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Effects of Neurofeekback Training on EEG, Continuous Performance Task (CPT), and ADHD Symptoms in ADHD-prone College Students

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Purpose: This study explored the effects of neurofeedback training on Electroencephalogram (EEG), Continuous Performance Task (CPT) and ADHD symptoms in ADHD prone college students. **Methods:** Two hundred forty seven college students completed Korean Version of Conners' Adult ADHD Rating Scales (CAARS-K) and Korean Version of Beck Depression Inventory (K-BDI). The 16 participants who ranked in the top 25% of CAARS-K score and had 16 less of K-BDI score participated in this study. Among them, 8 participants who are fit for the research schedule were assigned to neurofeedback training group and 8 not fit for the research schedule to the control group. All participants completed Adult Attention Deficiency Questionnaire, CPT and EEG measurement at pretest. The neurofeedback group received 15 neurofeedback training sessions (5 weeks, 3 sessions per week). The control group did not receive any treatment. Four weeks after completion of the program, all participants completed CAARS-K, Adult Attention Deficiency Questionnaire, CPT and EEG measurement for post-test. **Results:** The neurofeedback group showed more significant improvement in EEG, CPT performance and ADHD symptoms than the control group. The improvements were maintained at follow up. **Conclusion:** Neurofeedback training adjusted abnormal EEG and was effective in improving objective and subjective ADHD symptoms in ADHD prone college students.

Key words: Neurofeedback; Adult ADHD; Continuous Performance Task (CPT); EEG

INTRODUCTION

Attention Deficit Hyperactivity Disorder (ADHD) is a typical child mental disorder with major symptoms of inattention, impulsivity and hyperactivity. The prevalence of childhood ADHD has been estimated as up to 50% of pediatric·adolescent patients who visit a mental clinic [1]. ADHD was once regarded as a disorder unique to childhood, with symptoms limited only to be limited to childhood. However, a long-term follow-up study reported that clinically significant symptoms and dysfunction last to adulthood in 30~70% of patients diagnosed with ADHD in childhood [2]. ADHD adult prevalence in Korea is unknown. In the United State, National Institutes of Health epidemiological survey in 2006 indicated that adults with ADHD comprise 4.4% of all American adults. A US population and housing census conducted in 2000 indicated that about 9 million adults may suffer from ADHD [3]. ADHD is now recognized as a chronic disorder rather than being a disorder limited to childhood [1-3].

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This changed recognition has prompted revised ADHD diagnostic criteria for older adolescents and adults 17 years of age and older in recently revised Diagnostic and Statistical Manual of Mental Disorder, fifth edition [4]. In many cases, however, naturally decreasing maladaptive symptoms in adulthood such as impulsivity or hyperactivity, the major symptoms of ADHD are misunderstood as disappearance of ADHD itself [5] and problems appearing in ADHD adults in a variety of environments tend to be regarded as individual characteristics not due to ADHD [2]. Hence it is more difficult to diagnose in adults than in children.

Age-and social-related changes in living environment and level of activity can be apparent as different expression patterns, rather than major behavioral patterns, in adults with ADHD compared to childhood ADHD [5]. In addition, the range of problem behavior of adults with ADHD is more diverse than that of children with ADHD due to the more diverse living environments with increasing age. Adults with ADHD may additionally suffer from academic underachievement, job problem and consequent financial difficulties, or marital discord and the degree of depression may be severe and interpersonal relation may not be good, either [1]. The consequence can be difficulty in dealing with most, if not all, aspects of daily life.

Pharmacotherapy is the standard treatment for ADHD. Grounded in evidence that. ADHD results from neurological deficit due to the low arousal level of central nervous system, pharmacotherapy for ADHD relies mainly on amphetamine and methylphenidate. Such pharmacotherapy enables the patient to maintain arousal, which allows concentrated attention and selective attention on the desired stimuli and furthermore the result is a sense of control [6].

Although pharmacotherapy can improve major symptoms of ADHD, the approach cannot completely abate symptoms and functional deficits [6]. Pharmacotherapy has side effects such as relapse of symptom when medication stops, drug dependency, appetite decrease, sleep problem, variation of mood, amenorrhea and palpitation [1]. These drawbacks are not preferred for adults with ADHD with wider and more diverse living environment than that of children with ADHD.

