

4-2012

Analysis of EEG rhythms using custom-made MatLab application for processing of data collected during neurofeedback training in ADHD subjects.

Brent Hillard

University of Louisville

Follow this and additional works at: <http://ir.library.louisville.edu/etd>

Recommended Citation

Hillard, Brent, "Analysis of EEG rhythms using custom-made MatLab application for processing of data collected during neurofeedback training in ADHD subjects." (2012). *Electronic Theses and Dissertations*. Paper 620.
<https://doi.org/10.18297/etd/620>

This Master's Thesis is brought to you for free and open access by ThinkIR: The University of Louisville's Institutional Repository. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of ThinkIR: The University of Louisville's Institutional Repository. This title appears here courtesy of the author, who has retained all other copyrights. For more information, please contact thinkir@louisville.edu.

ANALYSIS OF EEG RHYTHMS USING CUSTOM-MADE MATLAB
APPLICATION FOR PROCESSING OF DATA COLLECTED DURING
NEUROFEEDBACK TRAINING IN ADHD SUBJECTS

By

Brent Hillard
B.S., University of Louisville, 2011

A Thesis
Submitted to the Faculty of the
University of Louisville
J.B. Speed School of Engineering
as Partial Fulfillment of the Requirements
for the Professional Degree

MASTER OF ENGINEERING

Department of Bioengineering

April 2012

ANALYSIS OF EEG RHYTHMS USING CUSTOM-MADE MATLAB
APPLICATION FOR PROCESSING OF DATA COLLECTED DURING
NEUROFEEDBACK TRAINING IN ADHD SUBJECTS

Submitted by: _____
Brent Allen Hillard

A Thesis Approved On

Date

by the Following Reading and Examination Committee:

Ayman El-Baz, Ph.D., Thesis Director

Estate Sokhadze, Ph.D.

Palaniappan Sethu, Ph.D.

Karla Welch, Ph.D.

ACKNOWLEDGEMENTS

Without the help of numerous individuals, this thesis and research presented herein would not be possible. The first such individual that has made this possible is Dr. Estate Sokhadze. Dr. Sokhadze has given me nearly unlimited access to his lab to aid in the research experience. His guidance throughout this project has been instrumental in its completion. Additionally, Dr. Sokhadze has provided valuable education over this year to me concerning aspects of the research process such as scientific poster preparations and the writing of journal papers.

Dr. Ayman El-Baz has played a highly influential role in this thesis, as well as throughout my entire academic career. In addition to serving as my advisor for this thesis, Dr. El-Baz served as my academic advisor during my undergraduate years in bioengineering. Dr. El-Baz has freely given me advice, time in the lab, and the knowledge base necessary to complete this thesis. His classes in signal processing have paved the way for completion of this thesis.

Finally, this thesis would not have been possible without the support –financial, mental, and spiritual – given to me by my family these past five years. I owe more to them than I can express in words and am truly grateful for all they do and continue to do. They have been with me every step of the way in my life, and have helped me in any way they can. Their guidance has been immensely helpful in my completion of this chapter of my life and the pursuit of the next chapter.

ABSTRACT

INTRODUCTION: Attention Deficit/Hyperactivity Disorder (ADHD) is a disorder that is prevalent throughout the world. It is believed that 5% of school aged children suffer from ADHD, with some estimates indicating as high as 10% may suffer from the disorder. Primarily, three subtypes of ADHD have been associated with certain electroencephalographic (EEG) abnormalities. The most common treatment for ADHD is medication. However, neurofeedback is considered an efficacious treatment for ADHD. It is proposed that neurofeedback training aimed to mitigate inattention and low arousal in ADHD will be accompanied by changes in EEG bands' relative power.

DATA COLLECTION: Patients were 18 children with ADHD. The neurofeedback protocol used to train patients has focused attention training mode, which according to specifications, represents an EEG desynchronization measure. The neurofeedback protocol provides one numeric output for "Focus" and one numeric output for "Alertness". This does not allow for collecting information regarding changes of specific EEG bands' power within 2-45 Hz range. Therefore, data was collected for EEG bands through the use of BioExplorer and BioReview software. Each subject completed 12 sessions with a target length of 25 minutes per session. Additionally, IVA+Plus test and ABC behavioral survey measures were administered both pre- and post- neurofeedback.

DATA PROCESSING AND ANALYSIS: Analysis was completed on each of the 25 min long twelve sessions using a custom-made MatLab application to determine the relative power of each of the EEG bands throughout each session and from the first session to the

last session. Additional statistical analysis was performed to determine significant changes in relative power within sessions (from minute 1 to minute 25), and between sessions (from session 1 to session 12) for an individual patient using an ANOVA. Additionally, a correlation analysis was performed to determine possible correlations between the “Focus” measure and changes in relative power of Theta, Alpha, Low and High Beta, Theta/Alpha, Theta/Beta, and Theta/Low Beta and Theta/High Beta ratios. Additional measures of patients’ post-neurofeedback outcomes were assessed using an audio-visual selective attention test and behavioral evaluation scores and analyzed through a paired t-test.

RESULTS: Through statistical analysis of the data computed in the MatLab application, we determined that, as expected, Theta/Low Beta and Theta/Alpha ratios decreased significantly from Session 1 to Session 12 and from minute 1 to minute 25 within sessions. "Focus" measure also demonstrated a significant gradual increase from session 1 to session 12 and from minute 1 to minute 25 within sessions. The “Focus” measure of the protocol showed high negative correlation with both Theta/Alpha and Theta/Beta ratios.

CONCLUSIONS: The findings will help in elucidation of neural mechanisms of neurofeedback aimed to improve focused attention in ADHD. Also, this analysis differs from those prior studies in the consideration of what is transpiring not only from session to session, but also within each session. Therefore, improvement can be indicated within a shorter number of sessions (i.e. 12) compared to previous protocols that required 30-40

sessions per subject to indicate statistically significant improvement either in EEG or clinical behavioral measures. Probably more than 12 sessions might contribute to better consolidation of results of operant conditioning using neurofeedback and currently, we have a study in progress that will compare outcomes of 12 vs. 18 sessions of neurofeedback using the same protocol.

