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Additive effects of neurofeedback on the treatment of ADHD: A randomized controlled study

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ABSTRACT

Neurofeedback (NF) has been identified as a “possibly efficacious” treatment in current evidence-based reviews; therefore, more research is needed to determine its effects. The current study examined the potential additive effect of NF for children diagnosed with ADHD beginning a medication trial first. Thirty-six children (6–12 years) with a DSM-IV-TR diagnosis of ADHD were randomly assigned to an NF with medication (NF condition) or a medication only condition. Children in the NF group attended 20 twice-weekly sessions. Outcome measures included individual cognitive performance scores (ADS, K-WISC-III), ADHD rating scores completed by their parents (ARS, CRS) and brainwave indices of left and right hemispheres before and after NF treatment. Significant additive treatment effect in any of the symptom variables was found and a reduction of theta waves in both the right and left hemispheres was recorded in NF condition participants. However our randomized controlled study could not demonstrate superior effects of combined NF on intelligent functioning compared to the medication treatment only. This study suggested any possible evidence of positive and additive treatment effects of NF on brainwaves and ADHD symptomatology.

1. Introduction

Attention deficit hyperactivity disorder (ADHD) is characterized by developmentally inappropriate levels of inattention, impulsivity and hyperactivity and is a common disorder in childhood. The prevalence rate of ADHD worldwide is 2%–9%, and the reported incidence rate of ADHD in the United States ranges from 2% to 20% for elementary school students, with a relatively high incidence rate of 3%–5% for children in the lower elementary school grades (Froehlich et al., 2007). Almost one-half of the children with ADHD exhibit these symptoms chronically, which may continue into adulthood (Holtmann and Stadler, 2006).

So far, the most successful and the most widely used treatment for ADHD is medication, though it has limitations and disadvantages, like side-effects, which has a robust effect in group data, with placebo-controlled effect sizes of 0.7 to 1.5 for methylphenidate and amphetamine (Arnold, 2004; Taylor et al., 2004). European clinical guidelines recommend a multimodal treatment, encompassing medication, cognitive behavioral and family treatments (Taylor et al., 2004). However, even when administered in a careful algorithm and combined with behavior modification, another established treatment for ADHD, 32% of children did not fully benefit from this presumed optimal combination treatment (Swanson et al., 2001). Furthermore, even for those with a good initial response, no study has been able to document the persisting benefit of medication beyond 2 years (Molina et al., 2009). In addition, an unknown percentage of families refuse to try the medications, even though their children might benefit, due to fears about possible side effects or addiction and dependence (Arnold et al., 2013). The 8-year follow-up of the Multimodal treatment Study of ADHD (MTA; 10) noted the disappointing long-term results of current treatments. Therefore, both new and alternative treatments are needed.

One alternative and complementary treatment for ADHD (Duric et al., 2014) is neurofeedback (NF). NF trains the brain by using operant conditioning principles based on real-time measurement and processing of electrical activity using scalp electrodes. It is a kind of behavioral therapy aimed at developing skills for self-regulation of cortical activity (Heinrich et al., 2007). The evidential foundation of NF for the treatment of ADHD is based on the theory that brain waves can be conditioned (Kamiya, 1968) and NF is aiming to normalize the EEG by improving cortical functioning

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(Butnik, 2005). Those with ADHD learns to enhance the EEG needed frequencies and suppress the unneeded ones in the form of a rewards system (Friel, 2007). This may affect the changes of attention or other neurocognitive processes.