Neurofeedback is the treatment method that may be an alternative for pharmacology. Neurofeedback is self-training regimen that improves brain function by reorganizing the networking and chemical effect of brain. participants become capable of changing brain wave activity by monitoring their brain wave activities in real time with specially designed computer equipment [7]. The basic assumptions of neurofeedback are consistent with a model that describes ADHD as a disorder involving low arousal of brain [8]. According to the model, insufficient production or utilization of neurotransmitters causes inefficient delivery among neurons. Neurofeedback enables a participant to promote connection among neurons through reinforcement during the effective delivery of neurons or faster spiking.

The human brain consists of neuron whose basic activity involves electrical properties. The collective recording of neuron electrical activity in the form of brain waves constitutes electroencephalography (EEG) [7]. When the human brain receives the strong stimuli, the synapse that has been barely in action will be suddenly active, and the synapse will maintain the same status after that. Neurofeedback monitor the status of the brain wave activity of a person in real time, and directly trains his brain in order to generate specific brain waves in the specific area of brain, and changes the direction of neurotransmitters before reaching the synapse through the neural network [9]. In other words, once neuron through the change of brain plasticity have changed, and such changed brain wave form becomes constantly maintained, the changes of mental state and behavior related to the changed EEG will take place [10]. EEG is classified according to frequency into delta wave (0.5~3 Hz), theta wave (4~7 Hz), alpha wave (8~12 Hz), SMR (sensorimotor rhythm) wave (13~15 Hz), low beta wave (16~20 Hz), high beta wave (21~40 Hz) depending on the frequency. Delta wave and theta wave represent slow wave and are associated with day-dreaming and drowsiness. The alpha wave is related to relaxation state of unfocused attention. A beta wave represents a fast wave and is associated with high arousal, concentration and focused attention [10].

Children with ADHD show higher theta wave activity and lower beta wave activity compared to normal children [8]. A similar pattern is evident in adults with ADHD [11]. That is, the EEG pattern of ADHD is typically characterized by a high rate between theta wave activity and beta wave activity. Therefore, Neurofeedback training for ADHD aims to reduce theta wave activity and increase beta wave activity. According to the results of a few clinical studies that have been conducted over the last

30 years, such neurofeedback is effective at reducing symptoms associated with ADHD that included hyperactivity, impulsivity, and attention [12]. Neurofeedback training in korean and elsewhere has shown effects similar to or better than pharmacotherapy in treating children with ADHD [8,13,14].

Several studies have explored neurofeedback training target adults with ADHD. The potential of neurofeedback in significantly improving Korean Version of Conners' Adult ADHD Rating Scales (CARRS-K) and subtest digit span of Korean Wechsler Intelligence Scale (K-WAIS-IV) was evident [15]. Another study documented significant improvements in inattention (omission error), impulsivity (commission error), and variation of response time in adults with ADHD [16]. Neurofeedback and cognitive retraining in adults diagnosed with mild traumatic brain injury or ADHD was explored [17]. Results of Neuropsychological Impairment Scale (NIS), Wisconsin Card Sorting Test (WCST), Wechsler Adult intelligence Scale-Revised (WAIS-R), and Continous Performance Task (CPT) revealed the significant benefits of neurofeedback and cognitive retraining in all attention scales and all response accuracy scale of CPT; neurofeedback effectively improved attention improvement of adults diagnosed with mTBI (mild traumatic brain injury)and ADHD.

While the effects of neurofeedback on ADHD are evident, its validity as a therapy technique remains contentious [18]. Studies were carried out mainly targeting children with ADHD, relatively few studies have targeted adults with ADHD. Furthermore, few studies in Korea have systematically examined the effect of neurofeedback on ADHD. One recent study in Korea that involved ADHD prone college students was done by attaching electrodes to a prefrontal region adjacent to the eyes. Neurofeedback training relies on electromyogram (EMG) monitoring. As such, an evaluation involving the prefrontal region is insufficient to prove the effectiveness of neurofeedback training due to the movement of eye-blink and facial muscles. Therefore, according to the previous study reporting that neurofeedback training less affected by the movement of eye-blink and facial muscles and reducing theta wave activity and increasing beta wave activity in C3 (international 10-20 system; Jasper [19]) area of children with ADHD and reducing theta wave activity and increasing SMR wave activity in inattention and C4 (international 10-20 system; Jasper [19]) area is effective for impulsivity, this study was to verify the effect of neurofeedback training reducing theta wave activity and increasing beta wave activity on ADHD prone college students by attaching the electrodes in C3 and C4 (international 10-20 system; Jasper [19]) areas. The hypotheses of this study are as follows:

Hypothesis 1. EEG of subjects engaged in neurofeedback will reveal more arousal than the control group after training.

