Int J Ment Health Addiction (2017) 15:100–109
DOI 10.1007/s11469-015-9621-7

Neurofeedback Associated with Neurocognitive-Rehabilitation Training on Children with Attention-Deficit/Hyperactivity Disorder (ADHD)

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Published online: 23 December 2015

Abstract Neurofeedback is a computer-based behavior training gaining increasing interest in the treatment of children with attention-deficit hyperactivity disorder (ADHD), but is not a complete therapy for these patients. To meet the need for a more integrative approach, this study used neurofeedback with cognitive rehabilitation therapy as a more comprehensive approach for children with ADHD. Thirty children (females) were selected randomly from visitors of 5 clinics in Tehran city. Subjects were placed into 2 experimental groups and 1 control group. Groups were matched based on age, gender and socioeconomic status. One experimental group solely received neurofeedback in 10 sessions, the other experimental group received neurofeedback with cognitive rehabilitation therapy, and the control group left therapy received no therapy or left in the initial stages of therapy. Integrated visual and auditory test (IVA) was used pre-test and post-test to measure attention and impulsivity in children with ADHD, in addition to Neurocognitive Joyful Attentive Training Intervention (NEJATI). Data was analyzed using dependent *T*-test and analysis of covariance (ANCOVA). There are meaningful differences between all groups in attention and impulsivity factors. The group who received neurofeedback with cognitive rehabilitation therapy showed more improvement in attention and impulsivity factors compared to the group who received only

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neurofeedback and the control group with no treatment. There was also a significant difference between the solely neurofeedback group and control group in the attention factor. Neurofeedback is a facilitator therapy to improve the attention factor in children with ADHD, but is not a complete therapy due to its lack of support in performance factors. A complementary therapy such as cognitive rehabilitation therapy that focuses more on performance factors would be a more effective therapy as it leads to more positive effects on impulsivity and hyperactivity.

Keywords Neurofeedback · ADHD · Cognitive rehabilitation · Neurocognitive joyful attentive training intervention (NEJATI)

Attention deficit and hyperactivity disorder (ADHD) is a pervasive developmental disorder. The main symptoms of ADHD include deficits in attention, hyperactivity. and impulsiveness. ADHD can often include executive function disorder (Biederman et al. 2004; Steiner et al. 2014). ADHD can cause significant impairment in the child development process causing poor academic performance and physical and verbal aggression (LeFever et al. 2002). There are different neuropsychological models in order to explain defects in self-regulation underlying these symptoms, such as deficits in neuropsychological resources (Sergeant 2005), maladjustment of interacting neuron networks (Sonuga-Barke and Castellanos 2007), and reward deficiency syndrome (Blum et al. 2008). Because ADHD has serious developmental implications in the short and long term that encompass problems in deferent aspect of life including social, academic and quality of life (Barkley et al. 2006), treatment should begin early in childhood (Gevensleben et al. 2012).

Although general treatment such as medication or behavior therapy are considered strong and suitable treatments for ADHD children, general treatments have fundamental limitations. Medication, as primary treatment of ADHD (Lansbergen et al. 2011), often improves symptoms; however, medication does not succeed completely at suppressing symptoms and is only effective in 13.2 to 64 % long-term medication therapy cases (Adler and Nierenberg 2010; Steiner et al. 2011). Once medication therapy is terminated, the symptoms often re-emerge. In addition, stimulating drugs have no impact on 20–30 % of children. Moreover, after terminating medication therapy, significant side effects will occur including insomnia, decreased appetite (Charach et al. 2004, 2006) and preventing child development (Faraone et al. 2008). Parents often do not prefer medication therapy due these limitations.

Some treatments with experimental evidences in ADHD treatment include training for parents and behavioral interventions in school (Chronis et al. 2006; Fabiano et al. 2009). Other interventions such as academic interventions and summer treatment plans (Chronis et al. 2004) and programs that combine parents' training and training social skills are promising in treating children with ADHD. However, psychological treatments are not as effective as medication therapy, due to the difficulty of generalizing psychological therapies across varying contexts (Farmer et al. 2002).