TABLE OF CONTENTS

APPROVAL PAGE.....	iii
ACKNOWLEDGMENTS.....	iv
ABSTRACT.....	v
LIST OF TABLES.....	ix
LIST OF FIGURES.....	xi
I. INTRODUCTION.....	1
A. ADHD Prevalence and Clinical Significance	1
B. Causes of ADHD in Childhood Population.....	2
C. EEG Subtype Characteristics of ADHD and Comorbidities.....	3
D. ADHD Treatment Options.....	6
E. Goals and Expectations of this Study.....	10
II. DATA COLLECTION.....	11
A. Subject Demographics and Recruitment.....	11
B. Neurofeedback Protocol and Data Recording.....	11
C. Clinical and Neuropsychological Measures of ADHD.....	15
III. DATA PROCESSING AND ANALYSIS.....	16
A. EEG Signal Processing.....	16
B. Statistical Analysis.....	21
IV. RESULTS.....	23
A. EEG Measures changes by Session.....	23
B. EEG Measures changes by Minute.....	27
C. Correlation between "Focus" Measure and EEG Band Relative Powers/Ratio.....	31
D. IVA+ and ABC Survey – Pre- and Post-Neurofeedback.....	34
V. CONCLUSIONS.....	37
VI. FUTURE WORK AND RECOMMENDATIONS.....	44
REFERENCES	46
APPENDIX I. MATLAB CODE.....	51
A. EEG Signal Processing Main Code.....	51
B. Input Signal Filtering Function.....	54
C. 2-45 Hz Band-pass Filter Function.....	55
D. Harris Window Function.....	56
E. Impulse Response LPF Function.....	58
F. Main Analysis Code.....	59
APPENDIX II. DATA TABLES.....	68
A. Raw Data for Analysis.....	68
B. T-test Results for ABC and IVA+Plus Measures.....	80
C. Minitab ANOVA Table Output and Pearson Correlation Test Output	82
VITA.....	86

LIST OF TABLES

Table 1: Summary of ANOVA results for each EEG measure and Investigated EEG band power ratio using Session as a Factor and the interested EEG measure as the response.

Table 2: Summary of ANOVA results for each EEG measure and investigated EEG band power ratio using Session as a Factor and the interested EEG measure as the response.

Table 3: Summary of results of Pearson correlation test using corresponding average values of EEG band relative powers and EEG band ratios with "Focus" measure. Table also includes linear relationship equations for significant correlations with R^2 values. In the table, the y-variable represents "Focus" and the x-variable represents either the EEG band relative power or the EEG band ratio.

Table 4: Summary of significant changes within the IVA+Plus using a two tailed t-test comparing data of Pre- and Post- Neurofeedback.

Table 5: Summary of significant changes in clinical measures as indicated by the Aberrant Behavior Checklist survey using a two tailed t-test comparing data of Pre- and Post- Neurofeedback. A p-value < 0.05 was considered significant for the t-test.

Table 6: Raw data from MatLab analysis for Session 1. Data used for ANOVA calculations in MiniTab.

Table 7: Raw data from MatLab analysis for Session 2. Data used for ANOVA calculations in MiniTab.

Table 8: Raw data from MatLab analysis for Session 3. Data used for ANOVA calculations in MiniTab.

Table 9: Raw data from MatLab analysis for Session 4. Data used for ANOVA calculations in MiniTab.

Table 10: Raw data from MatLab analysis for Session 5. Data used for ANOVA calculations in MiniTab.

Table 11: Raw data from MatLab analysis for Session 6. Data used for ANOVA calculations in MiniTab.

Table 12: Raw data from MatLab analysis for Session 7. Data used for ANOVA calculations in MiniTab.

Table 13: Raw data from MatLab analysis for Session 8. Data used for ANOVA calculations in MiniTab.

Table 14: Raw data from MatLab analysis for Session 9. Data used for ANOVA calculations in MiniTab.

Table 15: Raw data from MatLab analysis for Session 10. Data used for ANOVA calculations in MiniTab.

Table 16: Raw data from MatLab analysis for Session 11. Data used for ANOVA calculations in MiniTab.

Table 17: Raw data from MatLab analysis for Session 12. Data used for ANOVA calculations in MiniTab.

LIST OF FIGURES

Figure 1: Sample Neurofeedback interface as seen by a patient during a neurofeedback session showing the EEG signal with DVD video embedded in screen.

Figure 2: The setup is shown for a subject undergoing neurofeedback. The image clearly illustrates the positioning of sensors, subject, and monitor.

Figure 3: BioReview report block diagram with filters for each EEG band collected [raw signal, Delta (2-4 Hz), Theta (4-8 Hz), Alpha (8-13 Hz), Low Beta (13-18 Hz), High Beta (18-30 Hz), Gamma (30-45 Hz)]

Figure 4: Block Diagram to demonstrate MatLab coding for cell array. Each subsequent row in the array represents the subsequent session. Each column represents an additional subject. The mean for each session is calculated by summing across each row of the cell array to determine the mean of the EEG measures for each minute within that session.

Figure 5: Plot of average Theta/Low Beta ratio value for each session (session number 1-12) indicating a decrease in the value of Theta/Low Beta ratio as session number increases. R^2 value and equation for linear relationship included on the plot.

Figure 6: Plot of average Theta/Alpha ratio value for each session (session number 1-12) indicating a decrease in the value of Theta/Alpha ratio as session number increases. R^2 value and equation for linear relationship included on the plot.

Figure 7: Plot of average "Focus" value for each session (session number 1-12) indicating an increase in the value of "Focus" as session number increases. R^2 value and equation for linear relationship included on the plot.

Figure 8: Plot of average Theta/Low Beta ratios (averaged across all sessions) for each minute of Neurofeedback (1-25) indicating a decreasing Theta/Low Beta ratio as minute of NFB within a session increases. R^2 value and equation for logarithmic relationship included on the plot.

Figure 9: Plot of average Theta/Alpha ratios (averaged across all sessions) for each minute of Neurofeedback (1-25) indicating a decreasing Theta/Alpha ratio as minute of NFB within a session increases. R^2 value and equation for logarithmic relationship included on the plot.

Figure 10: Plot of average "Focus" values (averaged across all sessions) for each minute of Neurofeedback (1-25) indicating an increasing "Focus" measure as minute of NFB within a session increases. R^2 value and equation for logarithmic relationship included on the plot.

Figure 11: Plot of correlation between corresponding average "Focus" values and Theta/Low Beta ratios for Sessions 1-12 and Minute 1-25 of NFB within a session.

