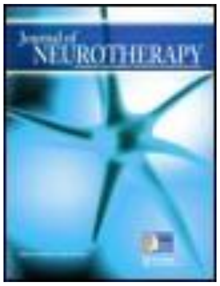

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Improved Neuronal Regulation in ADHD: An Application of Fifteen Sessions of Photic-Driven EEG Neurotherapy

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This study tested a 15-session electroencephalograph (EEG) driven photic stimulation neural training procedure designed to enhance the regulation of brain wave activity and thus improve cognitive functioning in Attention Deficit/Hyperactivity Disorder (ADHD) children. The subjects (N=25) were 8-14 year old children of intact families and were screened by a developmental pediatrician for other DSM-4 diagnoses and medical conditions. Some of the subjects were medicated and some were not. A quasi-experimental waiting control group design was used with repeated psychometric tests consisting of the Wechsler Intelligence Scale for Children Third Edition (WISC-3), Raven Progressive Matrices (RPM), Wechsler Individual Achievement Test (WIAT), Achenbach Child Behavior Checklist and Profiles (CBCL-P), the computerized performance Test of Variables of Attention (T.O.V.A.), and two separate EEG measures. No significant changes were noted in any waiting period control group tests. Experimental results revealed highly significant (P<.05 two-tailed) EEG changes, improvements in the WISC-3 processing speed and freedom from distractibility scales, WIAT, CBCL-P, and T.O.V.A. fourth quarter commission error test scores. The results of this study are encouraging. The primary goal was accomplished and the hypotheses were supported by the data. Further study is indicated to explore the effects of longer treatment courses, different training goals, and better data procurement procedures using outcome measures of EEG variability coupled with successful psychometric performance.

Study Significance and Background

The study of Attention Deficit/Hyperactivity Disorder (ADHD) has markedly changed in recent years. Children who have been identified as having ADHD have commonly been characterized by impulsivity, inattention, and overactivity. Psychometric and neurophysiologic studies have identified faulty regulation of certain key aspects of attention and nervous system arousal as being central to the understanding of this disorder.

Treatment with psychostimulants has been traditionally used under the assumption that symptoms can be alleviated if neuroendocrine changes can be achieved (Barkley, 1992; Bradley, 1937). This treatment, though commonly used and accepted, is not without some controversy (Forness, Cantwell, Swanson, Hanna, & Youpa, 1991; Swanson, Cantwell, Lerner, McBurnett, & Hana, 1991; Whalen & Henker, 1991). It is, therefore, not surprising that some researchers have explored the possibility of using biofeedback to increase the symptom control in these children. The initial results of biofeedback based on physiologic indicators of arousal such as skin sweat or muscle tension have not been encouraging according to Barkley (1992). More recently researchers such as Lubar (1989), Carter and Russell (1981), and Tansey (1990) have explored the possibility of using brain wave activity reflected in the electroencephalograph (EEG) as physiologic indicators for biofeedback treatment of learning disorders. This research is based on studies in the late 1960's indicating that subjects with severe epilepsy could learn to reduce their symptoms by over 50% through the use of EEG biofeedback that focused on 14 hertz brain wave activity (Lubar et al., 1981; Sterman & Friar, 1972). Researchers studying epilepsy also noted positive changes in sleep problems and concentration in their subjects (Lubar, 1991). Dr. Lubar subsequently focused on learning disorders and developed specific EEG-based clinical treatments. Preliminary research reports indicate promising results in the treatment of attention deficit disorders, dyslexia, and certain other disorders (Lubar, 1989, 1991; Othmer & Othmer, 1992; Tansey, 1990, 1991, 1993).

Along with the developments in EEG-based treatments, other treatments have evolved that are based on much earlier observations. It has been noted that flashing lights and rhythmic sounds have the capacity to affect mood and health, produce altered states of consciousness, and affect cognition (Hutchinson, 1986, 1992). Researchers Walter and Walter (1949) reported the human EEG could be altered by visually presented pulses of light, and that this process could be augmented by an elementary form of biofeedback consisting of an electric switch that was activated by the EEG signal. Recent researchers (Anderson, 1988; Ochs, 1993; Russell & Carter, 1992) have followed up on the effects of flashing lights or photic stimulation and report positive benefits in subjects with migraine headaches, strokes, minor head injury, and attention deficit disorders.