In most studies which have performed uncontrolled and non-randomized studies, NF has been shown to provide benefits as an efficacious treatment for ADHD (Duric et al., 2014; Arnold et al., 2013; Bakhshayesh et al., 2011; Lansbergen et al., 2011; Meisel et al., 2013; Lofthouse et al., 2012; Arns et al., 2012; Gevensleben et al., 2009). The 2009 meta-analysis by Arns of 6 peer-reviewed published randomized trials of NF for ADHD found a large effect for inattention and medium effect for hyperactivity and impulsivity (Bakhshayesh et al., 2011). In a more recent review of 9 controlled RCTs that reported Effect Sizes (ESs), there was a medium between-groups mean for overall ADHD symptoms (Lofthouse et al., 2012). Significant improvements of ADHD symptoms over time after NF treatment were found in a double-blind placebo feedback-controlled design by Lansbergen et al. (Lansbergen et al., 2011). Randomized studies from Duric et al. and Meisel et al. found promising evidence of ADHD symptom improvements in treatment with NF (Duric et al., 2014; Meisel et al., 2013) and superiority of the combined NF treatment indicated clinical efficacy of NF in children with ADHD in comparison to those of attention skills training (AST) as a control condition (Gevensleben et al., 2009). Also study by Linden et al. found improved ADHD symptoms and IQ of NF group than normal group (Linden et al., 1996), the results from study by Monastra et al. have reported the improvement of behavioral problem and attention of NF group comparing medication group (Monastra et al., 2002). However, a systematic review and meta-analysis of randomized controlled trials (RCTs) of non-pharmacological interventions in children with ADHD reported no significant results for the blind rating of ADHD symptoms ($p = 0.07$) and did not find any beneficial effect of NF on neurocognitive functioning (Vollebregt et al., 2014; Sonuga-Barke et al., 2013). Better evidence for efficacy of NF is required with blinded assessments.

Several studies provide evidence for positive effects of NF treatment in children with ADHD (Evans et al., 2014; Arns et al., 2009; Duric et al., 2014), however the designed ones have shown absent, such as lack of mixed multiple intervention strategies or an adequate control group, the use of self-reported measures only, the absence of the report of changed brain waves, protocol differences. These shortcomings preclude unambiguous interpretation or generalization of the results (Moriyama et al., 2012; Holtmann et al., 2014; Lofthouse et al., 2012; Duric et al., 2014). More research is needed to determine the efficacy of this treatment. Therefore, the objective of the current study was to examine a possible additive effect of NF on cognitive functions, parental symptom reports, and brainwave activity before and after treatment for children diagnosed with ADHD beginning a medication trial.

2. Methods

2.1. Participants

Thirty-six children who were beginning a medication trial for ADHD (mean age 8.75 years, standard deviation [SD] = 2.12, 27 boys, 9 girls) were enrolled. Participating children were randomly assigned (1:1 assignment using random block sizes of 2), to either NF with medication (combined condition) or medication treatment (control condition) group. The diagnosis of ADHD was based on DSM-IV-TR criteria and determined by child and adolescent psychiatrists. Children were excluded if they (a) used medication for a condition other than ADHD, (b) had a comorbid disorder other than oppositional defiant disorder or anxiety disorder, (c) had a neurological disorder and/or cardiovascular disease, (d) participated in another clinical trial simultaneously, (e) had received NF in the past, or (f) had a full-scale IQ (FSIQ) of below 80. In addition to the diagnosis, the psychiatrist and psychologist performed pre- and post-NF clinical evaluations. All required institutional review board approved consent/assent forms were signed by the participants and a parent. Demographic data, which are collected by means of minimization, including grade, age, sex and diagnosis are presented in Table 1.

2.2. Neurofeedback protocol and data collection

NF training was conducted by an experienced clinical psychologist with extensive background in biofeedback training. Participants were seated in a comfortable armchair in a quiet room. NF protocol in this study was Beta/SMR training using visual feedback reward. During the NF session, brain activity was shown to the participant using visual and auditory feedback and game type was airplane. The ongoing EEG was band-pass filtered in the following four frequency ranges: theta (4–7 Hz), sensorimotor rhythm (SMR, 12–15 Hz), beta (15–18 Hz), and high beta (22–30 Hz). The goal of NF training was to increase the power in the SMR or beta bands ("reward bands") and simultaneously decrease the power in the theta and high beta bands ("inhibit bands"). All EEG signals and training parameters were measured using 3 electrodes; one active electrode was at the specific position of the C3 or C4 site, the second was a reference on the left or right ear, and the third was a ground on the right or left earlobe. All participants received 20 sessions, two times per week for 2.5 months using c3 and c4 placement. The target length of each session was all 60 min (25 min for each site) including break time. Rewards were given if participants could keep theta levels below threshold 70% of the treatment time and keep beta levels above the threshold 20% of the time. Depending on the participant's performance these reward thresholds were manually adjusted by the therapist.