Hypothesis 2. Objective attention task performance of the neurofeedback group will be improved more than the control group.

Hypothesis 3. ADHD symptom of subjective response of the neurofeedback group will be reduced more than the control group.

METHODS

1. Participants

This study assessed 247 college students using Conners' Adult ADHD Rating Scale-Korean (CAARS-K) and Korean-Beck Depression Inventory (K-BDI). Students scoring >85.4 in CAARS-K (i.e., the top 25% of scores) were considered ADHD prone college students and were selected for participation. Those with a K-BDI score of more than 16 were considered prone to depression and were excluded. Twenty eight subjects met the study criteria. To twenty eight subjects, we introduced the purposes and methods of our research in detail through phone calls and interviews and explained about the side-effects they might occur as well as fully notified them whenever they do not want to continue, the tests could be stopped anytime, and were approved by them on the research participation agreements through informed consent. Sixteen students agreed to participate. Among them, eight participants who are fit for the research schedule were assigned to neurofeedback group and another eight participants not fit for the research schedule to the control group.

2. Instruments

1) Conners' Adult ADHD Rating Scale-Korean (CAARS-K)

The adult ADHD rating scale developed by Conners et al. [20] and adapted by Kim et al. [21] was used. It consists of total 66 items and is 4-point Likert scale (0, not at all; 1, yes; 2, frequently yes; 3, Yes, quite often). The range of total scores is

0~198 points. Factor analysis involved seven subscale of inattention and memory problem (18 items), hyperactivity and nervousness (18 items), impulsivity and emotional insecurity (12 items), self concept problems (6 items) and DSM-Ⅳ inattention symptom (9 items), DSM-Ⅳ hyperactivity and impulsivity (9 items) and ADHD index (12 items). The internal consistency coefficient of all CAARS-K items was Cronbach's α=.97.

2) Korean-Beck Depression Inventory (K-BDI)

BDI is a self-report scale developed by Beck et al. [22] to assess the presence for absence of symptoms and severity of depression. K-BDI measures cognitive, emotional, motive and physiological aspects of depression symptoms. Each of the 21 items is scored from 0 point to 3 points, with a range of total scores of 0~63 point. According to Beck, <9 points indicates no depression, 10~15 points mild depression, 16~23 points moderate depression and 24~63 points severe depression. BDI adapted and standardized by Lee and Song [23] was used in this study. Like the study of Lee and Song [23], this study used 16 points as cut off in order to exclude depression. The internal consistency coefficient of all K-BDI items was Cronbach's α=.86.

3) Adult attention deficiency questionnaire

This is a questionnaire developed by Lee [24] with reference to adolescent and adult Brown Attention Deficit Disorder Scale developed by Brown [25], Wender Utah rating scale (outpatient) developed by Ward et al. [26] and childhood symptom case of a disease reported by Grohol. The questionnaire used a 5-point Likert scale (1~5) to rate child and adults symptoms Questions about adult symptoms comprised 34 items consisting for four factors (disorganization, emotional deficit, hyperactivity, impulsivity). Questions about childhood symptoms comprised 14 items and consist of inattentiveness, impulsivity, hyperactivity. Only the questionnaire about adult symptoms was used. The internal consistency coefficient of adult attention Deficiency Questionnaire was Cronbach's α=.90.

4) Continuous Performance Task (CPT)

The Psychology Experiment Building Language (PEBL) Continuous Performance Task (CPT) [27] was used. PEBL CPT is the license-free or cost-free psychology software available from the program http://pebl.sf.net. Typically, CPT responds to specific target stimuli (e.g., 'X' or '9') and is not appropriate for assessing adults due to its low difficulty. Therefore, this CPT is similar to Go/NoGo task measuring inhibitory deficit . The English alphabet letters of A, B, C, D, E, F, G, H, I, J, L, M, O, P, Q, R, S ,U and X was randomly presented in the center of computer screen, with all letters except 'X' being the target for response. In the task, participants respond by pressing the spacebar of a computer when any target letters appeared. Letters appeared at intervals 1,000, 2,000, 4,000 ms. Twenty stimuli were presented by dividing 360 stimuli into 18 blocks, each stimuli is presented 3 times randomly with intervals between each presentation. Each letter appeared for 200ms. The task took about 14minutes. Analysis involved four variables: omission error, commission error, correct response time mean, response time mean standard deviation.