Neurotherapy treatment has traditionally consisted of 40-80 sessions (Lubar, 1991). Clinical improvement is measured via increased mean amplitude or power in SMR or beta bands and decreased amplitude or power in theta band, as well as improvement on certain psychometric tests (Lubar, Swartwood, Swartwood, & O'Donnell, 1995; Othmer & Othmer 1992; Tansey 1990). A recent review by the author revealed there are few controlled studies using brief and more intensive treatment procedures in the literature.

Examining EEG parameters while simultaneously engaged in computerized performance tasks has also not been reported. The presence of desynchronized high frequency activity in the frontal cortex in response to cognitive tasks is recognized as indicative of focused arousal in awake humans (Mattson, Sheer, & Fletcher, 1992), and brain wave activity in the 12-16 Hz may indicate "a more focused state of wakefulness" (Sterman, Macdonald, & Stone, p. 412). The persistance of developmentally inappropriate synchronous frontal low frequency activity may be indicative of learning or behavioral disorders (Lubar et al., 1995). This author would suggest that combining test performances with simultaneous EEG measures might be more revealing of generalization from training. The following study was designed to answer the questions:

1. Is it possible to effect changes in ADHD behavior using 15 sessions of intensive Photic-Driven EEG Neurotherapy?

2. Is it possible to measure the EEG while engaged in tasks such as the T.O.V.A.?

3. What changes in the EEG and test performance will indicate generalization from training?

Methods

The design utilized in the study was quasi-experimental and used a randomized waiting control group with repeated measures. Subjects were randomly assigned to one of two groups. The first group received psychometric testing followed by a 4-6 week waiting period. At the conclusion of the waiting period the testing was repeated and the subjects were assigned to treatment with the protocol. Members of the second randomized group were assigned to treatment immediately following initial testing (see Table 1 for specifics of testing procedures). Both groups were tested following treatment. The independent variable in the study was treatment with photic-driven EEG training and an attempt was made to align the dependent measures with current

DSM-IV diagnostic descriptors of attention and impulsivity/hyperactivity (APA, 1994). The dependent variables were as follows:

1. Attention as measured by the Wechsler Intelligence Scale for Children Third Revision (WISC-3) freedom from distractibility scale, Test of Variables of Attention (T.O.V.A.) errors of omission, Raven Progressive Matrices (RPM), Achenbach Child Behavior Checklist and Profiles (CBCL-P) attention problem profiles scale, and decreased 4-7 Hz (theta) and increased 15-18 Hz band EEG activity while doing the T.O.V.A. as well as in quantitative EEG brain maps.

2. Impulsivity as measured by the WISC-3 processing speed scale, T.O.V.A. errors of commission, CBCL-P attention problems profiles scale, decreased theta and increased 12-14 Hz (SMR) activity while doing the T.O.V.A. as well as in the quantitative EEG brain maps.

3. Scholastic Achievement as measured by the Wechsler Individual Achievement Test (WIAT).

Participants

A convenient sample of 32 children from intact families was used and were recruited from a developmental pediatrician's private practice, from personal referrals, and from the Children of Attention Deficit Disorder (CHADD) organization in Seattle, Washington. Following telephone contact by the researcher, 25 families agreed to enter the study. The children were ages 8-14. All children had a physical exam and were diagnosed by the developmental pediatrician using DSM-III-R criteria. Exclusionary criteria included any history (personal or familial) of epilepsy, severe hyperactivity, mental retardation, or other co-morbid psychiatric disorders. An attempt was made to limit intake of ADHD medications for at least 8 hours prior to testing or treatment sessions and medication dosages were not

Table 1
Testing procedures and responses obtained in the Neuronal Regulation and ADHD: An Application of Photic Driven EEG Neurotherapy study.

Instrument	#1 pretest	#2 pretest (controls)	Posttests (completed)	3 month (follow-up)	Analyzed
WISC-3	25	12/25	25		21 incl. 10 controls
WIAT	25			11	11
RPM	25	12/25	25		21 incl. 10 controls
CBCL-P *	25		13		13
CBCL-P **	25		11		11
QEEG	5	5	5		5
T.O.V.A. and EEG	25	12/25	25		21 inc. 10 controls

#1=pretest, #2= control repeat of pretest, posttest= repeat of test after treatment,WISC-3= Wechsler Intelligence scale for Children 3rd edition, RPM= Raven Progressive Matrices, CBCL-P=Child Behavior Checklist and Profiles Attention Problem Profile,*= parent reports, **= child self-reports, T.O.V.A.= Test of Variables of Attention, QEEG= quantitative EEG brain wave activity maps. CBCL-P (parent and child) and WIAT suffered from poor subject follow through post treatment.

changed throughout the study. A clinical and academic history was obtained and a brief neurological screening exam was performed by the researcher. The purpose of the exam was to identify any hearing or vision problems and consisted of testing the 12 cranial nerves as described by Goldberg (1990).

