Research Paper

Transcranial Direct Current Stimulation as an Effective Treatment Compared to Video Games on Executive Functions in Children With Attention Deficit Hyperactivity Disorder

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ABSTRACT

Objectives: This study aims to determine the effectiveness of transcranial direct current stimulation (tDCS) compared to video games on executive functions in children with attention deficit hyperactivity children (ADHD).

Methods: This was an unblinded randomized control trial study with ADHD participants recruited from various schools in Patiala District in Punjab, India. The participants were screened for ADHD using the NICHQ Vanderbilt assessment scale and then they were assessed for eligibility. The random allocation method was done for 61 participants and they were divided into two groups: the control group (video game only) and the intervention group (tDCS along with video game). tDCS was applied at the F3 (anode) and Fp2 (cathode) positions with 1 mA intensity for 20 min 3 times a week for 4 weeks. Pre-, mid-, and post- (day 0, 15, 30) intervention scores for the Raven progressive matrices, the Stroop test, and the trail making test were evaluated for all the participants.

Results: The present study had 61 participants in the age range of 10 to 16 years. They were randomly allocated to control and intervention groups. One-way analysis of variance was used to evaluate within-group differences and an unpaired t test was utilized for between-group analyses on different parameters with $P<0.05$ as the level of significance. Our analysis revealed that tDCS along with video games has a statistically significant effect on components of executive functions as evaluated via the Raven progressive matrices ($t=2.483$, $P=0.01$), the Stroop test ($t=3.507$, $P=0.001$) and the trail making test (TMT Part A: $t=3.238$, $P=0.02$; TMT Part B: $t=4.064$, $P=0.000$) compared to the control group.

Discussion: When compared with video games, tDCS is effective in improving executive functions in children with ADHD. A randomized control trial with a larger sample size is needed to strengthen the findings of this study and overcome its limitations.

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Highlights

- There is a negative correlation between ADHD symptoms and executive function performance.
- Executive functions can be trained using video games as well as noninvasive brain stimulation.
- tDCS has the potential to produce long-lasting and significant changes in neuroplasticity.
- When used to stimulate the dorsolateral prefrontal cortex, tDCS is an effective treatment to improve executive function in ADHD.

Plain Language Summary

ADHD is a developmental disorder commonly observed in children. Children with ADHD can have a short attention span (inattentiveness) or an inability to stay in one place (hyperactivity) as compared to their peers. These children often have difficulty in executive functions, such as memory while working, processing speed, and attention span. To improve these abilities, this study aims to investigate the effects of transcranial direct current stimulation and video games on children with ADHD. The study's results show that transcranial direct current stimulation along with video games are effective in improving executive functions.

1. Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder commonly seen in childhood as described by the Diagnostic and Statistical Manual of Mental Disorders, fifth edition. It can be categorized into three subtypes: combined (ADHD-C), predominantly hyperactive/impulsive (ADHD-H), and predominantly inattentive type (ADHD-I) [1].

The global prevalence of ADHD ranges from approximately 3% to 5% of school-age children [2]. In India, ADHD is estimated to be 11.33%, with the majority of children in the age group of 9 to 10 years. Further, it was identified that among the Indian population, boys (66.7%) are more affected than girls (33.3%), supporting the global findings [3].

Studies report an inverse relationship between ADHD symptoms and executive function performance [4]. Available evidence suggests that deficits in attention, impulsivity, and hyperactivity cause impairments in executive functions [5]. Executive functions include the regulation of future-oriented and goal-directed cognitive behavior by higher-level cognitive functions [3]. The executive function capacities along with the ancillary brain activity levels are not static and can be enhanced by task training or repetition. Gaming heightens long-term reinforcement of the neural connections, optimization of motivation, and training effects. Thus, gamification of a task has been suggested to improve learning ability during executive function training [5].

Traditional and virtual or video games play a pivotal role in the personal and emotional development of children. Video games provide an interactive environment and challenging situations that can promote the development of cognitive skills. The frontal areas of the brain increasingly activate while playing video games compared to parietal, temporal, and occipital areas as revealed by EEG analysis. The frontal cortex holds the centers for executive functioning, which get stimulated by video games; thus, these games can be used for executive function training [6].