5) EEG measurement

EEG measurements (QEEG-4) were made suing a LXE3204 device (Laxtha Inc., Korea). QEEG-4 is recognized by Korea Food & Drug Administration (KFDA) and its stability have been verified. Measurement were made at the C3 and C4 areas (international 10-20 system; Jasper [19]). The reference electrode was attached to the area behind the right ear lobe and ground electrode was attached to the area behind the left ear lobe. EEG signals of two channels acquired at 256 Hz sampling frequency, pass filter of 0.5~50 Hz and using a 12-bit analog-digital converter were stored in a computer. EEG of the participants was measured with their eyes open to create a situation similar to feedback training. Each participant was asked to look at the black desktop to present neutral stimuli not affecting the subjects. During measurement, body movements and stimuli from the external environment were minimized. EEG data were collected and analyzed using TeleScan Version 3.10 (Laxtha). The data represented digitalized absolute power values of theta wave (4~7Hz), SMR wave (13~15Hz), low beta wave (16~20Hz) by each channel and theta wave/low beta wave ratio through power spectrum analysis.

3. Procedure and neurofeedback training

This study was carried out after obtaining the approval of a four-year College Institutional Review Board (IRB No. 2014-06-017-002). Before starting this training, all participants in both groups completed Adult Attention Deficiency Questionnaire, CPT and EEG measurement. Neurofeedback training consisted of total 15 sessions conducted from July second week to August second week over 5 weeks with 3 sessions per week per. Each session lasted about 40 minutes.

Trainer implementing neurofeedback training was same with this study researcher and completed the brain wave training proceeded by Laxtha of neurofeedback company, which was used for this research. In addition, for supervising the process of the training, the researcher showed the training program of this research to the professor awarded of Ph.D degree in the area of neurofeedback and the person who is working as neurofeedback trainer in the field.

The eight people in the control group did not receive any treatment for 5 weeks. Each session of neurofeedback training was conducted in the biofeedback room of a four-year college. The aforementioned QEEG-4 neurofeedback apparatus operated in SMR-beta mode. Training was conducted alternately in C3 and C4 area (international 10-20 system; Jasper [19]) and aimed to increase SMR wave (13~15Hz) activity and low beta wave (16~20Hz) activity and reduce theta wave (4~7Hz) activity. The training program involved the NN-1 NeuroNicle archery and NN-2 NeuroNicle racing (Laxtha Inc., Korea). The games provided reinforcement as the SMR wave activity or theta/ low beta wave ratio increased. Participants played two games alternately in each session to eliminate boredom that could develop as a task was repeated. After 5-week training, all participants in two groups received CAARS-K, adult attention Deficiency Questionnaire, CPT, EEG measurement for posttest and also received the same test as posttest in the follow-up test after 4 weeks. And after the follow-up test, gift voucher (20,000 won) was provided to the control group only as a reward for participating in the study.

4. Data analysis

Before starting the treatment program, normality was originally checked the Shapiro-Wilk test. However, the nonparametric test method independent of the distribution of population was used because normality assumption was not met. In order to identify the homogeneity of neurofeedback group and the control group, the analysis was carried out through Mann-Whitney U test. And in order to find out the effect of neurofeedback training on EEG, CPT, ADHD symptom, the effectiveness of the program was verified by conducting Wilcoxon signed-rank test with the results measured by carrying out pre·post·follow-up test. All data was derived through SPSS 20.0 (SPSS, USA).

RESULTS

1. Homogenous

Mann-Whitney U test conducted prior to training revealed that both groups were homogenous. There were no significant differences between groups in CAARS-K, Adult Attention Deficiency Questionnaire, CPT and EEG.

2. Change of EEG

1) Left hemisphere

In the neurofeedback group, the left hemisphere theta wave activity and theta/beta wave ratio were significantly reduced comparing pre- and post-test scores ($Z=-2.52$, $p=.012$, $Z=-2.38$, $p=.017$, respectively) and low beta wave activity was also significantly improved comparing pre- and post-test scores ($Z=-2.38$, $p=.017$). Follow up test scores revealed no significant difference in low beta wave activity and theta/beta wave ratio in the neurofeedback group. However, theta wave activity was significantly improved comparing post- and follow-up test scores ($Z=2.52$, $p=.012$). The theta wave activity was significantly reduced comparing follow-up to pre-teat scores ($Z=-1.96$, $p=.050$). On the other hand, the control group showed no significant differences in pre-versus post-test and follow-up test scores (Table 1).