Table 1
Demographic characteristics.

Descriptive characteristics	NF + M (*N* = 18)	M (*N* = 18)	Analysis T, χ^2 *p*-value
Grade (M and SD)	2.11 (0.32)	1.89 (0.47)	0.108
Age (M and SD)	8.72 (2.42)	8.78 (1.83)	0.939
Sex (N and%)			
Boys	16 (88.9)	11 (61.1)	0.121
Girls	2 (11.1)	7 (38.9)	
FSIQ (M and SD)	100.06(16.60)	100.72(12.06)	0.891
ADHD subtype (N and%)			
Combined	9 (50.0)	7 (38.9)	0.772
Inattentive	7 (38.9)	8 (44.4)	
Hyperactive/impulsive	2 (11.1)	3 (16.7)	

Note. M = mean, SD = standard deviation, N = Number, NF + M = Neurofeedback with medication condition; M = Medication condition. T = *t*-test, χ^2 = chi-square test, FSIQ = Full scale IQ.

2.3. Test materials

2.3.1. Korean-Wechsler intelligence scale for children-III (K-WISC-III)

The intelligence test developed by Wechsler was standardized into the K-WISC-III by Kwak et al. (2001). Professionally certified or trained clinical psychologists or professional practitioners in clinical psychology administered the intelligence test to the children. The K-WISC-III includes seven types of intelligence quotients (IQs): full scale intelligence (FSI), verbal intelligence (VI), performance intelligence (PI), verbal comprehension (VC), perceptual organization (PO), freedom from distractibility (FD), and perceptual speed (PS).

2.3.2. ADHD rating scale for parents (ARS)

The DSM-IV ADHD Rating Scale is a measure of behavior developed by DuPaul, and it is based on the diagnostic compliance of the DSM-IV. This scale is comprised of eighteen questions, which are based on the DSM-IV diagnostic criteria for ADHD. These questions are used to distinguish between the three subtypes of ADHD: the Predominantly Inattentive Type, Predominantly Hyperactive-Impulsive Type, and Combined Type (DuPaul and Eckert, 1997). The questions measure the severity of the child's problem behaviors using a 4-point Likert scale.

2.3.3. Conners behavior rating scale (CRS)

The abbreviated Conners Behavior Rating Scale is the most widely used behavior measurement for evaluating children with ADHD (Conners, 1970). This scale consists of 10 questions, which are rated by the parent or teacher on a 4-point Likert scale.

2.3.4. ADHD diagnostic system (ADS)

The ADS (Hong et al., 1999) is a computerized continuous performance task and developed to diagnosis ADHD in Korea. The response variables of the ADS include one target stimulus and two types of non-target stimuli presented over 15 min. The participants are instructed to respond to by pressing the space bar when the target stimulus appears on the computer screen. The interval between the stimuli is 2 s and the presentation time of the stimulus is 0.1 s. Basic variables are inattention (the number of omission errors, i.e., missed targets), impulsivity (the number of commission errors, i.e., responses to non-targets), reaction time (the mean response latency), and variability (the standard deviation of response times). The results are transformed into standard scores (T scores).

2.4. Statistical analysis

Treatment (pre- vs. post-treatment) and Condition (NF with medication vs. medication) were entered as within and between participants factors, respectively, in separate repeated-measures analyses of variance (ANOVA) for each dependent variable. The nature of main effects or interactions was further explored with post hoc *t*-tests using a Bonferroni correction of the alpha level for multiple tests. Effect sizes were calculated as Cohen's *d* (Cohen, 1988); that is, the difference of group means was divided by the root mean square of the two standard deviations. Power values were calculated for an alpha level of 0.05 for the observed mean difference and standard deviations for each pre- versus post-treatment comparison. All statistical analyses were conducted using the SPSS statistical program (SPSS 21.0; The Data Solution, Inc., Seoul, Republic of Korea). The significance level was set at $p = 0.05$.