Conventionally, medication has been the primary line of treatment for ADHD; however, numerous problems have been reported, including poor compliance, side effects, unknown long-term sequelae, or even non-responsiveness to treatment, which escalates the need for an efficacious and compliant alternative treatment option [4, 7]. Many interventions that focus on cognitive training have been successful in improving specific domains of executive functions, namely working memory, processing speed, attention, or response inhibition [4]. However, the need to develop innovative interventions that target multiple components of executive functions is still unfulfilled [8].

Transcranial direct current stimulation (tDCS) uses a low-intensity electric current delivered via scalp electrodes. It is a suitable option because of its non-invasive nature, cost-effectiveness, safety, tolerability, and feasibility [9]. tDCS brings about a subthreshold change in resting membrane potentials of neurons; that is, it either depolarizes or hyperpolarizes them relative to the direction of the current flow concerning the orientation of axons. Previous studies have demonstrated that anodal tDCS applied over the prefrontal area of the brain corresponding to the F3 position (as per the international 10-20 EEG classification system of electrode placement) enhances attention, cognitive performance, inhibitory control, and working memory [10-15]. tDCS has the potential to induce long-lasting and significant changes in neuroplasticity; therefore, it can be used for therapeutic purposes (Soff et al., 2016). Repetitive transcranial current stimulation and tDCS have been established as safe noninvasive brain stimulation modalities for use in children and adolescents. These can have mild and transient side effects, including headache, tingling, fatigue, itching, redness, and relatively very few (<1%) serious adverse events [16].

The conventional treatment methods, including medication, psycho-education, and neurofeedback work on improving the symptoms of ADHD, while tDCS acts at the cortical level and modulates the neuronal activity, thereby treating the underlying cause. There is a paucity of evidence on the use of tDCS for ADHD to improve executive function [17]. Our research study aims to compare the effectiveness of tDCS on executive function in children with ADHD. We hypothesize that tDCS will produce a significant change in non-verbal reasoning, interference, attention, and cognitive flexibility in children with ADHD.

2. Materials and Methods

Study design

This is a randomized control trial study. However, because of the constraints in resources and manpower, blinding could not be done. The selection of participants was done via the purposive sampling method. Random allocation was done using a computer-generated randomization table to equally divide the study participants into two groups, namely the intervention group and the control group.

Study procedure

Children from various government and private schools of Patiala (a district in Punjab, India) were screened