With limitations of current treatments, the importance of alternative treatment options that can be applied in school settings remains an important issue. One possible alternative is Computer-based attention training (CompAt). CompAt is based on brain flexibility and conditional agent theories and is designed to improve core and critical skills that commonly have defects in ADHD children. Two main types of CompAt are Neurofeedback (NF) and Cognitive training (CT) (Steiner et al. 2011).

Neurofeedback has promising results for people with ADHD with less side effects than previous treatments (Arns et al. 2009). Obtained findings of EEG in ADHD children have shown increased theta wave activity as well as increasing theta ratio to beta in the frontal cortex. Therefore, neurofeedback can be applied in increasing beta waves (a situation requiring attention) and decreasing theta (θ) waves in children with ADHD. With these specific brain waves patterns, neurofeedback provides immediate feedback of how people concentrate.

Any change in brain wave patterns are illustrated on a computer screen through the movement of characters and figures with auditory feedback. By practicing, individuals learn to change their brain waves in achieving a target and enhancing attention (Sherlin et al. 2011). Indeed, the individual in treatment learns to control underlying processes of these brain waves to improve cognitive, emotional and self-regulate their behavior (Meisel et al. 2014).

Previous studies have demonstrated the application of neurofeedback treatment on children with ADHD (Arns et al. 2009). Meisel et al. (2014) studied the effect of neurofeedback and medication therapy on ADHD children by investigating the results based on parent and teachers reports. Both groups presented satisfactory results in a 6 month follow-up showing improved ADHD symptoms. However, the experimental group that received neurofeedback treatment showed more fundamental improvement in academic performance. This research is considered as the first controlled study in the next 6-month follow-up on ADHD with non-pharmacologic treatment, showing the impact of neurofeedback.

Cognitive training applies frequent computer feedback to enhance correct responses beside training attention, working memory and reducing impulsiveness. Studies show that cognitive interventions and effective training will improve working memory. Further, cognitive therapy reduces the amount of disorder symptoms reported by parents and teachers (Klingberg et al. 2005). Practicing working memory also contains improvement in various areas including improving mathematic problem solving and reading comprehension (Shalev et al. 2007).

Gevensleben et al. (2009) combined neurofeedback with cognitive training and found that both teachers and parents reported more improvements in ADHD symptoms. However, due to sample heterogeneity, the study was not generalizable to the larger population (Gevensleben et al. 2009). In another study, Steiner et al. (2014) compared neurofeedback with cognitive training. Children in the neurofeedback group offered better results compared to the cognitive training group and control group. The results in this study were also investigated in terms of teachers and parents reports. No previous studies combined neurofeedback and cognitive rehabilitation and investigated the integrated impact of these two issues (Steiner et al. 2014).

Studies show that executive parts of working memory are one of the challenging functions children with ADHD (Rapport et al. 2008). There are two opinions in the cognitive framework. Barkley et al. (2006) believed that failure in response inhibition is the main cause of this disorder, which may lead to damaging working memory and other executive functions (Barkley 2014). In contrast, Rapport et al. (2008) believed that ADHD is caused by early failure in working memory leading to executive functions' defects (Rapport et al. 2008).

As it is presented, both approaches represent working memory defects in this ADHD. Working memory is a set of cognitive processes to maintain and manipulate different information of daily routines. Some of these daily routines include rehearsal, retrieval, manipulation and controlled attention (Mashhadi et al. 2011). Applying an approach that improves working memory can lead to improving the symptoms of attention deficit and hyperactivity. Neurocognitive Joyful Attentive Training Intervention (NEJATI) is one program that can rehabilitate working memory.

NEJATI, designed by Nejati (2013a), is a software program designed to rehabilitate maintenance, transfer, update and inhibit information abilities. The program's effectiveness on working memory is shown in research. NEJATI uses a group of organized hierarchical tasks enhancing several aspects of working memory, including maintenance, transferring, updating and inhibiting information. The fundamental principle of this program is as follows:

1. Tasks are hierarchically organized and become more difficult based on user response beyond sessions.
2. Performing tasks correctly will be immediately rewarded; rewards are gradually offered in longer delays.
3. Tasks were designed based on various functions of working memory including updating, transferring and inhibition.
4. Tasks are fun and presented with motivational stimulators to enhance patient's motivation.
5. Tasks may be retrieved until the patient reaches the desired level.
6. Developing the program depends on patient efficacy; and, the therapist is required to improve task level (Nejati et al. 2013a).