2) Right hemisphere

In the neurofeedback group, theta wave activity and theta/beta wave ratio were significantly reduced from pre- to post-test scores ($Z=-2.02$ $p=.043$, $Z=-2.52$, $p=.012$, respectively). Theta/beta wave ratio showed no significant differences in follow-up test score. Additionally comparing follow-up and pre-test score, follow-up score of low beta wave activity was increased

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more significantly than pre-test score (Z= -1.96, p=.050). On the other hand, the control group showed no significant differences in pre- versus post-test and follow-up test score (Table 2).

3. CPT (Continuos Performance Task)

In the neurofeedback group, CPT commission error, omission error and response time mean standard deviation were reduced more significantly comparing pre- and post-test scores (Z= -2.53, p=012, Z= -2.12, p=.034, Z= -2.52, p=.012, respectively). Correct response time mean was improved significantly comparing pre- and post-test scores (Z= -2.38, p=.017). There were no significant differences in follow-up test score. On the other hand, the control group showed no significant differences in pre- versus post-test and follow-up test score (Table 3).

4. ADHD symptoms

1) CAARS-K (Conners Adult ADHD Rating Scale-Korean)

CAARS-K total score of the neurofeedback group and the con-

Table 1. Effects of Neurofeedback Training on Left Hemisphere EEG

Variables	Groups	Pre	Post	Follow up	Pre-post	Post-follow up	Pre-follow up
		M±SD	M±SD	M±SD	Z	Z	Z
Theta wave	Exp.	13.84±4.05	11.73±4.04	12.64±3.84	-2.52*	-2.52*	-1.96*
	Cont.	15.36±4.62	16.11±3.97	15.66±4.34	-1.26	-1.40	-0.84
SMR wave	Exp.	2.94±0.84	3.54±1.01	3.42±0.99	-1.54	-0.70	-1.26
	Cont.	3.54±1.34	3.18±0.93	3.56±0.98	-0.98	-1.54	-0.28
Low beta wave	Exp.	2.64±0.67	4.03±1.24	3.94±1.11	-2.38*	-0.42	-2.37
	Cont.	3.40±1.04	3.62±0.96	3.40±0.98	-0.70	-1.40	-0.56
Theta/beta wave ratio	Exp.	2.61±1.04	1.66±0.88	1.80±0.79	-2.38*	-1.68	-2.24
	Cont.	2.44±1.29	2.53±0.95	2.34±0.76	-0.70	-1.54	-1.54

*p < .05; Exp.=Experimental group (n=8); Cont.=Control group (n=8); SMR=Sensorimotor rhythm wave; EEG=Electroencephalogram.

Table 2. Effects of Neurofeedback Training on Right Hemisphere EEG

Variables	Groups	Pre	Post	Follow up	Pre-Post	Post-follow up	Pre-follow up
		M±SD	M±SD	M±SD	Z	Z	Z
Theta wave	Exp.	11.48±3.62	10.72±3.10	10.84±3.30	-2.02*	-0.70	-2.24
	Cont.	14.92±3.58	14.63±3.14	14.16±3.48	-0.28	-1.26	-0.70
SMR wave	Exp.	2.58±0.36	2.65±0.42	2.83±0.74	-0.28	-0.84	-1.40
	Cont.	3.17±1.20	2.81±0.87	3.12±1.13	-0.84	-1.54	-0.14
Low beta wave	Exp.	3.53±1.00	3.83±0.73	3.93±1.55	-1.12	-0.14	-1.96*
	Cont.	3.08±0.91	2.99±0.73	3.24±0.68	-0.42	-1.68	-0.56
Theta/beta wave ratio	Exp.	1.94±0.67	1.69±0.50	1.71±0.68	-2.52*	-0.42	-2.52
	Cont.	2.59±1.29	2.67±0.94	2.37±0.87	-0.70	-1.82	-0.84

*p < .05; Exp.=Experimental group (n=8); Cont.=Control group (n=8); SMR=Sensorimotor rhythm wave; EEG=Electroencephalogram.