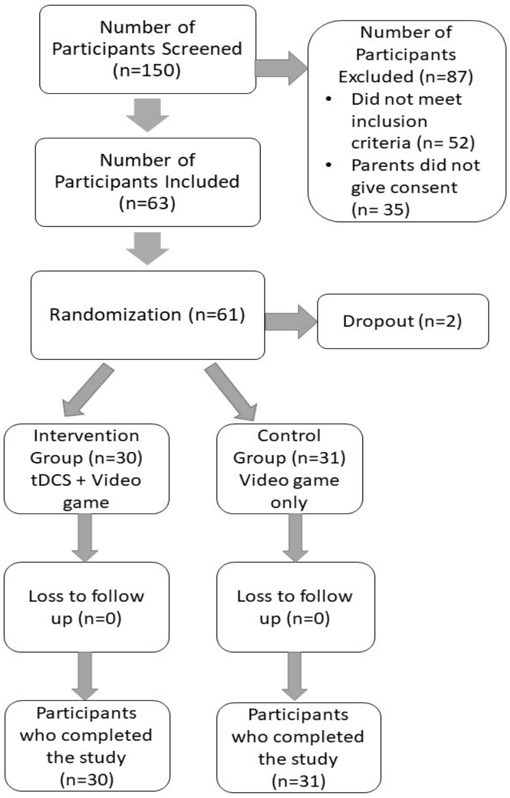

Figure 1. Intervention to the Intervention Group

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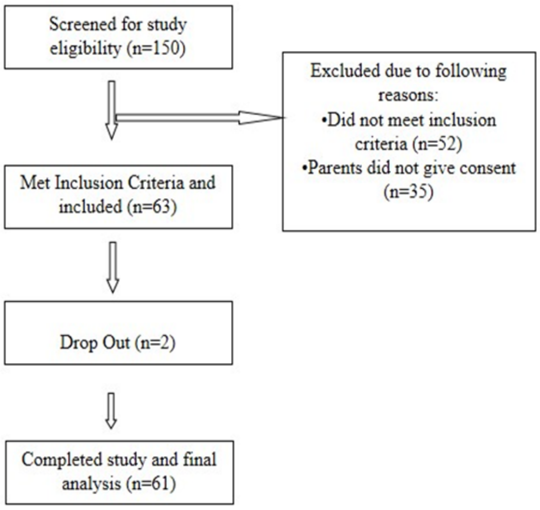

Figure 2. Flowchart Showing Participant Flow and Retention Iranian Rehabilitation Journal

for ADHD using the NICHQ Vanderbilt assessment scale. Children who met the ADHD criteria were then checked for the eligibility criteria. The inclusion criteria comprised the following items: diagnosed with ADHD via parent and teacher versions of the NICHQ Vanderbilt assessment scale, being in the age range of 10 to 16 years irrespective of gender, and being able to play video games. The exclusion criteria comprised the following items: children with other comorbid disorders, such as autism spectrum disorder, oppositional defiant disorder, and other neurological or psychiatric disorders; being on any medication or undergoing any treatment for ADHD during the study; having a visual disability; and being unable to adhere to the study guidelines. Before starting the study, each participant and their family were given information about the research. Parents gave a written informed consent form while verbal assent from the children was necessary to participate in the study. A total of 150 participants were screened for the study. From this population, 87 participants were excluded; 52 participants did not meet the inclusion criteria, and 35 participants' parents did not offer their consent for the study. Thus, 63 participants met the selection criteria out of which 2 participants dropped out. In the end, 61 participants underwent random allocation into the intervention group (n=30) and the control group (n=31). The participant flow and retention are depicted in Figures 1 and 2.

Intervention

The intervention included tDCS and a computer video game (Prince of Persia: Sands of Time). The intervention group played the computer game and received tDCS (Figure 3), while the control group only played the computer game (Figure 4). The treatment was given for 20 min per session 3 times a week for 4 weeks. In this study, the computer video game was Prince of Persia: Sands of Time, which is an action-adventure video game. In this game, a prince combats his enemies who threaten to destroy the world. The game includes components of executive functions, such as set-shifting, planning, attention, and knowledge, which made it an appropriate intervention for our study (Mondéjar et al., 2015; Prince of Persia, 2013). The electrode placement for tDCS was done following the international 10-20 EEG classification system of electrode placement (Figure 5). The anode was placed at the F3 position which corresponds to the dorsolateral prefrontal Cortex (DLPFC) [19] and the cathode was located at the Fp2 position corresponding to the orbitofrontal complex (OFC). tDCS was given using two saline-soaked sponges with 1 mA intensity for 20 min using a stimulator (Transcranial Direct Current Stimulator) (Figure 6). The electrical current was ramped up for the initial 15 sec of stimulation and then ramped down similarly during the end of the stimulation. The control group did not receive any sham stimulation.

Outcome measures

All participants were evaluated via the Raven progressive matrices (RPM), the Stroop test, and the trail making test (TMT). The RPM was used to assess non-verbal reasoning, the TMT to assess attention (TMT Part A) and cognitive flexibility (TMT Part B), and the Stroop test to assess interference. A baseline assessment was taken on day 0 before starting the intervention. Post-treatment

Figure 3. Intervention to the intervention group

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Figure 4. Intervention to the control group

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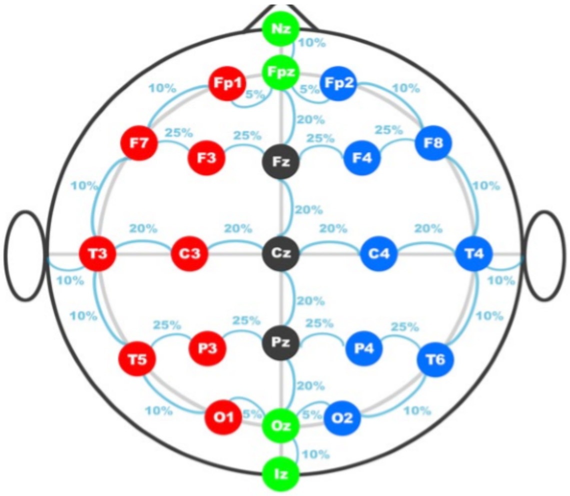

Figure 5. International 10-20 EEG classification system of electrode placement

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Figure 6. Transcranial Direct Current Stimulator (tDCS)

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assessment was taken on day 15 and day 30 of the intervention (Figure 7). The SPSS software, v. 13, was used for the statistical analysis.

