Title: The Effect of Neurofeedback Training on Aggression and Impulsivity in Children With Attention-Deficit/Hyperactivity Disorder: A Double-Blinded Randomized Controlled Trial

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Abstract

**Background and Objectives:** Aggression and impulsivity are some of the behavioral symptoms of Attention-Deficit/Hyperactivity Disorder (ADHD). Neurofeedback (NF) training has been suggested as a promising treatment in these children. The purpose of this study was to investigate the effect of NF training on aggression and impulsivity in schoolchildren with ADHD.

**Materials and Methods:** A total of forty male elementary schoolchildren with ADHD aged 11.17 ± 0.97 were randomized into NF and sham groups. The NF group received 12 NF training sessions each took about 60-min for 6 consecutive weeks (twice a week), based on the Hammond protocol. The subjects' parents were questioned to evaluate the outcomes including aggression and impulsivity using the Buss-Perry Aggression Questionnaire (BPAQ) and Barratt Impulsiveness Scale (BIS), respectively.

**Results:** After the intervention in the NF group, the BPAQ score changed from 87.60 ± 9.33 to 81 ± 7.23 and the BIS score from 94.7 ± 7.25 to 88.05 ± 5.4, which were significant with p = 0.001. The results indicated the large effect size of NF on aggression and impulsivity in ADHD.

**Conclusion:** Our findings suggest NF training as a clinically applicable method for decreasing aggression and impulsivity, also support concurrent use of medication and NF training in children with ADHD.

**Keywords:** ADHD, Neurofeedback, Aggression, Impulsivity
1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) is one of the most common childhood developmental disorders with a prevalence of 3.4% worldwide and 3-5% in school-age children (American-Psychiatric-Association, 2013, Polanczyk et al., 2015). It includes a constant pattern of inattention, hyperactivity/impulsivity, or both, lasting for more than 6 months (American-Psychiatric-Association, 2013). In addition to core symptoms, aggression as emotional dysregulation and a destructive reaction is a comorbid symptom in ADHD (Harty et al., 2009). Aggression is affected by a wide range of factors consisted of psychological, genetic, and neural circuit deficits (Bornmann et al., 2007, Nelson and Trainor, 2007). Impulsivity as a component of aggression (Nelson and Trainor, 2007) also is defined as a tendency towards rapid and unconsidered reactions to internal and external stimulants without caring about the possible unwanted consequences (Sperry et al., 2016). Children with ADHD usually represent “impulsive aggression” which is harmful to the individual, social and public health (Saylor and Amann, 2016). There is a relationship between deficits in prefrontal and cingulate functional activity with impulsive aggression in ADHD (Puiu et al., 2018). Aggression and impulsivity affect the relationship of children, especially boys, with their friends (Zucchetti et al., 2015) and may even affect a child's academic achievement and future employment (Moore et al., 2015). It has been shown that impulsivity could even be associated with aggression in adults with ADHD and leading these people to antisocial outcomes (Comai et al., 2019). According to these, determining therapeutic approaches to reduce impulsivity and aggression in ADHD are important issues. Medical treatment is proven to decrease aggression similar to the core symptoms of ADHD (Connor et al., 2002); In addition to medical treatments that have side effects such as decreased appetite, dry mouth, excessive sweating, headache, and so on (Morton and Stockton, 2000), there are non-medical treatments to reduce aggression (Murphy et al., 2014). Among the non-medical treatments in ADHD, neurofeedback (NF) training is one of the behavioral therapeutic methods that is more efficient than other behavioral approaches such as cognitive-behavioral therapy (Abbasi et al., 2018, Khodabakhsh Pirkalani et al., 2019, Pendar et al., 2018, Shokhmgar et al., 2019). NF facilitates emotion regulation through operant conditioning and learned control (Enriquez-Gepper et al., 2017, Sherlin et al., 2011). In this painless noninvasive method, scalp sensors measure and record brain activity, and the patient is taught to self-regulate their dissonant brain waves into normal frequency and rhythm. The research is shown an increase in theta potency as the prominent profile in electroencephalography (EEG) of children with ADHD (Chabot and Serfontein, 1996), and a recent study by Bridges (2018) indicated that theta and beta waves are correlated with impulsivity/hyperactivity in these children. These findings suggest that suppression of theta...
and enhancement of beta waves in these children could normalize their EEG and decrease the symptoms such as aggression and impulsivity.