EEG Procedures

The bands used in the study were as follows: delta (0-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), SMR (12-14 Hz), and beta (15-18 Hz). The EEG testing procedures consisted of an initial interview followed by arrangements for a 1-1/2 hour testing session. A representative sample of 5 was additionally tested to obtain quantitative EEG's and dynamic brain wave activity maps using a Lexicor Neurosearch 24 channel EEG system (Lexicor Medical Technology, Inc., Boulder, Colorado). The sampling rate was 128/second, the high and low pass filters were set at 0.5 and 32 Hz respectively, and the gain was set at 32K. An Electro-Cap was used (Electro-cap International, Eaton, Ohio) and impedance at the 19 active electrodes were kept below 5 KOhms. Subjects also had their EEG activity measured while they were engaged doing the T.O.V.A. using a monopolar placement at Cz and linked ears for ground and reference with the J&J I-400A and PDS software system. The J&J I-400A utilizes band-pass filters to sample EEG data at up to 128 samples per second. Electrode impedances were maintained below 5 KOhms.

The photic-driven EEG training consisted of 15 sessions provided in the Management of the Stress Response Clinic at the University of Washington School of Nursing. The equipment consisted of a set of wrap-around photic stimulation sunglasses provided by Synetic Systems Inc. They were coupled to a J&J I-400A EEG sensor system using the PDS software system. The EEG sensor system was utilized to measure the EEG and control the frequency of the photic driving. The system works by capturing and analyzing the subject's dominant EEG frequency. The energy is then converted into pulses of light by the use of an IBM 486 Personal Computer (PC). The light pulses are presented via the wrap-around sunglasses. The sunglasses have eight light emitting diodes (LED) that have four per side and produce 2 candle power at maximum intensity. The intensity was controlled by the researcher via the PDS software system and no subject received more than 25% of maximum light intensity.

The goal of the training sessions was to gradually increase the production of 12-14 Hz activity and decrease the production of 4-8 Hz activity. Subjects were instructed to keep their eyes closed throughout the training procedure. The light pulses emitted by the sunglasses produced distinct patterns on the subject's closed eye lids. The subjects were then assisted to identify and attempt to reproduce the pattern associated with 12-14 Hz. This was accomplished by using the software program to set the frequency of the lights at 12-14 Hz, and the subject was instructed to describe the resulting pattern. They were then told to "watch for this pattern." When they could reliably identify the 12-14 Hz pattern, and the researcher could also see this EEG frequency activity on the computerized graphic display, they were instructed to "try to make this pattern happen more frequently." An attempt was then made to pair the light patterns with a sound tone that came on when the subject exceeded a pre-set threshold of 12-14 Hz activity. The sound tone was inhibited when a preset threshold of 4-8 Hz occured. The researcher controlled the thresholds through software graphic displays available in PDS. The thresholds appeared as dotted lines superimposed on individually colored frequency display bars. The thresholds could be adjusted by manipulating the dotted lines up and down.

Up to this point the purpose of the photic stimulation was to aid the subject's production of 12-14 Hz. Over the last several sessions the photic stimulation was gradually withdrawn. The subjects were then encouraged to elicit the sound tones without

Table 2
Protocol for Photic-driven EEG Neurofeedback in the Neuronal Regulation and ADHD: An Application of Photic Driven EEG Neurotherapy study.

Session #.	Task	Indicators
1.	Adjust light levels.	Subject reports comfort.
2.	Introduce 14 Hz pattern.	Subject describes distinct predictable pattern (count & use spectral dominant as indicator to compare).
3	Introduce sound tone.	Subject indicates hearing tone in close proximity to pattern.
4.	Begin internal focusing.	Subject counts the tones/patterns & notes internal associated states.
5.	Continue internal focus.	Subject verbalizes an awareness of need to focus & inhibit movement.
6.	Increase tones/patterns.	Subject counts tones/patterns & can increase #'s.
7.	Establish training.	Therapist manipulates the inhibit/training thresholds & subject learns to evoke tones/patterns.
8.	Continue training.	As above.
9.	Consolidate training.	As above and add tone at last baseline-(no lights).
10.	Decrease dependence on computer/software.	Focus on association of lights and tone, and begin to decrease photic driving.
11.	Continue generalization.	When photic driving time is decreased subject continues to evoke tones/patterns.
12.	Same as above.	Decrease lights as above.
13.	Same as above.	Continue decreasing lights.
14.	Same as above.	Subject should be able to evoke tones/patterns in session without lights.
15.	Terminate and transfer skills.	Subject does session without lights & indicates confidence in ability to reproduce tones and associated feeling state.

benefit of the lights for longer periods of time, thus producing more 12-14 Hz activity and less 4-8 Hz activity on their own.

