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Use of Neurofeedback to Alter Attention Parameters in Children with Internet Addiction Disorder

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ABSTRACT

Background: The increasing prevalence of Internet Addiction Disorder (IAD) among adolescents and young adults has raised concerns about its impact on attention parameters, especially in those with comorbid attention deficit hyperactivity disorder (ADHD). Current treatment approaches, such as stimulant medications, pose potential risks, emphasizing the need for alternative strategies like neurofeedback (NF).

Methods: A total of 76 children (44 boys, 32 girls), aged 9-12 years, diagnosed with ADHD plus IAD, were examined. Neurofeedback therapy was administered over six weeks, comprising 30 sessions. Attention parameters were assessed using various psychological tests adapted for the Georgian population. The study group was compared to a control group of 25 children with low IAD scores who did not undergo NF therapy.

Results: Statistical analysis revealed significant improvements in attention parameters after NF therapy. Concentration, task switching, and parallelization of attention showed enhanced scores, while duration, volume of attention, and the index of attention exhibited decreases, indicating positive treatment effects. Distractions of attention and concentration scores increased significantly post-treatment, demonstrating improved attentional control.

Conclusions: Neurofeedback emerges as a promising nonpharmacological intervention for children with ADHD plus IAD. The treatment positively influenced attention parameters, addressing the complex interplay between ADHD and IAD. Notably, NF's efficacy was observed in subjective and objective attention assessments. The study suggests that NF may impact brain structures involved in ADHD and IAD pathogenesis, such as the prefrontal cortex, caudate nucleus, and thalamus. However, further investigations are required to ascertain the long-term efficacy of NF in this population and to explore the potential reciprocal effects of screen use during NF treatment.

Keywords: Attention; internet addiction disorder, neurofeedback.

BACKGROUND

Increasing digitalization in the last few decades has made the Internet a part of daily life worldwide. Internet use has significantly changed communication and socialization. While there are many advantages to living in a digital world, there are also dangers, including internet addiction disorder (IAD). At present, IAD is commonly described as an overwhelming urge to engage with the Internet, resulting in heightened anxiety and aggression when deprived, along with a gradual decline in social functioning. The prevalence of this disorder is increasing, especially among adolescents and young adults around the world.[1]

To date, there is no structured definition for IAD, although the concept of "internet addiction" was introduced in 1998 by Kimberley S. Young.[2] Later, Griffiths and colleagues postulated that IAD was a component of technological addiction and a subtype of behavioral addiction.[3] IAD is not classified as a medical condition according to the World Health Organization or the Diagnostic and Statistical Manual of Mental Disorders (DSM-5).[4] Nevertheless, the associated diagnoses of online gambling disorder (6C50) and online gaming disorder (6C51) have been incorporated in the 11th edition of the International Classification of Diseases (ICD-11).[5]

Over the last decades, IAD has become not only a medical challenge but also a social challenge due to its comorbid psychiatric conditions (anxiety, depression, attention deficit hyperactivity disorder (ADHD), obsessive-compulsive symptoms, insomnia, hostility/aggression).[6] The prevalence of IAD differs among countries due to different assessment tools and cutoffs. The estimated prevalence of ADHD within those with IAD ranged from 19.5% to 42.5%.[7]

As the prevalence of IAD has increased, researchers have investigated comorbid conditions that significantly affect the well-being of individuals with IAD. Attention problems are one of the leading concerns. It has been established that ADHD is related to addiction.[8] Children and adolescents diagnosed with ADHD exhibit a higher propensity for the misuse of alcohol, tobacco, and other illicit substances compared to their counterparts without ADHD. In the study by Lee et al., it was observed that in comparison to the control group, children with ADHD were twice as prone to having a lifetime history of nicotine use.