Many studies have demonstrated the effect of NF on core symptoms of ADHD, especially on impulsivity (Moriyama et al., 2012, Gevensleben et al., 2010, Duric et al., 2012, Arns et al., 2014). The meta-analysis of Micoulaud-Franchi et al. (2014), Arns, De Ridder, Strehl, Breteler, and Coenen (2009) on randomized controlled trials, and Bakhshayesh, Hänsch, Wyschkon, Rezai, and Esser’s (2011) study showed that the effect of NF training on impulsivity was less than inattention. Although, van Dongen-Boomsma, Vollebregt, Slaats-Willemse, and Buitelaar (2013) found that NF did not affect any of the ADHD symptoms. Some studies also have revealed that NF has a positive effect on externalizing behaviors such as aggression. In Konicar et al.’s (2015) study, NF training improved severe psychopathic offenders on the behavioral and neurophysiological level; they discussed that there is a relationship between learned control of the brain and factors that cause aggression. Shanshan and Zichao (2017) indicated that expressive aggression of children with dyslexia decreased resulting from NF and Walker (2013) showed the efficacy of NF on aggression in children and adults with the chief complaint of anger. Only one research was found that NF training has a significant effect in reducing the aggression of children with attention-deficit hyperactivity disorder (Kazerani et al., 2016). Eliminating or reducing negative behavioral traits, which are clinically challenging and mostly associated with schoolchildren with ADHD, is one of the important goals of treatment (Wilens and Spencer, 2010). The high prevalence of this disorder necessitates a reconsideration of therapeutic methods to help these children. Based on previous studies, in which the effectiveness of NF training as a modern treatment method on behavior has been approved, it has been assumed that its functions in children with ADHD can be evaluated as a non-invasive and safe therapeutic method (Moreno-García et al., 2015). As reviewed, studies on the therapeutic effect of NF on impulsivity in ADHD have been controversial and there is still a need for further research (Gevensleben et al., 2012, Lofthouse et al., 2012). The effect of NF on aggression as a consequence of impulsivity has not been sufficiently studied in ADHD. Also, an efficient and reliable clinical protocol for these symptoms is still in question (Yadollahpour et al., 2015). Therefore, the purpose of the present study was to find out whether NF training is effective on both aggression and impulsivity in a sample of schoolchildren with ADHD based on the Hammond Protocol. Given that physical aggression as an outcome of impulsivity is more prevalent in boys than girls (Björkqvist, 2018) and boys with ADHD due to aggression are susceptible to oppositional defiant disorder (ODD) and conduct disorder (CD) (Fadus et al., 2020), this study was done on boys with ADHD.
2. Materials and Methods

2.1. Trial design

In this double-blinded randomized sham group-controlled trial, subjects were selected by convenience sampling using the random-number table and randomly assigned to the intervention (n = 20) and sham (n = 20) groups. The ethical approval number 951342 was obtained from Mashhad University of Medical Sciences. The study was registered at the Iranian Registry for Clinical Trials (IRCT20160717028964N2). The subjects’ parents signed written informed consent with the children’s assent.

2.2. Participants and settings

Forty male elementary school children with ADHD were selected from five Consulting Centers in Pak-dasht (Tehran province, Iran) during 2015–2017. The disposition of the sample is presented in Figure 1. The sample size determination method was calculated with 90% power based on the study of Ghadampour et al. (2018) which had the closest intervention method to the present study (Ghadampour et al., 2018). Considering α = 0.05 and β = 0.1, the sample size was estimated to be 16.64 children in each group, which was considered to ensure the sample size for each group of 20 children. The inclusion criteria were: the diagnosis of ADHD using The Swanson, Nolan, and Pelham IV scale (SNAP-IV; Parent and Teacher Forms) and the report of a child psychiatrist based on DSM-5 (Diagnostic and Statistical Manual of Mental Disorders, 5th edition) criteria; An IQ ≥ 90 in Raven's progressive matrices test; studying at public elementary schools; no history of cerebral trauma/injuries, learning disability and behavioral disorders; taking a stable dose of psychostimulant under supervision of a child psychiatrist; no history of receiving any other types of non-medical therapies; the literacy and mental health of parents (Based on a score less than 7 on the General Health Questionnaire (GHQ-28)) for answering questions of the measurements. Exclusion criteria included absenteeism for more than two sessions, cancellation of cooperation, and receiving treatment and other interventions.

(Figure 1)
2. 3. Intervention

Each student in the experimental group underwent 12 NF training sessions each took about 60-min for 6 consecutive weeks (twice a week). A 5-channel ProComp 5 NF system (Canada) with Hammond protocol (a beta/theta NF treatment protocol with reduction at 4-7 Hz and increment at 15-18 Hz in Q1 and Q2) was used (Sterman and Egner, 2006). The active, reference, and ground electrodes were placed on Q1, Q2, and right ear, respectively. After a brief demonstration trial, an animation was presented to the subject. Diversion of brain waves from the intended goal resulted in the suspension of the animation. The subject had to regulate their brain waves in the right targeted direction to restart the animation. Each subject was allowed to select their desired animation. The brain practices what is needed to achieve the animation goal through the repetition of training; that it results in the regulation of brain waves and hence treatment. The sham group received no treatment and watched animations that had no therapeutic potency. They waited to receive NF training sessions after the study. NF sessions were performed by two non-blinded neuro therapists; Moreover, The participants were blinded to the study design and group allocation.