3. Results

3.1. Changes in ratings on the ADS

The effects of both types of treatment on the four ADS subscales are shown in Table 2. For inattention, a main effect of treatment, $F(1, 34) = 9.93$, $p < 0.01$, was identified. There were no effects of Condition or Treatment × Condition interaction. Highly significant improvements on the inattentive scale were found for the NF with medication group, $t(17) = 3.36$, $p < 0.01$, Cohen's $d = 1.10$, power = 0.99, and medication only group, $t(17) = 0.59$, $p < 0.05$, Cohen's $d = 060$, power = 0.78, treatment. Similarly, there was a main effect of treatment for impulsivity, $F(1, 34) = 13.08$, $p < 0.01$, but no effect of Condition or Treatment × Condition interaction. Impulsivity was reduced in NF with medication participants, $t(17) = 2.68$, $p < 0.05$, Cohen's $d = 0.69$, power = 0.87, and medication only participants, $t(17) = 2.57$, $p < 0.05$, Cohen's $d = 0.54$, power = 0.71.

For response time, there were no effects of Condition or Treatment or Condition × Treatment interaction. Variability was observed in the main effect of treatment, $F(1, 34) = 11.18$, $p < 0.01$, but there were no effects of condition or interaction. Variability was improved in the NF with medication treatment group, $t(17) = 2.88$, $p < 0.05$, Cohen's $d = 0.54$, power = 0.71.

3.2. Changes in parent ratings on the ARS and CRS

To examine changes in the attentiveness and impulsivity of the NF condition and control condition groups, the before and after treatment ARS and the CRS were evaluated. The effects of both types of treatment on the ARS and CRS are shown in Table 3. For the ARS, an interaction of Treatment × Condition, $F(1, 34) = 4.19$, $p < 0.05$, was observed, but post hoc tests did yield significant effects at the Bonferroni-corrected alpha level. Inattentiveness was improved only in the NF with medication group, $t(17) = 2.91$, $p < 0.05$, Cohen's $d = 0.84$, power = 0.96. For the CRS, there were no effects of Condition, Treatment or Condition × Treatment interaction. Improved ratings by parents were found for the NF with

Table 2
Changes in ratings on the ADS.

Variable	Condition	Pre M(SD)	Post M(SD)	*t* test	ES	Power	Condition × Treatment *F*
Inattention	NF + M	78.39(30.67)	52.67(11.78)	3.36**	1.10	0.99	0.56
	M	107.22(83.03)	66.00(48.49)	2.14*	0.60	0.78	
Impulsivity	NF + M	79.39(36.21)	59.44(17.87)	2.68*	0.69	0.87	0.55
	M	72.72(27.22)	59.50(20.70)	2.57*	0.54	0.71	
Response time	NF + M	52.33(9.25)	47.33(11.24)	1.78	0.48	0.62	0.37
	M	53.61(14.36)	51.67(11.62)	0.47	0.14	0.14	
Variability	NF + M	85.61(38.25)	67.72(25.67)	2.88*	0.54	0.71	1.78
	M	74.11(29.25)	66.78(27.13)	1.50	0.25	0.26	

Note. ES = effect size (Cohen's *d*), NF + M = Neurofeedback with medication condition; M = Medication condition; Pre = Before treatment; Post = After treatment.
* $p < 0.05$.
** $p < 0.01$.

Table 3
Changes in parent ratings on the ARS and CRS.

Variable	Condition	Pre M(SD)	Post M(SD)	*t* test	ES	Power	Condition × Treatment *F*
ARS	NF + M	14.33(3.40)	10.78(4.91)	2.91*	0.84	0.96	4.19*
	M	15.94(2.24)	15.22(2.86)	1.12	0.28	0.31	
CRS	NF + M	13.89(7.61)	7.61(4.90)	3.76**	0.98	0.99	0.74
	M	15.83(6.71)	11.33(5.03)	3.66**	0.75	0.92	

Note. ES = effect size (Cohen's *d*), NF + M = Neurofeedback with medication condition; M = Medication condition; Pre = Before treatment; Post = After treatment. ARS = ADHD Rating Scale; CRS = Conners Behavior Rating Scale.
***$p < 0.001$.
* $p < 0.05$.
** $p < 0.01$.

medication group, t (17) = 3.76, $p < 0.01$, Cohen's d = 0.98, power = 0.99, and the medication only group, t (17) = 3.66, $p < 0.01$, Cohen's d = 0.75, power = 0.92.