Moreover, they were nearly three times more likely to exhibit nicotine dependence during adolescence or adulthood, almost two times more inclined to fulfill diagnostic criteria for alcohol abuse or dependence, approximately 1.5 times more susceptible to meeting criteria for marijuana use disorder, twice as likely to develop cocaine abuse or dependence, and over 2.5 times more likely to develop a comprehensive substance use disorder.[8] ADHD is linked with a premature commencement of substance use and an increased probability of utilizing various substances.[9] Adolescents with IAD exhibit a 2.5-fold higher likelihood of having ADHD compared to control subjects.[10] Moreover, many studies have determined that the scores and severity of ADHD symptoms were higher in adolescents with IAD.[11] The neuroscientific foundation underlying the connection between ADHD and IAD is unknown. It is clear that ADHD and substance use disorder, in some cases, could share similar biological substrates. Dopaminergic transmission plays a pivotal role in contemporary frameworks for both ADHD and substance use disorders (SUDs).

In contrast to unaffected control subjects, individuals with ADHD exhibit an elevated density of dopamine transporters, potentially leading to swift clearance and diminished synaptic levels of dopamine. Substances of abuse, such as cocaine, amphetamine, methamphetamine, ecstasy, nicotine, alcohol, opiates, and marijuana, all induce heightened synaptic dopamine concentrations, particularly within the brain's reward center, the nucleus accumbens.[8] If it shares an underlying biological mechanism with substance use disorder, it becomes clear why ADHD is one of the most common comorbidities of IAD.[12] The American Academy of Pediatrics (AAP) provided clinical practice guidelines for ADHD, recommending that children six years old and older receive treatment for ADHD symptoms with both behavioral interventions and medications approved by the US Food and Drug Administration.[13] Stimulant medications are highly effective in reducing the leading symptoms of ADHD in children and adolescents. However, their usage is limited in children and adolescents with different types of addictive disorders due to the suspected relative abuse potential. This potential is expressed with different severities. For instance, methylphenidate and amphetamine have a high level of abuse potential, while non-stimulant medications such as clonidine and atomoxetine have a lower potential for abuse.[14] Thus, the recommended first-line medication therapy for ADHD, such as stimulant medications, poses risks of misuse and addiction. However, behavioral therapy, including neurofeedback (NF), may be an alternative technique to treat both ADHD and substance use disorder. Neurofeedback (NF) entails self-regulation wherein prevailing EEG parameters are displayed to a participant through visual, auditory, and tactile channels.

The individual consciously or subconsciously modifies these parameters to attain a more optimal state of brain functionality. NF leverages the spectral features of EEG within the 0.5–50 Hz frequency range. The NF procedures can be categorized into activation and relaxation protocols.[15] Neurofeedback has been proven to be a successful behavioral therapy for ADHD in children and adolescents, as it can significantly affect attention parameters.[16] Accumulating data on the use of NF in adolescents and adults with IAD are available.[17] However, the benefits of NF for children with AID have not yet been studied. Moreover, it remains unclear how NF affects specific components of the attention system in children with IAD plus ADHD.

Attention parameters are components of the attention process. Indicators of attention can be divided into two groups: subjective and objective. Subjective indicators of attention are assessed with psychological tests and include the following:

- Concentration of attention – the ability to concentrate on any object or situation;
- Duration of attention – the duration of continuous concentration of attention on one object or event;
- Distractions of attention – quick, purposeful distractions of attention from one object or one event to another or from one activity to another type of activity;
- Index of attention – an objective characteristic of attention; it is recorded during a digital EEG examination according to the ratio of β/θ rhythms;
- Task switching– the ability to switch attention between particular objects or events when a series of objects or events is presented;
- The volume of attention-– the typical number of simultaneously and sequentially perceived objects (images of objects, geometric shapes, letters, words, etc.)
- Parallelization of attention – the ability to simultaneously perform one or more tasks without quick distractions of attention.

All the above attention characteristics are integral parts of a single continuous exertion of attention. The quality of attention parameters is crucial for academic work and the daily activities of children with ADHD and those with ADHD plus IAD.

We aimed to examine attention parameters and their dynamic changes in children with ADHD plus IAD and to compare these values before and after the use of NF.