Figure 12: Plot of correlation between corresponding average "Focus" values and Theta/Alpha ratios for Sessions 1-12 and Minute 1-25 of NFB within a session.

Figure 13: The surface chart provides evidence supporting the decrease in the Theta/Low Beta ratio with regards to increasing session number and increasing minute of each session. As is consistent with the results of the ANOVA, Session trends, and Minute trend analysis, a general decrease is seen from (Session 1, Minute 1) through (Session 12, Minute 25) for the Theta/Low Beta ratio. The legend on the right side of the figure gives the color-coded ranges for the Theta/Low Beta ratio, as seen in the chart.

Figure 14: The surface chart provides evidence supporting the decrease in the Theta/Alpha ratio with regards to increasing session number and increasing minute of each session. As is consistent with the results of the ANOVA, Session trends, and Minute trend analysis, a general decrease is seen from (Session 1, Minute 1) through (Session 12, Minute 25) for the Theta/Alpha ratio. The legend on the right side of the figure gives the color-coded ranges for the Theta/Alpha ratio, as seen in the chart.

Figure 15: The surface chart provides anecdotal evidence supporting the increase in the "Focus" measure with regards to increasing session number and increasing minute of each session. As is consistent with the results of the ANOVA, Session trends, and Minute trend analysis, a general increase is seen from (Session 1, Minute 1) through (Session 12, Minute 25) for the "Focus" measure. The legend on the right side of the figure gives the color-coded ranges for the "Focus" measure, as seen in the chart.

I. INTRODUCTION

A. ADHD Prevalence and Clinical Significance

Attention Deficit/Hyperactivity Disorder (ADHD) is a disorder that is prevalent throughout the world. It is believed that 5% of school aged children suffer from ADHD, with some estimates indicating as high as 10% may suffer from the disorder (American Psychiatric Association, 2000; Faraone et al. 2003). Male children are 3 times as likely as female children to be diagnosed and treated for ADHD. The primary indications of ADHD are moderate to extreme inattention, evidenced by the inability to "focus" on specific tasks, and the hyperactivity component evidenced through fidgeting, agitation, and impulsivity (Biederman 2005; Gevensleben et al. 2009). Of the 5% of children that exhibit ADHD symptoms in childhood, 30-50% of those children exhibit symptoms in a chronic manner that continues to present into adulthood (Holtmann and Stadler 2006). Although, certain diagnostic differences exist between children who outgrow the disease compared to children who continue to present in adulthood (Clarke et al. 2010). The functional outcomes of ADHD can be detrimental to childhood development and prevent the necessary foundation for a successful life. Common problems associated and attributed to ADHD include poor academic performance, lower occupational success, increased risk-taking behavior, and diminished social relationships (Holtmann and Stadler 2006). The literature also cites that ADHD diagnoses increase the likelihood of other psychiatric diagnoses, which could lead to impaired functional adaptations later in

life (Gillberg et al. 2004; Gevensleben et al. 2009). This distinction of an ADHD diagnosis accounts for the high prevalence of comorbidities associated with ADHD that are common in childhood cases. For instance, diagnoses of ADHD are commonly associated with psychiatric disorders including, but not limited to, conduct disorder, oppositional defiant disorder, and learning disorders (Pliszka 1998; Holtmann and Stadler 2006).

B. Causes of ADHD in Childhood Population

Despite similar diagnosis amongst a large patient demographic, the underlying causes of ADHD are varied, but well documented. Extensive research (Biederman 2005) demonstrates the strongest indicator of ADHD is a genetic/hereditary etiology with environmental factors believed to play a key role. Studies (Faraone et al. 2005) have shown that a familial connection with ADHD increases the chances of exhibiting the disorder by a factor of 2 to 8. Since familial studies don't expressly separate genetic and environmental factors, twin and adoption studies have been utilized to determine the balance of effects believed to cause ADHD. Based on extensive twin studies (Faraone and Mick 2010), it was hypothesized that approximately 76% of the cause of ADHD could be attributed to familial factors and genetic. When correcting for bias due to interaction between twins, the estimate was reduced, although still the majority, with familial influence accounting for 60% of the diagnoses of ADHD (Cortese 2012; Wood et al. 2009). Additionally, adoption studies (Cortese 2012) have been clear in their implications regarding the hereditary nature of ADHD. In adoption studies, it has been

shown that children with a biological connection to ADHD are more likely to exhibit hyperactivity than their adoptive counterparts with no biological link to ADHD.

C. EEG Subtype Characteristics of ADHD and Comorbidities

Attention Deficit/Hyperactivity Disorder has been known to associate with certain symptoms for many years. However, recently interest has been focused on studying the EEG patterns of children with ADHD to determine whether certain abnormalities existed in the EEG patterns of diagnosed children and how those abnormalities correlate to clinical manifestations of ADHD. As a result of initial studies (Barry, Clarke, and Johnstone 2003), it has been determined that compared to gender- and age-matched control, children with ADHD express three different manifestations of EEG signals. In general, EEG signals are separated into frequency ranges for characterization purposes. The range of frequencies for each group can vary, but from low to high frequencies the characterization is Delta, Theta, Alpha, Beta, and Gamma ranges. One group shows an increase in slow wave activity (e.g. Delta) and a decrease in the faster wave (e.g. Alpha and Beta) frequencies (Clarke et al. 2001, 2002). This group was initially labeled as "maturationally-lagged." A second group, labeled "hyperaroused", showed increased Theta amplitude, with decreased Beta activity (Clarke et al. 1998, 2001, 2002). Intuitively, this manifests as an increase in the Theta/Beta ratio, which has been shown to be one of the most significant measures changing in ADHD treatment studies (Barry, Clarke, and Johnstone 2003). The third group, also identified tentatively as "hyperaroused", exhibited an increase in Beta activity (Clarke et al. 2001). However, as previously noted, ADHD diagnosis commonly presents with comorbidities. The studies

isolating these groups screened exclusively for children only presenting an ADHD diagnosis. Therefore it was not representative of the clinical population. As a result, an additional study has been completed where children were not screened for comorbidities prior to inclusion.