3.3. Changes in cognitive function assessed by the K-WISC-III

The means, standard deviations, and *t*-tests for treatment effects for the seven intelligence scores pre- and post-treatment are presented in Table 4. The main effects of Treatment were identified for all seven intelligence quotient categories, FSIQ: F (1, 34) = 41.30, $p < 0.001$; VIQ: F (1, 34) = 26.90, $p < 0.001$; PIQ: F (1, 34) = 51.88, $p < 0.001$; CIQ: F (1, 34) = 24.87, $p < 0.001$; POIQ: F (1, 34) = 38.36, $p < 0.001$; AIQ: F (1, 34) = 8.65, $p < 0.01$; SIQ: F (1, 34) = 9.72, $p < 0.01$, but no main effects of Condition or Treatment × Condition interaction were found. For treatment effects, improvement of the full intelligence score in the NF with medication group, t (17) = −5.24, $p < 0.001$, Cohen's d = 0.43, power = 0.54, and the medication only group, t (17) = −4.83, $p < 0.001$, Cohen's d = 0.80, power = 0.94, was observed. The verbal intelligence score was improved in the NF with medication group, t (17) = −4.25, $p < 0.01$, Cohen's d = 0.42, power = 0.52, and medication only group, t (17) = −2.59, $p < 0.05$, Cohen's d = 0.41, power = 0.50. Similarly, the performance intelligence scores in the NF with medication group, t (17) = −4.49, $p < 0.001$, Cohen's d = 0.47, power = 0.60, and the medication only group, t (17) = −5.43, $p < 0.001$, Cohen's d = 0.96, power = 0.98, were improved. An improvement in the verbal comprehension intelligence score was observed only in the NF with medication group, t (17) = −4.68, $p < 0.001$, Cohen's d = 0.44, power = 0.55. The perceptual organization intelligence score improved in both the NF with medication group, t (17) = −3.34, $p < 0.01$, Cohen's d = 0.48, power = 0.62, and medication only group, t (17) = −5.38, $p < 0.001$, Cohen's d = 0.82, power = 0.95. Highly significant improvement on the freedom from distractibility intelligence score was found only in the medication only group, t (17) = −2.22, $p < 0.05$, Cohen's d = 0.36, power = 0.42. The perceptual speed intelligence score was improved only in the NF with medication group, t (17) = −2.97, $p < 0.01$, Cohen's d = 0.51, power = 0.66.

3.4. EEG changes of the left and right hemispheres pre- and post-neurofeedback training

To determine any additive effects of NF training, the four frequency ranges were observed for each site; the mean and standard deviations for the four scores pre- and post-treatment, including *t*-test results for the treatment effects, are presented in Table 5. There was decreased activity of the theta wave, t (17) = 3.73, $p < 0.01$, Cohen's d = 0.79, power = 0.94, and decreased activity of high beta wave, t (17) = 2.54, $p < 0.05$, Cohen's d = 0.33, power = 0.38, based on the results of the EEG analysis for the left hemisphere. For the right hemisphere, only decreased the activity of theta wave, t (17) = 3.97, $p < 0.01$, Cohen's d = 0.14, power = 0.14, was found. There were no effects of different bands for left and right hemispheres.

Table 4
Changes in performance on the Korean-Wechsler Intelligence Scale for Children-III.