METHODS

We have examined 76 children (44 boys and 32 girls), aged 9-12 years, from the outpatient clinical setting of G. Zhvania Academic Clinic of Paediatry, Tbilisi, Georgia, from 22 September 2022-29 April 2023. Twenty-five children (17 boys and eight girls) exhibited low IAD scores on the Young test (< 20) and were excluded from the study. Fifty-one patients (27 boys and 24 girls) applied to pediatric neurologists complaining of excessive internet use. They were included in the study group and received NF therapy. Ethical approval was obtained from the study ethics committee of G. Zhvania Academic Clinic of Paediatry of Tbilisi State Medical University (20 September 2022).

The inclusion criteria were as follows:

- Consent provided by the child or legal caregiver;
- Normal pre- and perinatal medical history (absence of neurological or somatic diseases);
- IQ scores (using Raven's Progressive Matrices Test) ≥85 (absence of cognitive impairment);

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- ADHD as confirmed by the DSM-5; IAD as confirmed by the Young test;
- There is no pharmacological treatment for either disorder.

The exclusion criteria were as follows:

- Refusal to participate in the study;
- Neurological or somatic diseases in the pre-and perinatal medical history
- IQ < 85 (intellectual disability) according to Raven's Progressive Matrices Test
- Scores on the Young test<20.

ADHD was diagnosed according to the DSM-5.IAD was assessed using the Young IAD test, which is a 20-item scale. Scores of 20–49 were classified as mild IAD, scores of 50–79 were classified as moderate, and scores of 80–100 were classified as severe.

Thirty sessions of NF were performed, and attention parameters (concentration, duration, distractions, index, task switching, volume, parallelization) were evaluated before and after the NF treatment period. The same attention parameters were assessed on the day of admission and after 38 days (the treatment period for the 30 NF sessions).

Attention parameters were assessed with the following psychological tests adapted for the Georgian population:

- The concentration of attention was assessed by the Trial Making Test–Part A; accuracy and speed of task completion (expressed in seconds) reflected concentration, which was calculated in points according to the protocol provided (a maximum of 10 points) in this age group;
- Duration of attention was evaluated using Raven's Progressive Matrices Test (7 tests administered sequentially); 3 or more incorrect answers were interpreted as errors;
- Distractions of attention were assessed with the Trial Making Test–Part B; the number of correct answers and the speed of task completion (measured in seconds) reflected distractions, which were calculated in points provided by the protocol (max of 10 points) in this age group;
- Task switching was studied according to the Munsterberg method; the norm for completing this task is 2 minutes. The results include the number of highlighted words and errors (missing or incorrect words) and the time spent on the task;
- The volume of attention was determined by the Bourdon-Vois method; the volume norm is 850 characters or more, and the error rate norm is five errors or less;
- Parallelization of attention was assessed by the parallelization of numbers method; the normal task completion time is 2 minutes, and the results are evaluated according to the number of correctly written numbers. The norm is 22 or more correct numbers.
- The attention index was evaluated in a digital EEG examination, during which the characteristics of brain bioelectrical activity were assessed. The results were processed using the latest digital EEG methods (mapping, spectral and amplitude distribution, coherence). Children with ADHD plus IAD exhibit increased θ activity, which is more noticeable in the central leads, and decreased βactivity, which is more noticeable in the frontal leads. The β/θ ratio was calculated using the NF method (biofeedback program Reacor).

NF aims to teach the patient to control their brain activity (reflected on EEG) by presenting various tasks on the screen. Individuals can selectively control the frequency spectrum of their own EEG if a signal is provided that reflects success or failure in producing the desired EEG pattern; changes in brain activity are considered a key sign of ADHD plus IAD. NF was administered according to the protocol developed by J. Lubar.[18] The course of treatment was six weeks (5 sessions per week, a total of 30 sessions). The training was administered in two phases (each consisting of 15 sessions): In the first phase, we taught children to increase the sensorimotor rhythm (SMR) (12–15 Hz) and reduce the amplitude of θ activity (4–7 Hz). In the second phase, children were taught to modify the β/θ ratio by decreasing the amplitude of θ activity and increasing the amplitude of β1activity (15–18 Hz). It is known that an increase in SMR affects hyperactivity, and β/θ training decreases the level of inattention by reducing θ activity. Statistical analysis was done in two directions: To determine a correlation between the age of IAD children and IAD scores, Spearman's rank correlation coefficient was used. To test the null hypothesis (H0) that the difference between the two samples is not confident, the Mann-Whitney U test was used (since the distribution function is unknown). The SPSS statistical program was used to process the results.