Therefore, considering the effect of this program on cognitive memory, it is assumed that it can also be effective as an alternative, supplementary treatment in improving attention deficiency disorder.

Nejati's (2013a) study investigates a more complete treatment in improving attention deficiency and hyperactivity by concentrating on working memory executive functions to achieve more positive results in addition to neurofeedback, which has been proven to be effective in previous studies. The current study seeks to compare the effect of neurofeedback as the only treatment and neurofeedback with cognitive rehabilitation. The authors hypothesize that neurofeedback will be effective alone, but integration with cognitive rehabilitation and training will lead to better results for children with ADHD.

Methods

This study followed an experimental research design with pre-test and post-test in comparison to the control group. Three experimental groups were randomly selected from children (females) referred to 5 clinics of Tehran city Participants were 85 children with symptoms of ADHD based on DSM-V criteria. Of these children, 45 individuals were randomly assigned into three (15 individuals) groups. Subjects of the first experimental group solely received neurofeedback, whereas the second experimental group received a combination of neurofeedback and cognitive rehabilitation. The control group received no treatment. All children were homogenized in all aspects. The age range was within 5 to 7 years old from the same economic level. Moreover, the subjects all had no history of ADHD treatment including medication and non-medication treatment in order to avoid affecting the present study's results.

Initially, the subjects were tested as a pre-test by IVA+plus to measure their impulsion and attentions' basic rate. Following IVA+plus, two experimental groups received ten treatment sessions according to protocol and the determined timing. Finally, a post-test IVA+plus was done in order to measure changes during treatments. Cognitive training program or cognitive rehabilitation in the combined group was done one day after IVA+ plus followed by neurofeedback.

Design and Procedure

Neurofeedback training was conducted using Atlantis II 2 × 2 equipment from Brainmaster. This equipment uses an impedance check (below 5 k) and controls artifacts automatically (>120 V). The EEG was analyzed in two frequency bands (theta: 4–7 Hz, beta: 15–20 Hz). The training was presented to the child as a computer game (puzzles, races, Pac-man, etc.), in which they had to concentrate to win the games. Specifically, children were instructed by the trainer to develop and use the strategy that best helped them to win points in the game. The children received visual and auditory reinforcement contingent on their success in controlling microvolts of theta and/or beta.

Joyful computer based tasks were presented to participants. These tasks were graded and increased in level of difficulty based on the responses of the child. Grading of tasks was based on amount of flanker stimuli, velocity of stimuli presenting, number of goal stimuli and changing task rule. For example, in one of these tasks, the user arranges faces in different categorizes based on three properties: emotional status (sad, angry and neutral), hair color (green, white and black) and skin color (yellow, white and black). Each face has one property from each categories; the participant should act only based on presented rule. In each set of tasks, the child should inhibit two properties of the face and act based on one property. The cognitive demand of this task is inhibition of unrelated properties of stimuli and selective attention to these stimuli (Nejati et al. 2013b).

Tools

IVA+PLUS test: this is a continuous auditory-visual 13-min test evaluating two main factors such as impulsion response control and attention. IVA+PLUS test is formulated by relying on the statistical and diagnostic manuals of mental disorders DSM-IV, which distinguishes different types of ADHD including the attention deficit type, hyperactivity type (impulsion), combined type as well as unknown NOS type. Moreover, this test was used to study difficulties and other disorders such as self-inhibitory problems related to head traumas, sleep disorders, anxiety, learning disorders, dementia, and other medical problems. This test was applied for children older than 6 years old and adults and required 20 min to complete. The tasks involved responding, or not responding to 500 test stimuli. Each stimulus was only provided in 1.5 s, thus required careful attention. IVA+PLUS test consists of 6 total scales and 22 subscales classified in to 5 groups: response inhibition, attention, attribution, indicator, and delicate movements. However, this study solely considers the scores of two response and attention scales.