The goal was accomplished gradually over a total of 15 daily sessions. Total treatment session length averaged 40 to 50 minutes. Each treatment session consisted of photic-driven training intervals that typically lasted 2-4 minutes as well as frequent rest periods of up to 4 minutes to forestall fatigue (see Table 2 for specific details of training protocol).

Results

There were 8 girls and 17 boys, and 14 of the 25 subjects were medicated. Twenty-five percent of the girls were medicated as opposed to 75% of the boys. One subject dropped out of the study after 10 sessions due to an exacerbation of aggressive behavior. Three subjects were removed from the data base due to severe hyperactive behavior that precluded valid interpretation of the data. One of these subjects had a prenatal exposure to cocaine, and the other two were poorly controlled on a combination of antidepressant and stimulant medications. Unfortunately, one of the subjects who was removed from the database was from the control group, and an additional control subject dropped out. This resulted in only 10 subjects remaining in the control group. In all, 21 subjects were included for analysis in the complete database.

A significance level of .05 (two tailed) was accepted for this study and only results that exceed the significance level are presented in Tables 2-5. Analyses were performed using split sample Paired-t-Tests. Due to the fact that the data were not normally distributed, nonparametric Wilcoxon Matched-Pairs Signed-Ranks Tests were additionally performed (Hinkle, Wiersma, & Jurs, 1988).

Discussion of Results

Psychometric Data

The subjects did benefit from the 15 sessions of neurotherapy. Overall none of the 10 control group subjects showed significant changes in any measure. The experimental group subjects made major gains in controlling impulsivity. This was especially evident in the WISC-3 processing speed scale scores (81% improved), T.O.V.A. fourth quarter errors of commission (95% improved), and the CBCL-P scores (69% of parent ratings improved and 72% of child ratings improved) (see Tables 3 & 4). The subjects also made highly significant gains in attention as evidenced by the scores on the WISC-3 freedom from distractibility scales (81% improved) and CBCL-P scores (see Tables 3 & 4). The post-treatment improvements in WIAT scores were statistically significant and although only 11 of the 25 subjects agreed to retesting at 3 months, all 11 improved. There was a lack of significant improvements in other measures such as the RPM or T.O.V.A. omission error scores.

The gains made on the WISC-3 scores could be explained on the basis of the fact that they were repeated at less than the recommended six months period between testing episodes. The T.O.V.A. results are less open to such interpretation as the

Table 3
Statistical significance in Paired-t-Test values post treatment for the Neuronal Regulation and ADHD: An Application of Photic-Driven EEG Neurotherapy study.

Tests, df=degrees of freedom	t=t-value, M=Mean, SD= Standard Deviation	t critical at 0.05 (two-tailed)	p value (two-tailed)
WISC-3 PS, df=20	t= -5.48, M= -4.33, SD =3.62	2.09	<.001
WISC-3 SD, df=20	t= -3.68, M= -3.19, SD =3.97	2.09	.001
WIAT, df=10	t= -4.55, M=-8.73, SD=6.34	2.23	.001
RPM, df=20	t= -1.57, M= -1.76, SD 5.15	2.09	.132
CBCL-P*, df=12	t= 2.78, M= 2.61, SD 3.31	2.18	<.05
CBCL-P**, df=10	t=2.83, M= 1.54, SD 1.81	2.23	<.05
TOVA4om, df=20	t= 0.67, M= 0.48, SD 3.27	2.09	.512
TOVA4com, df=20	t= 4.26, M=16.76, SD 18.23	2.09	<.001

WISC-3= Wechsler Intelligence Scale for Children 3rd Edition, PS= processing speed scale, FD= freedom from distractibility scale, WIAT= Wechsler Individual Achievement Test, RPM= Raven Progressive Matrices, CBCL-P= Child Behavior Checklist and Profiles Attention Problem Profile, *=parent form, **= youth self report form, TOVA4com= T.O.V.A. fourth quarter errors of commission, TOVA4om= T.O.V.A. fourth quarter omission errors.