In the most recent study into EEG subtypes relating to ADHD, Clarke et al. (2011b) separated the EEG manifestations into five clusters, with two being later combined due to similarities to yield a total of four central nervous system (CNS) abnormalities. In this study, the two combined clusters displayed an increase in total power and Theta signals with a decrease in Alpha and Beta activity. This combined cluster was designated in a previous study (Barry, Clarke, and Johnstone 2003) as "hyperarousal" and represented 35% of patients in this study (Clarke et al. 2011b). Another cluster of patients presented with an increase in Delta and Theta activity and a decrease in Alpha activity coupled with a decrease in total power (Clarke et al. 2011b). This cluster is comparable to the previously labeled group defined as "maturationally-lagged (Barry, Clarke, and Johnstone 2003)." The final cluster that was previously noted and tentatively labeled as "hyperarousal" (Barry, Clarke, and Johnstone 2003) represented 23% of patients in this study (Clarke et al. 2011b). This group presented with increased total power and Beta activity. Additionally, this cluster displayed some decrease in Theta and Alpha activity. Finally, the last cluster determined in this group of patients, representing 17% of patients, did not present in the previous study which excluded all comorbidities (Clarke et al. 2011b). As a result of this newly identified group, which displayed increased Alpha activity with decreased Delta and Theta activity (Clarke et al. 2011b), no attempt was made to characterize this subtype.

An extension of the linking of EEG characteristics to the ADHD diagnosis, concerns the connection between EEG patterns and clinically relevant subtypes of the ADHD diagnosis. The three DSM-IV subtypes of ADHD investigated by Clarke were Inattentive, Hyperactive-Impulsive, and Combined (2011b). Inattentive and Combined subscales showed a correlation with the Theta band, represented by two clusters in one EEG characteristic study (Clarke et al. 2011b). The other measure to display correlation specifically with a subtype was the Theta/Beta ratio, which showed a correlation with Hyperactive-Impulsive subtype, as well as the Combined subtype with two EEG clusters associating with these clinical subtypes (Clarke et al. 2011b).

As previously noted, a common clinical manifestation of ADHD involves many possible comorbid diagnoses. The increased Theta activity found in ADHD EEG characterizations has also been found in some of these diagnoses (e.g. learning disabilities, mental retardation, etc.). Whereas, increased Theta activity was originally theorized to be a result of brain dysfunction, the association of increased Theta activity with Inattentiveness shows that it is possible that Theta activity is actually an indicator of inattention (a symptom present in all these comorbid diagnoses) (Clarke et al. 2011a). A study (Clarke et al. 2011a) of ADHD patients presenting with a comorbid diagnosis of autism with a group presenting only with ADHD found several qualitative differences between the two groups. However, the primary diagnosis for each group was ADHD. This study found that a second comorbid group presented EEG abnormalities that could be considered independent of the ADHD diagnosis. Based on these findings by Clarke et al. (2011a), the inclusion of participants with comorbid disorders in ADHD studies seems logical.

D. ADHD Treatment Options

1. Pharmacological

Due to the broad, highly present, and potentially severe impact of ADHD, it is of high importance to efficaciously and safely treat the symptoms of ADHD. The most prevalent method of treatment for ADHD is the use of medication, whether it be stimulant based (i.e. methylphenidate – the most prominent medication) or nonstimulant based (i.e. atomoxetine) (The MTA Cooperative Group 1999). Both varieties of medication have been shown to be efficacious for treatment of symptoms; however, 25 - 30% of patients experience no response to medication or adverse effects (Greenhill et al. 1999, 2001). Additionally, withdrawal of medication results in patients reverting to previous levels of symptoms. Another important consideration regarding disadvantages of pharmacological treatment is that parents/guardians generally are hesitant to this approach due to side effects commonly associated with medicine (e.g. appetite loss) and the stigma associated with long-term medication in children (Taylor et al. 2004; Banaschewski et al. 2006). Besides pharmacological treatments, several non-pharmacological treatments have been considered in the clinical setting, such as dietary elimination strategies, with results showing a non-significant impact for the majority of ADHD patients (Ferguson 2000).

2. Non-Pharmacological

However, one non-pharmacological solution that has yielded positive results is neurofeedback (also called EEG biofeedback) training. The primary rationale for the utilization of neurofeedback in the treatment of ADHD stems from studies showing abnormal EEG findings in patients with ADHD (Barry, Clarke, and Johnstone 2003). In the majority of patients presenting with ADHD, studies have shown that there is a cortical slowing, or hypo-arousal, in some cases during EEG examinations (Monastra 2005; Holtmann and Stadler 2006). Therefore, neurofeedback treatments have been developed to target the two previously noted EEG abnormalities. It was theorized that through reinforcing a specific change in cortical activity through an auditory or visual display that the patient could normalize this reinforced activity and develop the ability to maintain and control targeted behavior (i.e. hyperactivity or inattention) (Monastra 2005).

Initially, proof of biofeedback producing significant changes in EEG signals was demonstrated in non-human models (Wyrwicka and Sterman 1968). Later, the first documented use of "Sensorimotor Rhythm" (SMR) training in the treatment of ADHD was accomplished in humans (Lubar and Shouse 1976). SMR training targets the brain waves in the 12-15 Hz range at the motor cortex, but this research was later expanded to include increasing EEG activity at higher frequencies (16-20 Hz or "Beta"), while suppressing activity at lower frequencies (4-8 Hz or "Theta"). As a result of these studies, clinical responses have been demonstrated in hyperactive children when treated with neurofeedback (Lubar and Shouse 1976). Most recently, several papers (Arns et al. 2009; Gevensleben et al. 2009; Sherlin et al. 2010a; Van den Bergh 2010) have reported

neurofeedback as being an efficacious treatment in subjects with ADHD. These include meta-analysis, randomized clinical trials, and literature reviews supporting clinical efficacy associated with the utilization of neurofeedback. Therefore, neurofeedback as a treatment for ADHD is widely regarded as having Level 5 (efficacious and specific) efficacy as described by the American Psychological Association (Sherlin et al. 2010a). However, some clinicians in ADHD treatment area have certain concerns and argue that neurofeedback should be considered less efficacious clinically (Lofthouse, Arnold, and Hurt 2010). Nevertheless, the topic of clinical efficacy level of neurofeedback-based intervention in ADHD is still far from consensus and encourages more basic EEG research and clinical trials (Sherlin et al. 2010b).

