes was 1.0±0.

According to the results of the EEG study conducted before the start of the EEG-NFB therapy, most of the participants of the 1st group had incomplete formation of the main rhythm, as well as low amplitude of alpha and beta rhythms, interhemispheric asymmetry, violation of the cooperation of speech zones. In the 2nd group, irregularity of bark biorhythms and delay of the main alpha rhythm were noted. In the pre-training background of all examined children, in the EEG, α-rhythm did not exceed 20%, and β-rhythm was 25-40%.

All twenty-one children who underwent EEG-NFB training demonstrated statistically significant ($p < 0.02$) improvement across all assessed domains as determined by questionnaires and parent interviews. Additionally, changes were observed in EEG-NFB. The theta wave amplitude and theta-to-beta ratio of the frontal lobes in the first group had a considerable drop. Children diagnosed with DS had substantial enhancements in various domains, including verbal and nonverbal communication, as well as short- and long-term memory, after undergoing up to 10 sessions of EEG-based neurofeedback. These changes were statistically significant ($p<0.05$).

Furthermore, motor control and bimanual coordination were improved which was another benefit of non-drug treatment. Individuals with DS and ADHD frequently experienced challenges related to impaired motor control and coordination, as well as difficulties in regulating strength. These issues can significantly impact their ability to do complicated and fast tasks, ultimately leading to subpar academic performance.

In addition, using Forbrain headsets allowed children to become more attentive listeners, and they also improved the quality of their voice and speech: the child heard his own voice in an adjusted form, and accordingly, in response to these changes, the brain rearranges its work, thereby improving the cognitive sphere.

TABLE 2. Results of the EEG study in children

Children with DS		Children with ADHD	
Before training	**After training**	**Before training**	**After training**
• incomplete formation of the main rhythm • low amplitude of alpha and beta rhythms • interhemispheric asymmetry • violation of the cooperation of speech zones	• The theta wave amplitude and theta-to-beta ratio of the frontal lobes decreased*. • alpha rhythm formed (4-6 Hz)*	• irregularity of bark biorhythms • delay of the main alpha rhythm	alpha rhythm formed (6-8 Hz)*

** - P <0.05 interrater reliability*

After using the Forbrain method, vocabulary has improved, increasing by 20-40% in all groups.

It can be seen that working vocabulary noticeably expanded, especially in children with DS, increasing from an initial vocabulary of 15-30 words to 65 and more. In the 2nd group, along with the expansion of the vocabulary, the pronunciation also improved.

CONCLUSION

The result of this study indicates that rehabilitation with EEG-NFB significantly improved cognitive function, especially attention, without any side effects. Cognitive performance was reevaluated using the WPPSI scale, the 1st group had 70.8 ± 5.8 points, and 2nd group had 95.1 ± 2.2 points. According to the Schulte table, concentration skills improved, with a score of 92.1 ± 5.4 seconds and 1.5 ± 0.5 errors after training, which means that the ability to find numbers became much faster and more efficient. Furthermore, this treatment allowed to decrease impulsivity and hyperactivity, these positive changes such as reduction of theta waves in EEG parameters were also observed. This, in turn, is one of the activities that are important for the rapid development and improvement of the communication skills of children with special needs and for their place in society. The effectiveness of the Forbrain method was determined by an increase in vocabulary and pronunciation at 20 - 40%.

Ethics approval and consent to participate: voluntary parents participated, they consented to the study

Availability of data and materials:

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Authors' contributions

SS and KS were the initiators of the proposed concept and made significant contributions to the final manuscript. The first author was responsible for the development of the theoretical framework and provided support in data collection. The second author conducted a thorough review of the final manuscript, played a role in the conceptual development, and made valuable additions. All authors made substantial contributions to the article and have given their approval for the submitted version.

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The authors declare that they have no competing interests

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