Results

A one-way between groups covariance analysis was completed to compare the effectiveness of two different interventions of participants' response inhibition and attention scales. Intervention type (neurofeedback and neurofeedback with cognitive rehabilitation treatment) was the independent variable with the dependent variable consisting of two subscales of the IVA+PLUS test. Participants' scores of two response inhibition and attention subscales before intervention were used as covariance in this analysis Table 1.

Table 1 Covariance for therapy effects on 2 subscales of IVA+PLUS test (compulsivity and attention) before therapy

Variable source	ss	df	Ms	*f*-ratio
Covariance (impulsive scores before therapy)	143.403	1	143.403	0.538**
Main effect of therapy	51.648	2	25.824	** 8.167
Residual error	123.322	39	3.162	
Covariance (attention scores before therapy)	138.496	1	138.496	39.697**
Main effect of therapy	48.174	2	24.087	6.904**
Residual error	136.064	39	3.489	

Preliminary analyses were done to ensure that normality, linearity, variance homogeneity, regression slope homogeneity and the reliability of covariance hypotheses were not violated Tables 2, 3, 4, and 5.

Followed by correcting pre-intervention scores, there was a significant difference among three groups (two under intervention groups and one control group) response inhibition subscale, $f(2, 39) = 8.167$, $p = 0.001$, Partial Eta Squared 0.29.

Moreover, there also a significant difference among the three groups (two under intervention groups and one control group) in attention subscale followed by correcting pre-intervention scores, $f(2,39) = 6.904$, $p = 0.003$, Partial Eta Squared 0.26. Eta squared statistics in both subscales (0.29 and 0.26) showed a large effect and determined that there is a strong relation between pre-intervention and post-intervention scores in the two IVA+PLUS test subscales (response inhibition and attention). In addition, as data shown in Tables 6 and 7, the group received neurofeedback with cognitive rehabilitation displayed more improvement compared to the other group in two attention and impulsion factors.

Discussion

The goal of this research was to create a more enriched and integrated protocol to successfully treat attention deficit and hyperactivity disorder in children. Based on the obtained results, the neurofeedback group and neurofeedback integrated with cognitive training showed better results in comparison to the control group. This result indicated that the neurofeedback has an effective impact in treating children with ADHD disorder. This finding is consistent with previous studies such as Gevensleben et al. (2009), Ahmadlou et al. (2012); (Gevensleben et al. 2009; Ahmadlou et al. 2012; Maurizio

Table 2 Mean and standard deviation scores in attention scale

Group	Mean	Standard deviation	Number of subjects
1. Neurofeedback & rehabilitation	93.06	1.751	15
2. Neurofeedback	75.11	2.892	15
3. Control	74.85	14.693	15
Total	81.10	12.539	45

Table 3 Mean and standard deviation scores of impulsivity scale, after therapy

Group	Mean	Standard deviation	Number of subjects
1. Neurofeedback & rehabilitation	93.12	1.463	15
2. Neurofeedback	74.21	2.927	15
3. Control	74.93	15.763	15
Total	80.97	12.505	45

et al. 2014). The purpose of neurofeedback seeks to change brain waves with cortex self-regulation where people learn how to focus on a current task. In addition, neurofeedback concentrates on generalizing the focus shown in treatment to other situations outside the treatment environment, allowing children to show better results in attention in their daily lives.

The combined group of neurofeedback and cognitive rehabilitation provided better results when compared to the sole neurofeedback experimental group and control group. In preceding research, applying the cognitive training method was not practical. Hence, only some executive areas of the brain were enabled (Steiner et al. 2014; Heinrich et al. 2007). This research used cognitive rehabilitation program, which focuses on working memory and executive processes subsets. Thus, improving this part of memory is will aid children with ADHD.

As mentioned, in theta/beta treatment with neurofeedback, children learn to decrease theta activity (4–8 HZ), and increase Beta activity in neurofeedback, which indicates a neurophysiological defect in children with ADHD. Regardless of this possible defect, neurofeedback is considered as a method to improve cognition and attention (Klingberg et al. 2005).

While neurofeedback influences brain waves and enhances concentration, cognitive rehabilitation works on cognitive processes involving in keeping attention on information and improves controlling. In fact, one of the difficulties children with ADHD face is concentrating on an issue and resisting distractions. Since response control and inhibition are difficult areas for children with ADHD, impulsion symptoms are manifested. Rehabilitation influences impulsion symptoms, and therefore shows better results in response inhibition in children with ADHD.