RESULTS

After the treatment period, the attention parameters of each patient were evaluated. These parameters were compared before and after the NF treatment period in the treatment group. The purpose of the statistical study was to determine whether there was a correlation between the two characteristics included in the study: the age of 51 children with Internet Addiction Disorder and their Internet Addiction Disorder (IAD) Score. Since the distribution function is unknown, Spearman's rank correlation coefficient was determined (level of significance $\alpha = 0.05$ (confidence 95%) and degrees of freedom $f = 49$). The following value was obtained: $R_s=-0.056$. This proves that the relationship between these two parameters is not confidence.

Statistical processing of the data allowed us to determine whether there is a difference between the two samples, before treatment and after treatment, according to the following parameters: concentration of attention, duration of attention, distractions of attention, Task switching, Volume of attention, parallelization of attention, and the index of attention.

Fifty-one children were included in the study. The research results were processed. To test the null hypothesis (H0), the

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Mann-Whitney U test was used (since the distribution function is unknown). The following values of the U criterion are obtained:

- Concentration of attention U=558.5
- Duration of attention U= 586.5
- Distractions of attention U= 477
- Task switching U= 547
- The volume of attention U=642
- Parallelization of attention U=475
- The index of attention U=677

The Critical value of the U criterion is $U_{0.05;51,51.}$=1222.7 ($p<0.05$). In all cases, it was found that $U<U_{0.05;51,51}$, which confirms that the difference between the two samples (before treatment and after treatment) according to each indicator is confidence. ($\bar{X} - \bar{Y} \neq 0$, where $\bar{X}$ and $\bar{Y}$ are the averages of the first and second samples). It should be noted that after treatment, the average rate increases according to the following parameters: concentration of attention, distractions of attention, parallelization of attention, and decreases according to parameters: duration of attention, task switching, volume of attention, the index of attention, which indicates the effectiveness of the treatment.

The SPSS statistical program was used to process the results. The obtained results are included in the conclusions.

DISCUSSION

As shown by the results, NF is one of the most effective nonpharmacological treatments for ADHD plus IAD.NF may affect the functional activity of brain structures involved in the pathogenesis of both ADHD and IAD. In particular, dysfunction of the prefrontal cortex, also called hypofrontality, plays an important role in the pathogenesis of ADHD. It is the basis of inattention, which is the main symptom of ADHD. The main link in this process remains the ventral catecholaminergic system, which is projected into the frontal and prefrontal cortex. In addition to the frontal and prefrontal cortex, subcortical structures (particularly the caudate nucleus, globus pallidus, and thalamus) play an important role in the pathogenesis of ADHD. Dysfunction of the caudate nucleus and prefrontal cortex leads to defects in lexical components and semantic categorization, and isolated basal ganglia dysfunction may cause a deficit in executive attention. Several studies have found that cerebellar dysfunction also occurs in patients with ADHD, which leads to the fine motor disability that is characteristic of children with ADHD.

Cerebellar dysfunction plays a role in the development of cognitive disabilities associated with ADHD. In the pathogenesis of ADHD, the most important connections are neuronal circuits of the basal ganglia and thalamus with the prefrontal cortex and the cerebellum. Makris et al. suggest pathways connecting the prefrontal cortex with the corpus callosum, globus pallidus, and cerebellum are essential for attention.[19] The caudate nucleus receives information from other subcortical structures, the lateral parietal, lateral frontal, and temporal regions through the corticostriatal pathways. Posner et al., identified two systems of attention. The anterior system is localized in the frontal cortex and is responsible for semantic operations, while the posterior system of visual spatial attention is associated with the right parietal cortex.[20] Dysfunction in these areas leads to dyslexia and acalculia, which are often observed in children with ADHD. The medial areas of the temporal lobe (especially the hippocampus) are responsible for memory processes, which are very important for performance on neuropsychological tests. Thus, regulation of the functions of the abovementioned structures through NF improves perceptual processes needed for normal attention. Cortico-pallidal circuits receive information from the premotor and motor cortex. The role of the motor cortex is critical since hyperactivity and restlessness are partly associated with dysfunction of these areas of the cortex; finally, the fronto-cerebellar pathways connect all of the above structures with the brain stem and thalamus. These connections are crucial to the success of NF therapy in children with ADHD. Regulating the influx of sensory impulses from the reticular formation through feedback limits the information flow and enhances concentration. Sensory attention is associated with the corresponding cortical areas that implement modality-specific aspects of attention.