Statistical analysis

The 1-way analysis of variance (ANOVA) method was used to evaluate within-group differences and an unpaired t test was used for between-group analyses on different parameters. The level of significance was set at $P < 0.05$ for all statistical analyses. The sample of our study consisted of 61 participants in the age range of 10 to 16 years, divided into two groups, namely control and intervention groups with a mean age of 12.81±2.01 and 12.80±1.75, respectively. Males accounted for the majority of the participants with 80.32%, and the rest were female. The inattentive type of ADHD was most prevalent in our sample followed by the hyperactive and combined type. Both groups had similar baseline characteristics. Additional information about the descriptive characteristics is provided in Table 1.

Results

The within-group comparison for non-verbal reasoning component as evaluated by RPM revealed significant results for the intervention group (F=9.826, P=0.000) while the control group (F=1.398, P=0.252) showed non-significant results. The between-group analysis for RPM showed a statistically significant difference between the two groups (t=2.483, P=0.01). The results for the TMT Part A indicated that the intervention group (F=9.864, P=0.000) had significant interactions while the control group (F=1.287, P=0.281) had non-significant results. The between-group

Table 1. Mean value of age (y), gender, and the type of ADHD among participants

Demographic Characteristics	Mean±SD	
	Intervention	Control
Age	12.80±1.75	12.81±2.01
Gender	% of participants	% of participants
Male	27 (90%)	22 (71%)
Female	3 (10%)	9 (29%)
Type of ADHD	% of participants	% of participants
Inattentive type	17 (56.66%)	16 (51.63%)
Hyperactive type	8 (26.67%)	12 (38.7%)
Combined type	5 (16.67%)	3 (9.67%)

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Table 2. Comparison of the study measures between the intervention group and the control group

Outcome Measures	t	P
RPM	2.483	0.01
TMT Part A	3.238	0.02
TMT Part B	4.064	<0.001
Stroop test	3.507	0.001

P<0.05: significant; P<0.01: highly significant; P>0.05: not significant.

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Table 3. Comparison of the study measures within the intervention group

Variables	Mean±SD			
	RPM (Score)	TMT Part A (Duration in Sec)	TMT Part B (Duration in Sec)	Stroop Interference (Score)
Day 0	26.83±9.68	60.23±21.82	132.90±54.53	32.75±15.65
Day 15	33.40±7.82	49.27±26.29	92.63±43.51	22.10±14.03
Day 30	36.97±9.34	36.57±10.60	77.80±29.84	12.47±8.55
Mean difference (0-30 day)	10.13±9.39	23.67±17.83	55.10±39.15	20.28±12.09
F	9.826	9.864	12.707	18.003
P	<0.001	<0.001	<0.001	<0.001

P<0.05: significant; P<0.01: highly significant; P>0.05: not significant.

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comparison showed that participants of the intervention group took lesser time to complete the TMT Part A relevant to the control group yielding significant results (t=3.238, P=0.02). Similar to the TMT Part A, significant results were observed for the TMT Part B in the intervention group (F=12.707, P=0.000) as compared with the control group (F=0.639, P=0.530). Further, statistically significant differences were detected between the intervention and control groups (t=4.064; P=0.000) for the TMT Part B. As for the interference measured by the Stroop test, both groups showed significant results in the within-group analysis (intervention group: F=18.003, P=0.001; control group: F=5.733, P=0.003). However, the 2-tailed t test showed a statistically significant difference in the Stroop Interference of both groups, with the intervention group performing better than the control group (t=3.507; P=0.001). Table 2 provides the between-group comparison of the study measures. Table