Variable	Condition	Pre M(SD)	Post M(SD)	*t* test	ES	Power	Condition × treatment *F*
FSIQ	NF + M	100.06(16.60)	107.33(16.93)	−5.24***	0.43	0.54	1.19
	M	100.72(12.06)	110.72(12.80)	−4.83***	0.80	0.94	
VIQ	NF + M	100.39(16.21)	107.06(15.39)	−4.25**	0.42	0.52	0.54
	M	100.44(10.65)	105.28(12.44)	−2.49*	0.41	0.50	
PIQ	NF + M	99.22(16.21)	107.06(16.54)	−4.49***	0.47	0.60	3.52
	M	101.06(14.58)	114.61(13.45)	−5.43***	0.96	0.98	
VC	NF + M	100.22(15.89)	107.22(15.40)	−4.68***	0.44	0.55	2.07
	M	101.94(10.71)	105.61(10.78)	−2.07	0.34	0.39	
PO	NF + M	101.67(16.83)	109.78(16.92)	−3.34**	0.48	0.62	1.78
	M	100.17(15.51)	112.78(15.19)	−5.38***	0.82	0.95	
FD	NF + M	95.94(15.14)	100.39(16.25)	−1.99	0.28	0.30	0.30
	M	93.94(17.55)	100.39(17.42)	−2.22*	0.36	0.42	
PS	NF + M	95.11(13.56)	101.78(12.36)	−2.97**	0.51	0.66	0.07
	M	99.61(11.67)	105.06(19.83)	−1.39	0.33	0.38	

Note. ES = effect size (Cohen's *d*), NF + M = Neurofeedback with medication condition; M = Medication condition; Pre = Before treatment; Post = After treatment. FSIQ = Full Scale IQ; VIQ = Verbal IQ; PIQ = Performance IQ; VC = Verbal Comprehension IQ; PO = Perceptual Organization IQ; FD = Freedom from Distractibility IQ; PS = Perceptual Speed IQ.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Table 5
EEG of the left and right hemispheres pre- and post-neurofeedback training.

Band		Pre M (SD)	Post M (SD)	t test	ES	Power
Left	θ wave	18.83(4.17)	15.36(4.51)	3.73**	0.79	0.94
	SMR wave	6.31(1.73)	5.92(1.85)	1.28	0.21	0.21
	High β wave	9.09(2.16)	8.41(1.95)	2.54*	0.33	0.38
	θ:β ratio	2.57(1.47)	2.76(1.49)	−0.91	0.12	0.12
Right	θ wave	16.00(4.22)	15.37(4.55)	3.97**	0.14	0.14
	β wave	7.57(1.92)	7.86(2.19)	−0.79	0.14	0.14
	High β wave	8.43(2.13)	8.16(2.07)	1.40	0.12	0.12
	θ:β ratio	2.17(1.13)	2.07(1.08)	1.54	0.09	0.10

Note. ES = effect size (Cohen's *d*), NF + M = Neurofeedback with medication condition; M = Medication condition; Pre = Before treatment; Post = After treatment.
* $p < 0.05$.
** $p < 0.01$.

4. Discussion

The present study examined possible additive effects of NF on cognitive functioning and behavior symptom ratings, brainwave changes in children with ADHD who were beginning a medication trial and randomly assigned ADHD children. The effects of combined treatment (namely, NF with medication) were evaluated on top of a medication regime aiming to provide further information about the additive efficacy of NF treatment.

In most cases, there were no main effects of Condition and Condition × Treatment interactions for cognitive variables and symptoms, but the only significant interaction effect found was on the ARS. Also main effect of Treatment was significant, in which there was a greater improvement in the combined NF group. Effect sizes were mostly large for the NF condition relative to the control condition.

First, In terms of ADHD symptoms, children in combined condition was shown the improvement of significant symptoms in ADHD specific ratings after treatment. This results were found from the ES change for ADS, ARS and CRS measures. The ES for three ratings was large for combined treatment, while was from small to medium for medication only. Variables of computerized ADS tests and symptoms ratings of ADHD by parents revealed a superiority of the combined NF treatment in decreasing ADHD symptomatology. Especially large effect sizes for inattention of the ADS tests and ARS ratings by parent in comparison to the medication only indicate that NF effects are substantial and of practical importance and our results confirm findings of previous NF studies ever under strict control and randomized conditions (Bakhshayesh et al., 2011; Duric et al., 2014; Gevensleben et al., 2009; Fuchs et al., 2003; Monastra et al., 2002; Meisel et al., 2013). One possible explanation for these results is that more inattention than hyperactivity/impulsivity problems in distribution of both groups was reported at baseline. Consequently, more pronounced improvement in inattention could be expected. Another explanation would be that combined treatment (NF with medication) may be more effective to improve inattention than hyperactivity/impulsivity symptoms when compared to medication treatment.