Table 3. Effects of Neurofeedback Training on Continuos Performance Task

Variables	Groups	Pre	Post	Follow up	Pre-Post	Post-follow up
		M±SD	M±SD	M±SD	Z	Z
Commission error	Exp.	13.13±4.94	7.25±2.38	6.25±2.12	-2.53*	-1.50
	Cont.	15.00±5.40	12.50±4.60	13.38±5.18	-1.17	-0.07
Omission error	Exp.	3.00±2.20	1.13±0.99	0.75±0.46	-2.12*	-1.13
	Cont.	3.25±2.55	2.88±2.80	2.63±1.92	-0.78	-0.63
Correct response time mean	Exp.	365.73±31.85	393.10±21.63	389.64±12.40	-2.38*	-0.42
	Cont.	397.03±32.79	392.82±21.99	396.17±29.43	-0.56	-0.85
Response time mean standard deviation	Exp.	80.36±12.20	69.29±10.43	67.48±10.44	-2.52*	-0.84
	Cont.	83.15±26.28	83.76±29.06	80.52±22.98	-0.14	-0.85

*p < .05; Exp.=Experimental group (n=8); Cont.=Control group (n=8).

trol group was reduced comparing pre- and post-test scores (Z= -2.52 p=.012, Z= -2.10, p=.035, respectively). Both groups showed no significant differences in the follow-up test score. Comparison of pre- and follow-up scores revealed a significant reduction only in the neurofeedback group (Z= -2.38, p=.017).

Examination of the subscale change of CAARS-K in the neurofeedback group determined that Comparison of pre- and post-test scores were reduced more significantly in inattention and memory (Z= -2.10, p=.035), impulsivity (Z= -1.96, p=.050) and DSM-Ⅳ inattention (Z= -2.39, p=.017). Comparison of follow-up test scores revealed no significant differences in inattention and memory and impulsivity, while the score was improved more significantly in DSM-Ⅳ inattention (Z= -2.21, p=.027). Comparison of pre- and follow-up test score revealed significant reduction in follw-up scores of DSM-Ⅳ inattention (Z= -1.97, p=.049), DSM-Ⅳ hyperactivity (Z= -2.31, p=.021) and ADHD index (Z= -2.02, p=.043). On the other hand, the control group showed no significant differences both in pre- and post-test score and follow-up score (Table 4).

2) Adult Attention Deficiency Questionnaire

Comparison of pre- and post-test Adult Attention Deficiency Questionnaire scores revealed a significant reduction in the neurofeedback group (Z= -2.38 p=.017). No significant differences were apparent in follow up test scores. Control group showed no significant differences in any of the scores.

Examination of subscale change af Adult Attention Deficiency Questionnaire in the neurofeedback group determined that comparison of pre- and post-test score were reduced more significantly in disorganization (Z= -2.10, p=.035), hyperactivity (Z= -2.52, p=.012) and impulsivity (Z= -2.52, p=.012). Follow up test scores showed no significant differences in these categories. Comparison pre- and post-test scores of the control group were reduced significantly only in emotional deficit (Z= -2.10, p=.035), with no significant difference evident in follow-up test scores (Table 5).

DISCUSSION

This study was undertaken to find the effect of neurofeedback training on ADHD symptoms, CPT, EEG of ADHD prone college students.

First, hypothesis 1 that EEG of neurofeedback group will be aroused more after training compared to the control group was supported. The present results echo prior finding in children and adults with ADHD [9,15,17]. The similarity of the results likely reflects the basis of neurofeedback training. Thorndike's law of effect states that positive feedback for a response makes the re-

Table 4. Effects of Neurofeedback Training on Conners' Adult ADHD Rating Scale

Variables	Groups	Pre	Post	Follow up	Pre-Post	Post-follow up	Pre-follow up
		M±SD	M±SD	M±SD	Z	Z	Z
Total score	Exp.	100.38±19.58	63.88±16.50	76.25±15.28	-2.52*	-1.95	-2.38*
	Cont.	104.00±9.70	92.88±14.07	98.50±14.89	-2.10*	-1.40	-0.42
Inattention and memory	Exp.	18.88±5.44	12.13±4.88	14.88±3.91	-2.10*	-1.95	-1.41
	Cont.	20.50±3.55	18.75±6.07	18.88±6.18	-0.84	-0.18	-0.63
Hyperactivity and emotion	Exp.	18.88±4.73	12.63±7.15	14.62±6.48	-1.54	-1.80	-1.41
	Cont.	20.75±4.74	16.63±4.81	19.63±5.81	-0.98	-1.52	-0.56
Impulsivity	Exp.	15.25±4.98	9.38±3.42	12.63±5.42	-1.96*	-1.63	-1.12
	Cont.	17.25±3.41	15.25±3.62	14.38±3.16	-1.12	-0.92	-1.33
Self concept	Exp.	10.13±3.27	7.88±4.36	9.50±3.70	-1.26	-1.36	-0.09
	Cont.	7.50±3.07	8.75±4.06	10.25±5.26	-0.28	-1.16	-1.13
DSM-IV inattention	Exp.	15.25±3.77	7.88±2.95	10.00±3.55	-2.39*	-2.21*	-1.97*
	Cont.	15.38±2.72	13.00±2.73	15.13±3.80	-1.62	-1.83	-0.21
DSM-IV hyperactivity	Exp.	13.75±5.75	6.38±5.93	6.75±4.56	-1.89	-0.51	-2.31*
	Cont.	12.75±2.92	11.38±3.38	10.63±4.41	-0.93	-0.21	-1.27
ADHD index	Exp.	17.63±4.81	12.63±4.41	13.50±3.67	-1.90	-0.53	-2.02*
	Cont.	16.38±3.78	15.63±2.88	17.25±2.92	-0.94	-2.23*	-0.51