Three general protocols are prevalent in the literature and have been investigated and shown efficacy in the treatment of ADHD. One such protocol is the SMR Enhancement/Theta Suppression. In this protocol, patients receive feedback based on the amount of time that the SMR signal is above pretreatment thresholds and the Theta signal is below pretreatment thresholds (Rossiter and La Vaque 1995). A secondary protocol utilizes SMR Enhancement combined with "Beta-2" (22-30 Hz) suppression (Fuchs et al. 2003). A third protocol, derived from the second protocol, involved the reinforcement of Theta suppression with "Beta-1" (13-22 Hz) enhancement (Linden, Habib, and Radojevic 1996). One more approach to neurofeedback application in ADHD treatment proposes a protocol (so called "Focus/Alertness" training) that uses wide band EEG spectrum suppression (Sokhadze 2012) rather than control of individual bands.

Due to the difficulty in interpretation of the meaning of the Theta-Beta ratios and other EEG terminology, terms such as "Focus" and "Alertness" that are defined in a clear

way and can be understood through some simple introduction lessons have been developed. Sokhadze has described this protocol in detail (Sokhadze 2012). For instance, instead of telling a subject to suppress Theta or increase Beta, the subject is only instructed to increase "Focus". "Focus", in actuality, is a desynchronization measure of activation of the underlying cortex. This protocol has also been referenced as "InAll", "InhibitAll", or wide band suppression. Using "Focus" as a measure, the higher the quality of visualization of an activity, the larger the resulting "Focus" measure. This is extremely valuable for training via visualization. In contrast to "Focus", "Alertness" is primarily a numerical representation of the arousal of the central nervous system, responsible for creating the underlying pattern of psychophysiological changes associated with excitement and the "fight or flight" response. This measure of the underlying common pattern of emotional engagement can potentiate a variety of emotions: anxiety, anger, interest, and excited happiness. If these experiences are absent, then lower values of "Alertness" may reflect a calm or relaxed state. Alertness seems to be a good measure of the continuum underneath the inverted U shaped curve relating the quality of performance to arousal. Finding the ideal level of "Alertness" for every point in the sequence of an activity by recording the EEG during visualization or video replay can be very valuable. It is far better training than just trying to adjust the level of Alertness at the beginning of the sequence. The "Focus" and "Alertness" measures were trained using the "Peak Achievement Trainer" that is commercially available (Cowan and Albers 2008). Prior studies have shown positive outcomes using this device (Sokhadze 2012).

E. Goals and Expectations of this Study

The goal of this study was to conduct neurofeedback in ADHD subjects using the Peak Achievement Trainer (PAT) device with the "Focus/Alertness" protocol to investigate:

- 1) relative changes in EEG measures throughout the entire course of neurofeedback,
- 2) success of neurofeedback over 12 sessions could be shown through IVA+Plus (Braintrain Inc, VA) and ***Aberrant Behavior Checklist (ABC)*** (Aman and Singh 1994) measures,
- 3) and most importantly, how EEG power ratios are changing and how the changes correlated with measures of "Focus" and "Alertness."

A number of expectations were held prior to the study. It was expected that all participants would complete 12 sessions of "Focus/Alertness" training and learn to control "Focus" and "Alertness" parameters in biofeedback mode. Additionally, it was expected that there would be an improvement in the clinical (ABC) and neuropsychological (IVA+Plus) measures as previously reported in the treatment of ADHD in neurofeedback. It was expected that an improvement in "Focus" would manifest in the gradual decrease of the Theta/Beta EEG ratio. As more of an exploratory aim, it was planned to analyze correlations between the "Focus" measures with specific EEG relative powers and proportions. Finally, MatLab (Mathworks, Inc. MA) would be used to code an application that could effectively and efficiently analyze and compute all the desired measures.

II. DATA COLLECTION

A. Subject Demographics and Recruitment

Eighteen children and adolescents with ADHD (mean age 13.6 years, SD=3.5, 6 female, 12 males) were enrolled in this study. Participating subjects and their parents were provided with all information about this study purposes and the consent/assent forms were signed. During the course of the study, only 4 subjects were not taking stimulant medication. Participants were not required to be off medication during the course of neurofeedback training; however, all participants were requested to not take medication before their neurofeedback session on a day of visit. Participants with ADHD were recruited through the University of Louisville Weisskopf Child Evaluation Center (WCEC). Diagnosis was made according to the DSM-IV-TR and was further ascertained by Dr. Sears through a clinical interview. In addition to diagnosis, Dr. Sears performed pre- and post-neurofeedback clinical evaluations. Neurofeedback sessions were conducted by Dr. Sokhadze. All required IRB-approved consent/assent forms were signed by the participants and parent/guardian of the participating subjects.

B. Neurofeedback Protocol and Data Recording

This study involved the use of existing neurofeedback protocols to train the measures of "Focus" and "Alertness". Subjects completed sessions using a "Focus/Alertness"

protocol designed to train the "Focus" and "Alertness" measures. The goal of each subject was to enhance "Focus" throughout the session while maintaining an adequate measure of "Alertness" within a certain range. All sessions were completed using different fragments of documentary films depicting nature scenes from the BBC "Planet Earth" and "Life" series. Different scenes were utilized to maintain the engagement and motivation of participants. Based on the thresholds set, the subject would receive biofeedback both in the visual and auditory modalities. Visual feedback was arranged in a form of control of brightness, size, and continuation of the documentary by the "Focus" and "Alertness" measures. For instance, based on processing of "Focus" and "Alertness" measures in real time, the video feed will shrink or enlarge and fade or become brighter. Auditory feedback was used to inform subjects when these measures were under the threshold level, in the case of "Focus", or outside the acceptable range, in the case of "Alertness". Figure 1 illustrates a sample interface seen by a subject during a neurofeedback session.