To study the changes in the cognitive function, the Wechsler intelligence test for children was conducted before and after treatment. Concerning the effect of treatments on intelligence test, medication treatment seems better than NF at post. Effect sizes were mostly medium for combined group, from medium to large for medication group. Specially, large effect sizes for medication group indicated ES = 0.80 for full IQ and ES = 0.96 for Performance IQ. For cognitive variables, both treatments were the change in neuro-cognitive performance before and after treatment, but medication treatment was similar or superior to those of the combined group after treatment. According to previous studies, some studies suggested any beneficial effect of NF on neurocognitive functioning (Lubar et al., 1995), while in others they were not (Vollebregt et al., 2014; Sonuga-Barke et al., 2013). The most likely explanation for different findings is that the studies were quite heterogeneous in their design and methodology, such as different sample sizes and control conditions, NF-protocol, the choice of neurocognitive tasks (Vollebregt et al., 2014; Sonuga-Barke et al., 2013). Other alternative explanation is that the treatment frequency of NF training may have been too low to result in a pronounced clinical effect of NF treatment in this study. To have an effect of NF training, a treatment frequency of more than 60 sessions or about six months is necessary (Fox et al., 2005), and in most of the studies that showed significant differences among groups, more than 30 sessions had been conducted (Gevensleben et al., 2009; Monastra et al., 2002; Meisel et al., 2013). Further study must take account of this point to detect a pronounced cognitive improvements because the systematic review suggests that neurocognitive improvements occur over time (Vollebregt et al., 2014).

The actual power changes in EEG frequency bands as a result of NF were monitored and analyzed. As a result of the EEG analysis across pre- and post-treatment, decreased activity of the theta wave in both the left and right hemispheres and a decreased high beta wave in the left hemisphere were found. Multiple studies have determined that children with ADHD, compared to gender- and age-matched controls, have greater theta activity (Barry et al., 2003, 2009). Other studies have found a correlation between the inattentive and combined subtypes of ADHD and the theta band and between the theta/beta ratio and the hyperactive impulsive and combined subtypes (Clarke et al., 2011). There were no differences in different bands reported as significant measures of EEG alterations in some previous studies (Barry et al., 2009; Ogrim et al., 2012), but our results are concordant with studies that reported Beta or SMR waves did not change over short training periods (Rossiter and La Vaque, 1995). However, this is not a credible reason to criticize the clinical efficacy of NF.

This study has some limitations. First, the current study is smaller in size than planned, due to recruitment difficulties including cost and time required to participate in the study. Although we have appropriated to assess the additive efficacy of NF compared to medication treatment, there was the limited statistical power in this study due to small sample. Children with all subtypes of ADHD and with an FSIQ of at least 80 were included in this study. Therefore, the generalization of effects to subgroups of individuals with ADHD or children with a significantly lower IQ cannot be made. The low number of NF training sessions is also a limitation. Most studies that reported significant differences conducted more than 30 sessions. Finally, this study did not investigate whether the residual effects of NF only could be observe in children with ADHD when wash out of the medication. To a precise observation and detection, further studies need to pay particular attention this points in designing.

4.1. Conclusions

This study was a randomized study and was methodologically the least controlled study. So this was minimized an expectation effect because parent unselected a self-wanted treatment. Our results indicate that NF may be considered as a possible effective treatment for children with ADHD. Especially the improvement of inattention symptom by combined treatment showed more pronounced and additive treatment effects after treatment compared to medication treatment only and reduced the activity of theta waves. However this study was unable to establish more superior additive treatment effects of NF on intellectual functioning than medication treatment. This finding is probably influenced by methodological limitations including small sample. Further studies should evaluate whether NF is able to decease the dosage of medication or the residual effects of NF only could be investigated more reliably in the absence of medication.

Declaration of conflicting interests

The authors declare no conflicts of interest with respect to the research, authorship, and/or publication of this article.

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