Table 4

Statistical significance in Wilcoxon Matched-Pairs Signed-Ranks values pre and post treatment for the Neuronal Regulation and ADHD: An Application of Photic-Driven EEG Neurotherapy study.

Tests	Ranks *=posttest<prestest, **=posttest > than prestest, *** = tie	Z score	2-tailed p
1WISC-3PS with 2WISC-3PS, n=21	*=3,**=17,***=1	-3.58	<0.001
1WISC-3FD with 2WISC-3FD, n=21	*=3,**=17,***=1	-2.99	0.003
1WIAT with 2WIAT, n=11	*=0, **=11, ***=0	2.93	0.003
1CBCL-P* with 2CBCL-P*, n=13	*=9,**=1,***=3	-2.65	0.008
1CBCL-P** with 2CBCL-P**, n=11	*=8,**=1,***=2	-2.19	0.028
1TOVA4com with 2TOVA4com, n=21	*=20,**=1,***=0	-3.86	<0.001

1=prestest, 2=posttest, WISC-3=Wechsler Intelligence Scale for Children, 3rd Edition, PS=processing speed scale, FD= freedom from distractibility scale, WIAT=Wechsler Individual Achievement Test, CBCL-P=Child Behavior Checklist and Profiles Attention Problem Profile, *=parent form, **= youth self report form, TOVA4com= T.O.V.A. fourth quarter errors of commission.

T.O.V.A. has "little practice effect" according to Greenberg (1991, p. 9). In a separately performed analysis the T.O.V.A. results also correlated quite robustly with the WISC-3 results (r = .58, P = .01).

EEG data

There were some interesting changes indicated in the EEG measures. Overall mean amplitudes in theta, SMR, and beta bands failed to change significantly in either the QEEG's or while doing the T.O.V.A. However, when the standard deviations of the EEG bands were examined as indicators of variability around the mean samples, the standard deviations of subjects' theta, SMR, and beta band activity increased significantly while engaged in the T.O.V.A. Specifically, 67% of the subjects increased variability in theta, 72% of subjects increased variability in beta, and 50% of the subjects increased variability in SMR (see Table 5). Increased variability in the EEG band sample means indicates some samples were much higher

Table 5

Statistical significance in Wilcoxon Matched-Pairs Signed-Ranks electroencephalograph values post treatment for the Neuronal Regulation and ADHD: An Application of Photic-Driven EEG Neurotherapy study.

Tests	Ranks *=posttest<prestest, **=posttest > than prestest, ***=tie	Z score	2-tailed p
1T-var with 2T-var, n=18	*=5,**=12,***=1	-2.012	0.044
1SMRvar with 2SMR-var, n=18	*=9,**=9,***=0	-0.065	0.948
1Beta-var with 2Beta-var, n=18	*=5,**=13,***=0	-2.374	0.018

Variability= standard deviations in amplitude, T-var=theta band variability, SMR-var SMR band variability, Beta-var= beta band variability while subject engaged in doing the T.O.V.A.

and some much lower. This may indicate some degree of training. However, due to the lack of temporal linkage with performance, it is unclear as to when the subjects actually increased beta or decreased theta in response to the cognitive task. For example, it would be significant if subjects increased beta and decreased theta just before pressing the button.

Three from the small subsample of 5 QEEG subjects also had increased frontal beta band coherence (coherence >1, 1, and 2 respectively) when examined using the QEEG procedure. Increased frontal beta coherence may also indicate the subjects were able to learn to modify their EEG patterns. However, the small number of subjects makes interpretation of this data risky.

Summary

It was possible to measure subject performance during the T.O.V.A. and the subjects made dramatic gains in some of the psychometric tests. The psychometric results combined with the increased EEG variability while the subjects were successfully engaged in doing the T.O.V.A. may call into question the conventional wisdom of using mean amplitude or power measures as indicators of training efficacy. Perhaps variability in the EEG when performing a cognitive task such as the T.O.V.A. is an important and much overlooked indicator of successful generalization from EEG neurotherapy training. If the variability can be more closely linked to actual performance, it may indicate increased subject flexibility in response to cognitive challenges. This may be more important than overall EEG mean amplitude or power changes. An interesting venture would be to more accurately measure the EEG dynamics in close temporal relationship with the subject's actual performance during the T.O.V.A., or some other computerized performance test. If the increased variability could thus be more closely temporally linked with improved subject performance during the performance test, a stronger case could be made for using variability as an outcome measure.

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