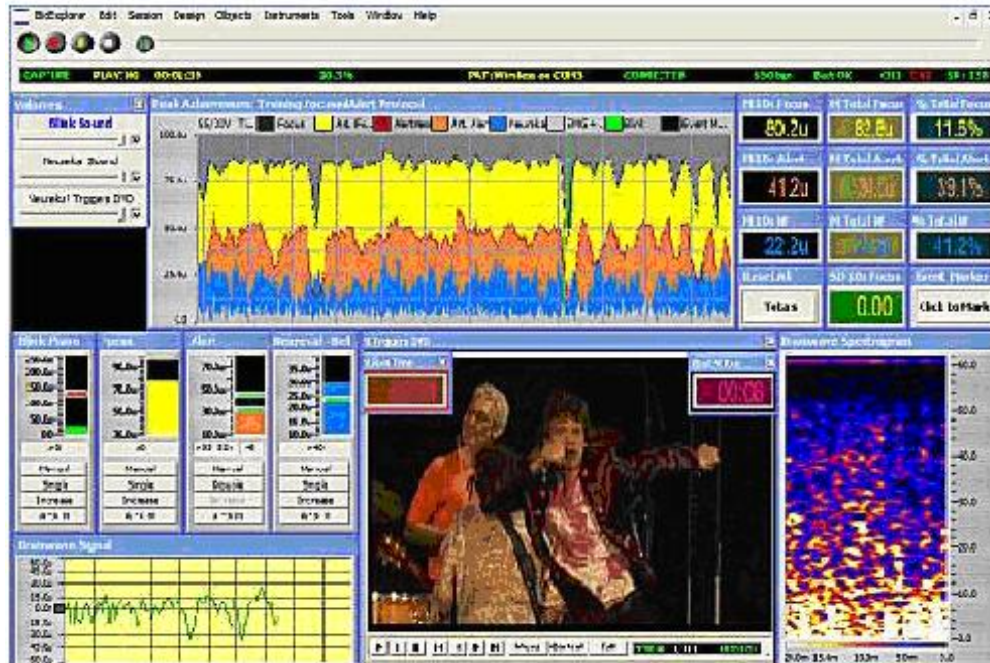


FIGURE 1: Sample Neurofeedback interface as seen by a patient during a neurofeedback session showing the EEG signal with DVD video embedded in screen.

All EEG signals and training parameters were measured from the same sensors, one active electrode at the prefrontal EEG (FPz) site and the second a reference on the left ear with a third sensor serving as a ground at the right earlobe. The sensors were soaked in a potassium chloride solution, compatible to concentration of salt in medical saline solution. The setup (e.g. sensor placement, monitor placement, patient orientation, etc.) for each neurofeedback session is shown in Figure 2.



FIGURE 2: The setup is shown for a subject undergoing neurofeedback. The image clearly illustrates the positioning of sensors, subject, and monitor

Each subject completed a minimum of 12 weekly neurofeedback sessions. The goal, as explained to each subject, was the training of an increase in "Focus" using the "Focus/Alertness" protocol. The target length of each session recorded was 25 min, with most sessions reaching 20-min minimum length goal ($n= 185$ sessions out of 216 total sessions), with the shortest session recorded containing only 15 minutes of data. Eye blink artifacts removal was implemented using a custom made BioExplorer (BioExplorer 1.5, CyberEvolution, WA) application.

C. Clinical and Neuropsychological Measures of ADHD

1. Clinical Measures and Evaluation

In conjunction with neurofeedback, clinical measures along with pre- and post-neurofeedback data were collected. A clinical behavioral outcome measures in ADHD patients included scores from the *Aberrant Behavior Checklist (ABC)*. The ABC is a rating scale assessing five problem areas: Irritability, Lethargy/Social Withdrawal, Stereotypy, Hyperactivity, and Inappropriate Speech, and is based on caregiver reports (Aman and Singh 1994). Scoring of the ABC reports was completed by Dr. Sears.

2. Neuropsychological Measures and Evaluation

In addition to the collection of clinical measures, commonly accepted neuropsychological measures of selective attention were collected. The continuous performance IVA+Plus (BrainTrain Inc, VA) selective attention test was administered before and after the 12 session "Focus/Alertness" neurofeedback course. This 20-min long test provides accurate measures of sustained auditory and visual attention quotients and is widely accepted as an acceptable neurocognitive test of attention in children (Sandford 2009).

III. Data Processing and Analysis

A. EEG Signal Processing

1. BioReview

As previously stated, the EEG signal was collected and recorded with BioExplorer-based software application. The first goal of signal processing was to separate the raw signal based on the desired frequency bands. The first step in the filtering process was completed in BioReview – an extension of BioExplorer that serves for analysis of recorded sessions. The frequency ranges for each selected band are similar to, yet a slight modification of those described by Miller (2007). The signal was separated into Delta (2-4 Hz), Theta (4-8 Hz), Alpha (8-13 Hz), Low Beta (13-18 Hz), High Beta (18-30 Hz), and Gamma (30-45 Hz) components using a band-pass filter with a Harris window configuration. Additionally, the raw signal was exported for later use if additional filtering would be needed. The report design in BioReview is based on a Visual Basic design. Each filter is added to the report block diagram and then the settings of the filter are customized and edited according to what is desired. Figure 3 shows the layout of the block diagram designed for this application.