Regarding the mechanisms underlying these types of attention, the local orienting response plays an important role; in this response, EEG activation is observed in the sensory cortex corresponding to the modality of the stimulus and is due to activation of the mediodorsal part of the thalamus. Thus, the thalamus plays an outsize role in attention. According to Lubar et al., the thalamus and the cortex generate various EEG rhythms; depending on which cortical circuits are targeted, the arousal level of the thalamic pacemaker changes.[21] Thus, it is clear that NF therapy, as used in the present study, can influence the activity of the frontal and motor cortex and, accordingly, their connections with other CNS structures involved in attention. One of the developers of NF, Sterman, stated in his review that "variations in behavioral control are directly related to specific generators of the thalamocortical system.[22] These variations are reflected in the EEG rhythms recorded in separate parts of the brain". According to Kropotov, various neuropsychiatric conditions, including ADHD, lead to altered EEG rhythms.[15] The benefit of NF therapy for ADHD over pharmacological methods is also because psychostimulants are ineffective or cause serious side effects in children with ADHD.[23] In addition, psychostimulants have several side effects, including growth retardation and sleep disorders, which highly affect children in this age group.[24,25]

Our results indicate that after NF therapy, task-switching performance improved, with reductions observed in both the task completion time and the number of highlighted words. A decrease in the volume of attention was noted regarding the

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number of words erroneously remembered. However, the dynamics of the sequence of words were much more important as this is highly important for teaching children. Regarding attention disruptions, there was a significant change in the time required to complete the task and a significant decrease in incorrect responses. Regarding concentration and attention distractions, we found a significant increase in scores.

The effectiveness of NF therapy was also noted in terms of the duration of attention. Increases in the attention index are also important because this index is the only objective parameter of attention. After NF therapy, most children exhibited a maximum value of this indicator. Thus, based on our results, NF is an effective treatment for ADHD according to both subjective and objective assessments of attention.

Proper management of ADHD contributes to children's adaptation and improves school performance; without the abovementioned benefits, attention is not as satisfactory. Indeed, in the absence of full attention, children with ADHD exhibit poor academic work and social functioning despite high cognitive function, which significantly increases the risk of comorbid conditions.

This study has several limitations. The duration of NF's efficacy in children with ADHD plus IAD is not precise, and it needs further investigation. Besides, there is no information regarding the reciprocal effect of the screen used during NF treatment, as screen dependency could be considered a separate entity of IAD.

CONCLUSIONS

Neurofeedback emerges as a promising nonpharmacological intervention for children with ADHD plus IAD. The treatment positively influenced attention parameters, addressing the complex interplay between ADHD and IAD. Notably, NF's efficacy was observed in subjective and objective attention assessments. The study suggests that NF may impact brain structures involved in ADHD and IAD pathogenesis, such as the prefrontal cortex, caudate nucleus, and thalamus. However, further investigations are required to ascertain the long-term efficacy of NF in this population and to explore the potential reciprocal effects of screen use during NF treatment.

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ETHICAL APPROVAL

This study was conducted according to the Declaration of Helsinki and approved by the Ethics Committee of Tbilisi State Medical University Zhvania Academic Clinics of Paediatrics (protocol code N5, 20 September 2022).

INFORMED CONSENT STATEMENT

Informed consent was obtained from all subject's parents or legal careers involved in the study. Written informed consent was obtained from the patient's parents or legal careers to publish this paper.

DATA AVAILABILITY STATEMENT

The data presented in this study are available on request from the corresponding author. The data are private due to the study academic institution's research committee regulations.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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