*p<.05; Exp.=Experimental group (n=8); Cont.=Control group (n=8); ADHD=Attention deficit hyperactivity disorder; DSM=Diagnosis and statistical manual for mental disorder.

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Table 5. Effects of Neurofeedback Training on Adult Attention Deficiency Questionnaire

Variables	Groups	Pre	Post	Follow up	Pre-Post	Post-follow up
		M±SD	M±SD	M±SD	Z	Z
Total score	Exp.	116.88±20.17	77.00±18.19	82.38±18.06	-2.38*	-0.93
	Cont.	109.25±13.74	100.25±15.30	99.88±16.80	-1.47	-0.95
Disorganization	Exp.	42.75±11.07	26.38±7.98	28.38±4.50	-2.10*	-0.95
	Cont.	39.88±9.49	40.75±6.21	39.38±5.90	-0.17	-0.95
Emotional deficit	Exp.	33.13±5.99	26.25±11.50	24.25±7.89	-1.33	-0.84
	Cont.	30.00±4.87	24.38±5.98	25.25±6.65	-2.10*	-0.18
Hyperactivity	Exp.	22.13±6.58	12.63±3.85	16.00±6.05	-2.52*	-1.15
	Cont.	21.63±4.41	19.25±3.92	18.63±6.09	-1.48	-0.14
Impulsivity	Exp.	18.88±2.42	11.75±4.06	13.75±3.96	-2.52*	-0.81
	Cont.	17.75±3.11	15.88±2.53	16.63±2.33	-1.62	-0.53

*p < .05; Exp.=Experimental group (n=8); Cont.=Control group (n=8).

sponse very likely to happen. In the present neurofeedback training, participants received feedback as positive change in the game being played when theta wave activity and theta/beta wave ratio were reduced by improved SMR wave activity or low beta wave activity. Contrarily, if the theta/beta wave ratio increased, participants received negative feedback during the game. Participants learned to self-modify EEG, based on positive feedback for increased EEG activity they and negative feedback for reduced EEG activity. In the neurofeedback group, the SMR wave activity of the left and right hemisphere showed and increasing, but statistically non-significant, tendency even after training. Additionally The results revealed that the intervention effect began to decrease after the post-test. These may have reflected the short training of 15 session. Yoo [9] said that longer training may be necessary for effect SMR wave activity change and the therapeutic effects, and Rossiter and LaVaque [28] recommended to have more than 20 sessions that allows participants to stabilize such status and continue learning improvement if SMR wave activity was increased after 20 sessions. This study showed the arousal of brain wave and the improvement of symptoms with 15 sessions, however, it is regarded short in term of number of sessions to stabilize the changed status after training, and because of it, it is considered that the remedy effect has been reduced after the post-test.

Second, hypothesis 2 that performance of the objective attention task is improved by neurofeedback training was supported. These results are consistent in certain part with the finding prior studies [8,9,16,17]. Consistent with the results of prior studies [8,9,16,17], this study revealed the significant reduction in omission error and commission error, however, different from prior studies [16,17], the response time showed a significant increase. The main measures of CPT are commission error and omission error. Commission error measures impulsivity as the error responding to non-target stimuli and omission error measures inattention as the error omitting target stimuli. Lee [29]'s study comparing the difference in CPT performance between normal adults and ADHD prone college students reported that ADHD prone college students have more commission error and omission error than normal adults. These results can be interpreted that adults with ADHD have more difficulty with continuous attention than normal adults, and are more likely to display inhibitory deficit (i.e. impulsivity). Additionally the reasons that the significant increase of the response time due to the discrete attitudes to carefully explore the surroundings after neurofeedback training when they coped with new assignments. This cognitive performance has been related to brain wave activity. A comparison of the difference in EEG and CPT between children with ADHD and normal children revealed that children with ADHD showed relatively stronger theta wave and weaker beta wave activities compared to normal children [30]. Also, their performance of CPT was lower than that of normal children. Major symptoms of ADHD can be improved as evident in the objective attention task by real-time feedback based on EEG in neurofeedback training which involves reduced theta wave activity and improved beta wave activity.