2. 4. Instruments

The Raven's progressive matrices test was used to assess IQ as an inclusion criterion. This test consists of sixty matrices that form a logical sequence and are arranged with an increasing degree of difficulty. The test has high validity and reliability in detecting general intelligence (Burke, 1985).

The Swanson, Nolan, and Pelham IV scale (SNAP-IV; Parent Form) was used to screen ADHD. The questionnaire is an 18-item scale. The first 9 questions examine inattentive behaviors, the second 9 questions examine hyperactivity/impulsivity symptoms, and all 18 questions identify the combined type of ADHD. Sadrolsadat, Hooshyari, Zamani, and Sadrolsadat (2007) reported a reliability coefficient of 0.82 based on the test-retest method, 0.90 based on Cronbach's alpha, and 0.76 based on the split-half method. They also confirmed the content validity of SNAP-IV.

The Buss-Perry Aggression Questionnaire (BPAQ) as an outcome measure in this study has 29 items rated using a five-point Likert scale of one to five (1 = strongly disagree to 5 = strongly agree). The higher score shows higher aggression. Buss & Perry (1992) reported the reliability of the questionnaire with Cronbach's alpha of 0.89 and stated that the questionnaire had good predictive validity. Samani (2008) reported the test-retest reliability of 0.78 for the Persian version of this scale.
The Barratt Impulsiveness Scale (BIS) was used as an outcome measure. The instrument has 30 items rated using a four-point Likert scale from one to four (1 = rarely or never up to 4 = almost always). The higher score demonstrates more impulsivity. Patton, Stanford, and Barratt (1995) have confirmed the convergent validity of the instrument and reported its reliability with Cronbach’s alpha of 0.83. The Persian version of this scale has been approved by Javid, Mohammadi, and Rahimi (2012), Cronbach’s alpha & test-retest reliability 0.81 and 0.77, respectively.

Participants accomplished the assessments, a senior occupational therapist, who was blinded in neurofeedback training, gathered the questionnaires and gave them to a senior biostatistician, who was also blinded to the study.

2.5. Statistical analysis

Data analysis was performed by using IBM SPSS Statistics version 19. The normal distribution of the data was investigated with the Kolmogorov–Smirnov test. Descriptive statistics consist of means ± standard deviation (SD) and relative frequencies for continuous and categorical data, respectively (Mehdizadeh et al., 2019). Multivariate analysis of covariance (MANCOVA) between the groups was used to test the statistical assumptions. The effect sizes were calculated based on the partial eta squared estimation. The values of .01, .06, and .14 were calculated as a small, medium, and large effects, respectively (Levine and Hullett, 2002, D’Amico et al., 2001). The significance level was defined as less than 0.01.

3. Results

The mean age of the subjects in the study was 11.17 ± 0.97 years. All subjects received methylphenidate. The baseline characteristics of the groups are shown in Table 1. The assumptions of MANCOVA were investigated. The Kolmogorov–Smirnov test proved the normal distribution of data (P = 0.200). Both M-Box (P = 0.115) and Levin tests for aggression (P = 0.807) and impulsivity (0.087) confirmed homogeneity of co-variances.

While no significant changes were seen in the pre-and post-test of aggression and impulsivity in the sham group, the NF group showed a significant decrease in both aggression and impulsivity in the post-test (P < 0.01) (Table 2; Figure 2).
According to the results in Table 3, the NF group had a significant effect on the post-test scores which considering eta squares, 60.2% of changes in aggression and 60.9% of changes in impulsivity were due to the effect of NF training. Therefore, in response to the research question on the effect of NF on aggression and impulsivity, it can be considered that this method significantly reduced both aggression ($F = 54.395; P = 0.001$) and impulsivity ($F = 56.047; P = 0.001$) variables in elementary male students with ADHD. As a total result, NF training was effective in reducing aggression and impulsivity with a large effect size.

(Table 3)

4. Discussion

In this study, the efficacy of NF training was evaluated on decreasing the impulsivity and aggression of male schoolchildren with ADHD. Our findings revealed that this intervention can significantly decrease both aggression and impulsivity.