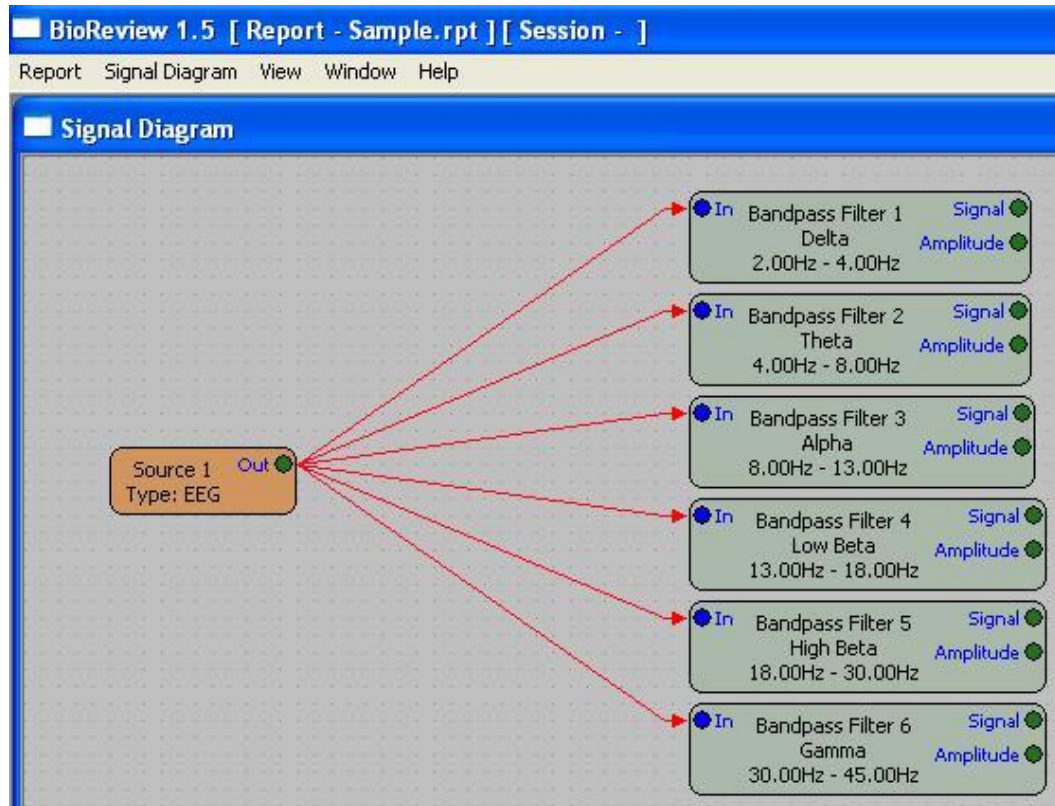


Figure 3: BioReview report block diagram with filters for each EEG band collected [, Delta (2-4 Hz), Theta (4-8 Hz), Alpha (8-13 Hz), Low Beta (13-18 Hz), High Beta (18-30 Hz), Gamma (30-45 Hz)]. The raw signal is output once the report is run.

Each session was processed using this report. The sampling rate for all data was 256 Hz.

After processing through the BioReview report, each session was exported as raw data.

In this configuration, every data point was exported to a text file where the different measures were organized into columns and each subsequent row represented the change in time between samples.

2. MatLab

After exporting the text file from BioReview, the data was then to be analyzed and processed in MatLab. Based on the nature of the neurofeedback system, it was determined that relative power comparisons between bands would be appropriate for this analysis. For instance, the system used in neurofeedback did not have a calibration measure. As a result, of this lack of calibration it was decided power measures were more appropriate based on an assumption of constant resistance within the system instead of assuming the system measured voltage consistently across all subjects. Through this assumption of equivalent resistance based on constant wire length, wire gauge, thermostat controlled temperature (at room temperature) of lab where neurofeedback occurred, and uniformity in the EEG sensors used across all subjects the relative power equation could be simplified. As can be seen in equation 1 showing the traditional calculation of power in electrical signal, resistance is present.

$$P = \frac{V^2}{R} \quad (1)$$

However, resistance being constant across each session would allow for the removal of that term in any relative power calculation. This is pertinent since the exact resistance of the system is not known for each session.

Therefore, it was necessary to filter in MatLab from 2-45 Hz to gain the total power of the band of interest. To complete the filtering necessary for completion of the

analysis, MatLab code was designed using a custom band-pass filter application created through the integration of wavelet transformation of the raw signal (effective for handling any noise in the signal) and a Harris window configuration that separates the 2-45 Hz portion of the raw signal into its own filtered signal. Therefore, band-pass filtering of the raw signal in MatLab provided a "total" signal (2-45 Hz) that could then be utilized in relative power calculations.

After filtering of the raw signal to the desired frequency, relative power calculations for each minute of every neurofeedback session were completed in MatLab using an iterative *for loop* function on each recorded session with the filtered total signal of interest replacing the raw signal. The formula used to calculate relative power in this analysis is given in Equation 2, where b represents the band signal and t represents the "total" signal from 2-45 Hz.

$$RP = \frac{\sum_i^n b^2}{\sum_i^n t^2} \quad (2)$$

The summation includes every data point for 1 minute of recorded data, 15360 data points per minute based on a 256 Hz sampling rate. Therefore, an average relative power for each band was calculated for each minute of each session. It is important to note that since relative power was investigated instead of relative amplitude, that the calculated measure is not a pure percentage and will not be labeled as such. In addition to the calculation of relative power for each band, the ratio of certain bands was calculated

using the relative power values calculated for each band. The formula for calculating the ratios of certain bands is given in Equation 3.

$$BR = \frac{RP_1}{RP_2} \quad (3)$$

Therefore, the band ratio was calculated for each minute of each session. The ratios of interest for this study were the Theta/Low Beta, Theta/High Beta, Theta/Beta, and Theta/Alpha proportion. Theta/Beta ratio was calculated using the sum of the Low Beta and High Beta relative powers for each minute, but otherwise the formula in Equation 3 was followed.

Initially, each session for each subject was analyzed independently and output into an Excel summary file for that subjects' session. However, the goal of the research involved a deeper look into EEG changes according to minute and session of neurofeedback. Therefore, to differences between subjects were assumed to be normal during each minute of each session of neurofeedback. This facilitated the averaging of EEG measures across subjects which made possible a more intensive analysis of session number and minute number of neurofeedback possible. In order to gain single output files for each session of neurofeedback, a cell array configuration was utilized in MatLab where each session for each individual subject was placed in a row of the array corresponding to session number. Then session 1 averages for all measures were calculated across the row according to minute and number of sessions with data at that

minute of neurofeedback. Figure 4 uses a block diagram setup to illustrate the concept utilized for this method of data processing.

Σ	Subject 1 Session 1			Subject N Session 1	➔	Mean Session 1
Σ	Subject 1 Session 2			Subject N Session 2	➔	Mean Session 2
Σ	Subject 1 Session 3			Subject N Session 3	➔	Mean Session 3
Σ	Subject 1 Session 4			Subject N Session 4	➔	Mean Session 4
Σ	Subject 1 Session 5			Subject N Session 5	➔	Mean Session 5
Σ	Subject 1 Session 6			Subject N Session 6	➔	Mean Session 6
Σ	Subject 1 Session 7			Subject N Session 7	➔	Mean Session 7
Σ	Subject 1 Session 8			Subject N Session 8	➔	Mean Session 8
Σ	Subject 1 Session 9			Subject N Session 9	➔	Mean Session 9
Σ	Subject 1 Session 10			Subject N Session 10	➔	Mean Session 10
Σ	Subject 1 Session 11			Subject N Session 11	➔	Mean Session 11
Σ	Subject 1 Session 12			Subject N Session 12	➔	Mean Session 12

FIGURE 4: Block Diagram to demonstrate MatLab coding for cell array. Each subsequent row in the array represents the subsequent session. Each column represents an additional subject. The mean for each session is calculated by summing across each row of the cell array to determine the mean of the EEG measures for each minute of neurofeedback within that session.