Goals of ADHD interventions are complicated, which can be a challenge to detect the impact of goals on symptoms. For example, one treatment can be useful for a symptom that leads to improve quality of daily life, but there may not be a questionnaire to measure the symptom (Steiner et al. 2014). In the current study, there was short interval between treatment sessions. For some children, however, it may better to consider more sessions with longer interval between sessions, which may lead to stability and more self-regulation as children can transfer strategies learned from sessions to daily life more

Table 4 Weighted MEAN OF 3 situation of experiments on impulsivity subscale

Groups	Mean	Standard deviation	Confidence level 95 %	
			Low limit	Up limit
1. Neurofeedback & rehabilitation	91.619	1.410	88.767	94.472
2. Neurofeedback	81.859	1.689	78.443	85.275
3. Control	69.689	0.486	68.706	70.671

Table 5 Weighted mean of 3 situation of experiments on impulsivity subscale

Groups	Mean	Standard deviation	Confidence level 95 %	
			Low limit	Up limit
1. Neurofeedback & rehabilitation	91.606	1.521	88.530	94.682
2. Neurofeedback	81.846	1.771	78.264	85.427
3. Control	69.668	0.511	68.635	70.700

easily. Future studies should explore applying similar methods that are common in conventional cognitive behavior therapy in children with ADHD (Fabiano et al. 2009),

Limitations

The goals of ADHD interventions are complex, which makes isolating the change required to improve symptoms challenging. Not achieving a certain result can be due to instrumentation. Therefore, neurofeedback and cognitive rehabilitation therapy can only be applied in the attention and impulsion areas of response inhibition of children with ADHD and not to other areas of response inhibition or other populations.

Another additional issue in the current study is sample size. In this study, the number of each group was finally reduced to ten people, as some limitations such as distance to sessions (ten sessions commuting was difficult for families). The small sample size makes it difficult to generalize the current findings to larger samples. It was also difficult not possible to control children's environmental and family events during intervention, which could have interacted with the child's outcome. Therefore, more studies are required to be carried out with larger samples, expanded tools according to family context (Derevensky et al. 2010).

Conclusion

Both experimental groups showed improvement in attention and response inhibition factors as compared to control group. The group that only received neurofeedback

Table 6 Multiple comparison of interacting between variables (3 groups) on attention subscale

I group	J group	Compare means (I-J) groups	Standard deviation	Significant level	Confidence level 95 %	
					Low limit	up limit
1	2	9.760*	2.334	.000	5.039	14.481
	3	21.938*	1.604	.000	18.693	25.183
2	1	−9.760*	2.334	.000	−14.481	−5.039
	3	12.178*	1.843	.000	8.451	15.906
3	1	−21.938*	1.604	.000	−25.183	−18.693
	2	−12.178*	1.843	.000	−15.906	−8.451

Groups: 1. Neurofeedback & rehabilitation 2. Neurofeedback 3. Control

Table 7 Multiple comparison of interacting between variables (3 groups) on impulsivity subscale

I group	J group	Compare means (I-J) groups	Standard deviation	Significant level	Confidence level 95 %	
					Low limit	up limit
1	2	11.753*	2.334	.000	5.039	14.481
	3	23.947*	1.604	.000	17.693	25.183
2	1	−8.662*	2.334	.000	−13.481	−5.039
	3	11.178*	1.843	.000	7.451	14.906
3	1	−22.838*	1.604	.000	−25.183	−17.693
	2	−11.185*	1.843	.000	−15.906	−7.451

Groups: 1. Neurofeedback & rehabilitation 2. Neurofeedback 3. Control

showed better results in IVA test by improving and increasing beta waves. In contrast, the group which received cognitive rehabilitation in addition to neurofeedback showed improvements in waves with working memory enhancement and also attained better scores in IVA, particularly in response inhibition factor.

This study demonstrated that the effect of neurofeedback on children with ADHD can be increased by using a supplementary treatment like cognitive rehabilitation as an alternative treatment that is more complete and no drug therapy risks. Moreover, this study approved the role of training-based computer treatments.

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