Third, hypothesis 3 that neurofeedback training reduces self-assessed symptoms of ADHD was supported. These results echo studies that reported reduced symptoms in children with ADHD and ADHD prone college students following neurofeedback training [8,9,13,15]. These symptoms of ADHD are related to the deficit of dominant slow wave and beta wave activity [7,9]. EEG of adults with ADHD shows higher theta wave and slow wave activities, and lower beta wave and fast wave activities compared to normal adults. The arousal level of ADHD is lower. ADHD may be suspected based on excessive theta wave activity and low beta wave activity, with the latter related to inattention. Adults with ADHD have difficulties in overall daily life, such as lack of academic performance ability, difficulties in time management, alcohol abuse and poor interpersonal relationships. Overall, ADHD symptom can be improved as arousal level of brain improved by EEG modification and learned behaviors through neurofeedback training that focuses on SMR-beta wave mode.

The current data indicate that SMR-beta wave mode neurofeedback training increases the arousal level by reducing the activities of theta and slow waves, as has been documented in children with ADHD, and increasing the activities of beta wave and fast wave. These changes are effective in normalizing the abnormal EEG associated with ADHD prone college students, and are also effective for test performance measured objectively and subjectively evaluated ADHD symptoms.

Despite the plethora of studies concerning the effect of neurofeedback training on ADHD, the validity of neurofeedback training remains contentious [18]. Rather than depending only on self-report test that may be vulnerable to a placebo effect, this study verified the effect of neurofeedback training on ADHD prone college students more objectively through objective measurement tools. Most studies on the effectiveness of neurofeedback training for ADHD have targeted children with ADHD. Only a few studies have addressed adults with ADHD because of the difficulty in diagnosing adults with ADHD, and because of the incorrect assumption that major symptoms of ADHD disappear naturally in adulthood. If these symptoms are apparent in adults, they tend to be regarded as individual characteristics unrelated to ADHD. The present data should hopefully stimulate follow-up studies of neurofeedbak training for adults with ADHD. Pharmacotherapy is the primary treatment strategy for ADHD. However, pharmacotherapy may not be effective side effect, and who can be reluctant to visit psychiatric clinics. According to the results of this study, neurofeedback training alone was effective in the subjective and objective test of inattention, hyperactivity and impulsivity, which are major symptoms in ADHD prone college students. Therefore, this study offers a non-invasive and relatively easily accessible treatment for adults with ADHD.

There are several limitations to the current study. First, neurofeedback program used in this study measured and utilized only parietal lobe EEG of the C3 and C4 areas. However, inattention, impulsivity and hyperactivity of ADHD may be affected in a variety of brain regions. Therefore, follow-up studies need to measure and examine EEG of overall brain regions other than the parietal lobe. Second, this study did not carry out random assignment. This may have affected the motivation in the groups, and it is difficult to generalize the results. Follow-up studies should be dome with more participants who are randomly assigned to treatment. Third, the participants were limited to ADHD prone college students. In many cases, adults with ADHD do not become highly-educated due to the lack of the ability to perform academic and daily life activities, and ADHD prone college students symptoms show less severe symptoms compared to other adult with ADHD [15]. Therefore, it is difficult to generalize the results of this study to all adults with ADHD. Also, this study measured and excluded only depression among various comorbidities and follow-up studies seem necessary to conduct training targeting actual adult with ADHD who excluded various comorbidities of ADHD. Finally, sessions of the neurofeedback group lacked variation of SMR wave. 15 session was less than in other studies. The number of session will need to be increased to at least 20 session in follow-up studies.

CONCLUSION

Neurofeedback training aiming to increase arousal level by reducing theta wave activity and increasing beta wave activity was effective for normalization of abnormal EEG shown in ADHD prone college student, and was also effective for test performance measured objectively and subjectively ADHD symptoms felt due to normalization of EEG. Neurofeedback training is an effective intervention to improve ADHD symptoms.

CONFLICTS OF INTEREST

There are no conflicts of interest.

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