Findings of reducing impulsivity as a result of NF training are consistent with Micoulaud-Franchi et al. (2014), Arns et al. (2009), and Bakhshayesh et al.'s (2011) studies. By comparing our method with those mentioned, it was found that the number of NF sessions in the present study was less than the others. Given that one of the criteria for inclusion in the present study was receiving a psychostimulant, it seems that NF training in these conditions can lead to greater effects during fewer treatment sessions. In this regard, Zubener, Minder, Brandeis, and Drechsler (2018) found that methylphenidate increase learning in the NF sessions. Although, van Dongen-Boomsma et al. (2013) concluded, to the contrary, that NF did not affect the ADHD symptoms. In their study, not all samples received the drug, so that, more subjects in the control group ($3/4$) than the NF group ($1/2$) received methylphenidate (van Dongen-Boomsma et al., 2013). Perhaps this was a reason for the lack of impact of NF in their work. While in the current study, all subjects were treated with methylphenidate.

The previous studies on different samples showed that NF training is an effective therapeutic method for aggression as an unpleasant behavioral problem (Behboodi et al., 2015, Wilson, 2013, Yaghoobi, 2011, Walker, 2013, Shanshan and Zichao, 2017, Konicar et al., 2015). But a few studies are conducted about the effect of NF on aggression in children with ADHD. The results of the only study found in this case were consistent with the results of our study. Kazerani et al. (2016) approved improvement in aggression in children with ADHD resulting from NF training. There were some differences between their study and the present study. In their study, the number of sessions were 30 and the subjects received no medication. Based on
our findings and Zuberer et al.’s (2018) study, fewer NF sessions will need if children with ADHD receive methylphenidate.

It seems that the Hammond protocol could be useful for children with ADHD. Consistent with this, Bridges (2018) recommended that behavioral symptoms of ADHD were correlated with coherence values within beta and theta bands. Egner, Zech, and Gruzelier (2004) and Duric et al. (2012) confirmed that enhancement of beta (15-18 Hz) and suppression of theta (4-7 Hz) brain activity have a positive effect on children with ADHD. As an explanation, the effect of reduction or increase in the amplitude of brain waves (particularly 4-7 Hz and 15-18 Hz) can be noticed to improve higher mental functions. NF training facilitates autoregulatory mechanisms which play essential roles in its normal function (Demos, 2005, Saryghadi et al., 2019) and increase the ability to inhibit prepotent responses (Baumeister et al., 2018). These positive effects of NF can likely be attributed to the high relevance of neuronal oscillations for complex cognitive processes (Singer, 2018). In this regard, especially medial frontal theta oscillations have been demonstrated to reflect an important mechanism mediating cognitive control (Cavanagh and Frank, 2014). This training system persuades the brain to correct, modify, and maintain its optimal function through feedback on what has been done and how the normal bioelectrical rhythms have been worked during the last few seconds in an NF session; therefore, the brain is trained to enhance some and suppress some other waves. This practice for the brain eventually might alleviate aggression and impulsivity.

On the other hand in an NF session, based on the operant conditioning theory (Sherlin et al., 2011), when the change in the stimulus (amplitude of brain waves) will result in the predetermined favorable outcome (moving the animation or developing a voice) and learning (self-regulation) will happen. As a result of this process, a child with ADHD learns to change towards optimal behavior, which in turn reduces aggression and impulsivity.

As a study limitation, generalizing the findings of the study would be impossible as a result of the restricted sample size and follow-up deficiency, which was also a considerable hurdle in evaluating the consistency of findings. Making a comparison between NF training and other therapeutic methods like pharmaceutical and behavioral should be taken into account. Gender discrepancy may also elucidate more information.
Acknowledgments

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Conflict of Interest

The authors declared no conflicts of interest.
References


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Table 1. Demographic information of participants (n = 40)

Table 2. Descriptive statistics of the groups in pretest and posttest

Figure 2. Comparison between the pre-and post-test aggression and impulsivity scores in the groups (* P < 0.01)

Table 3. Results of the multivariate analysis of covariance between-subject effects
Figure 1. Participants flow
Table 1. Demographic information of participants (n = 40)

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<thead>
<tr>
<th></th>
<th>Neurofeedback group</th>
<th>Sham group</th>
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<td>Grade, n (%):</td>
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<td>Fifth</td>
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Table 2. Descriptive statistics of the groups in pretest and posttest

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<th>Posttest (Mean ± SD)</th>
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<td>94.85 ± 4.48</td>
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Figure 2. Comparison between the pre-and post-test aggression and impulsivity scores in the groups (* P < 0.01)
Table 3. Results of the multivariate analysis of covariance between-subject effects

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<th>Scale</th>
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