Table 4. Comparison of the study measures within the control group

Variables	Mean±SD			
	RPM (Score)	TMT Part A (Duration in Sec)	TMT Part B (Duration in Sec)	Stroop Interference (Score)
Day 0	30.77±11.49	54.71±23.01	112.35±54.77	26.77±15.21
Day 15	34.48±11.77	48.42±22.07	105.19±50.97	17.84±10.94
Day 30	35.19±10.21	46.06±20.66	98.87±32.03	16.53±10.66
Mean difference (0-30 day)	4.42±8.57	8.65±18.39	13.48±40.77	10.24±10.22
F	1.398	1.287	0.639	5.733
P	0.252	0.281	0.530	0.003

P<0.05: significant; P<0.01: highly significant; P>0.05: not significant.

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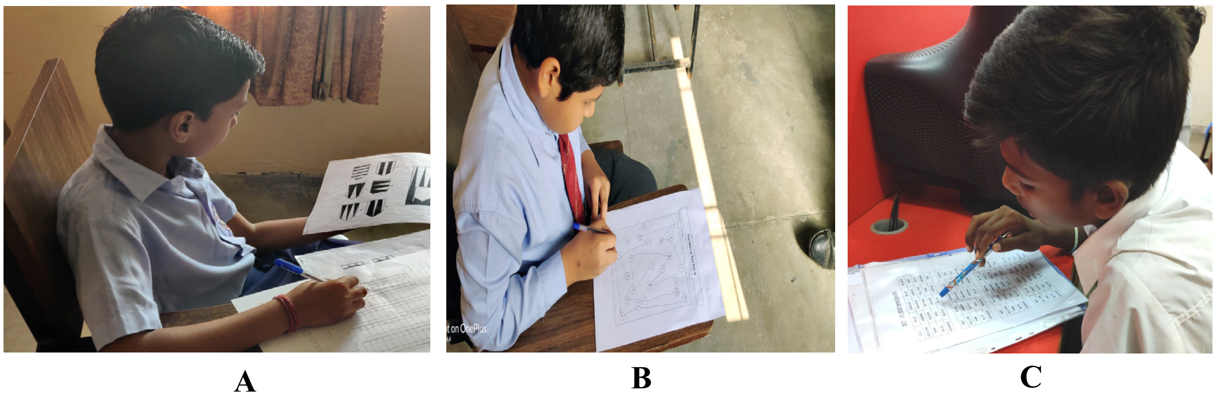

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Figure 7. Administration of A) the raven progressive matrices, b) the trail making test, and c) the stroop test

3 and Table 4 provide the within-group comparison of the study measures for both groups.

Discussion

Several executive function components are impaired in children with ADHD, including attention, cognitive flexibility, non-verbal reasoning, and response inhibition [21]. The present study was conducted to observe the effectiveness of tDCS along with video games in comparison with video games alone on executive functions in children with ADHD. We used tDCS and video games as interventions to improve executive function components in children with ADHD. The intervention group received tDCS as well as a video game while the control group only received a video game as an intervention. Our results indicate that children who received tDCS and video games performed better than the control group on executive function tests. The results of the present study indicated a significant improvement in RPM scores, time taken to complete TMT Part A and Part B, and the Stroop interference of the intervention group relative to the control group.

Cognitive training can aid in ameliorating executive function deficits, including non-verbal reasoning, visuospatial recall, and verbal working memory in children with ADHD with the effects persisting for a period as long as 6 months. Further, intense training aids in improving function by enhancing neural plasticity as opposed to the prior belief that working memory is a heritable component and remains impervious to training [22]. Previous studies demonstrate that individuals with ADHD have cognitive impairments, such as deficits in working memory, non-verbal reasoning, cognitive flexibility, and inhibitory control, which are linked to the compromised function of the frontal lobe [23]. The present study involved the stimulation of DLPFC and OFC which augmented the non-verbal reasoning as assessed by RPM in participants of the intervention group relative to the control group. According to Sotnikova et al. (2017), a single session of anodal tDCS for 20 min causes an increase in neuronal connectivity and activation under the stimulated area as well as other remote areas of the brain. Thus, tDCS has an immediate effect on non-verbal reasoning as revealed by the increase in scores of RPM in the present study.

The results of the current study for improving attention and cognitive flexibility are in line with the existing literature. The working memory, including the ability to transiently retain information, manipulate it, and relate it to new information, is affected in ADHD. The working memory is regulated by the frontal as well as parietal lobe functioning. It can be improved by stimulating these areas and working memory-based training interventions [24]. Our results are in accordance with Bandeira et al., 2016, who conducted a pilot study to see the effect of 5 sessions of tDCS applied on the left DLPFC with an intensity of 2 mA. They reported that tDCS stimulation heightens the ability to switch between tasks, and improved the detection of stimulus as well as processing speed in children with ADHD [9]. Thus, tDCS is efficacious in inducing short-term changes in attention and cognitive flexibility as evident in the results of the present study.

Inhibitory control is the frequently affected component of the executive function in both children as well adults with ADHD owing to the decreased prefrontal cortex activation. This prevents the individual from responding to distracting stimuli and often leads to socially inconvenient behavior manifestations [19]. Our findings match those of Breitling et al., (2016) who compared anodal, cathodal and sham tDCS stimulation in children with ADHD. It was reported that anodal stimulation was better in improving interference control relative to that cathodal and sham stimulation. It is noteworthy that tDCS modulates the activity of prefrontal cortex regions, including DLPFC and OFC, and can enhance performance on various executive function tasks.

The results of our study can be explained by understanding the physiological mechanism of tDCS. tDCS modulates neural plasticity by altering cortical excitability of the underlying cortex and produces an excitatory or inhibitory effect depending on the electrode placement. The effect on working memory is because of the amplification of the underlying oscillatory activity of the brain in alpha and theta bands after the application of anodal tDCS [24]. The application of anodal tDCS on the left DLPFC increases the excitability of the prefrontal cortex, which aids in improving attention [9]. Cosmo et al., (2015) showed that anodal tDCS applied at F3 at 1.0 mA intensity given for 20 min, similar to the stimulation parameters of the present study, is effective in enhancing attention. Furthermore, DLPFC-OFC interactions are beneficial in augmenting attention, cognitive flexibility, and set-shifting abilities. Anodal tDCS acts by increased activation of the DLPFC while cathodal montage works indirectly by facilitating disconnection from one task and promoting engagement in another task, thereby enhancing set-shifting abilities [25]. Our study expands the understanding of tDCS as an effective intervention to improve non-verbal reasoning, attention, interference, and cognitive flexibility in children with ADHD.

Study limitations

There were several limitations to our study. We had a small sample size with an age limit of 10 to 16 years. The diagnosis of ADHD was made using the NICHQ Vanderbilt assessment scale; further, it was not confirmed by a child psychologist/psychiatrist, which could have increased the possibility of a false diagnosis. The absence of a sham stimulation in the control group is another limitation that might have affected our findings. The participants of the current study included only school children from an urban background which also limited the scope of our study. In addition, various factors such as the duration of playing video games at home and learning effects could not be controlled during the study. Further, because of the short duration of intervention, the long-term effects of tDCS could not be studied. There was no record maintained for the adverse effects of tDCS during the study. In addition to these shortcomings, gender-based comparisons could not be made owing to the relatively lesser number of female participants. Thus, it is difficult to draw inferences and generalize the findings for both genders. However, these limitations give opportunity for improvement and provide scope for further research.

Conclusion

The present study concluded that participants who received tDCS and video games as intervention had significantly greater improvement in executive function compared to the participants who only received video games as the intervention. There was an improvement observed in both groups after the intervention; however, the intervention group had more significant results relative to the control group. Therefore, tDCS is an effective intervention compared to video games alone to improve non-verbal reasoning, cognitive flexibility, attention, and interference in children with ADHD.

Ethical Considerations

Compliance with ethical guidelines

The present study was ethically approved by the Institutional Ethics Committee of Punjabi University, Patiala (Ref No.: 147/IEC-2019). Prior to the commencement of the study, each participant was given information about the study and verbal assent was taken from them. Written informed consent was offered by the parents for their child's participation in the study.

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declare no conflict of interests.

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