The end result of the data processing was twelve Microsoft Excel files output according to session number with essentially the summary data for each measure (organized by columns) at each minute of neurofeedback.

B. Statistical Analysis

Statistical analysis techniques were utilized to determine the significance of session number (1-12) and minute (1-25) with regards to each EEG measure calculated. A General Linear Model ANOVA was utilized with $\alpha=0.05$ to determine significant changes in each EEG band, band ratio, and "Focus/Alertness" measures. Potential linear correlations between session and minute averages of "Focus" and other significant EEG

measures were investigated using the Pearson Correlation statistic with $\alpha=0.05$ for significance. Additionally, student's two tailed t-test ($\alpha=0.05$) was used to determine significant changes between pre- and post- data collected through the IVA+ tests and the ABC survey. Statistical analysis was conducted using MiniTab16.0 (State College, PA) and SPSS v.15 software (SPSS, Inc., IL).

IV. RESULTS

A. EEG Measures changes by Session

The ANOVA supported that there were main effects of session for all interested EEG measures. Specifically, the effect of session was determined to be significant for Theta relative power [$F(11,264) = 6.96$, $p\text{-value} < 0.001$], Low Beta relative power [$F(11,264) = 6.85$, $p\text{-value} < 0.001$], Theta/Low Beta ratio [$F(11,264) = 9.02$, $p\text{-value} < 0.001$], Theta/Alpha ratio [$F(11, 264) = 19.74$, $p\text{-value} < 0.001$], and "Focus" [$F(11,264) = 32.39$, $p\text{-value} < 0.001$]. The full summary of the ANOVA results for changes in EEG measures from session 1-12 are presented in Table 1.

TABLE I

SUMMARY OF ANOVA RESULTS FOR CHANGES IN EEG MEASURES FROM SESSION 1-12 OF NFB ($P < 0.05$ SIGNIFICANT)

EEG Measure	Degrees of Freedom	F-Statistic	p-value	Direction of Change
Delta Relative Power	11	8.03	<0.001	Decrease
Theta Relative Power	11	6.96	<0.001	Decrease
Alpha Relative Power	11	7.74	<0.001	Increase
Low Beta Relative Power	11	6.85	<0.001	Increase
High Beta Relative Power	11	5.67	<0.001	Decrease
Gamma Relative Power	11	5.97	<0.001	Decrease
Theta/Low Beta Ratio	11	9.02	<0.001	Decrease
Theta/High Beta Ratio	11	7.64	<0.001	Decrease
Theta/Beta Ratio	11	7.49	<0.001	Decrease
Theta/Alpha Ratio	11	19.74	<0.001	Decrease
"Focus" Measure	11	32.39	<0.001	Increase
"Alertness" Measure	11	3.85	<0.001	Decrease

Changes were determined to be either increasing or decreasing based on the trend the data exhibited when charted. Therefore, from session 1-12 Theta relative power, Theta/Low Beta ratio, and Theta/Alpha ratio are shown to be significantly decreasing. An increase is seen from session 1-12 with Low Beta relative power and "Focus" measure. Changes in Theta/Low Beta ratio, Theta/Alpha ratio, and "Focus" measure were of particular interest. To gain an understanding of the relationship between changes in session number and these measures, the average value for each session of each EEG measure were plotted from session 1-12. Figures 5-7 display the change in average Theta/Low Beta ratio, Theta/Alpha ratio, and "Focus" measure, respectively, from session 1-12. A linear relationship is the most obvious fit for average changes from session 1-12.

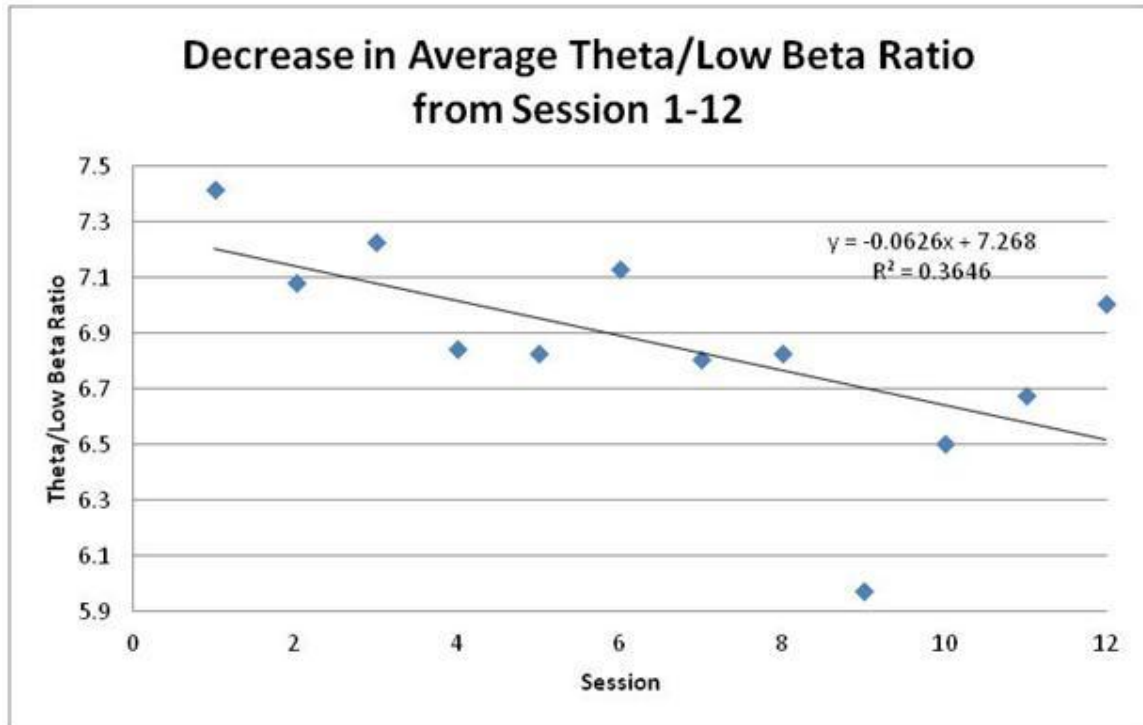


FIGURE 5: Plot of average Theta/Low Beta ratio value for each session (session number 1-12) indicating a decrease in the value of Theta/Low Beta ratio as session number increases. R^2 value and equation for linear relationship included on the plot.

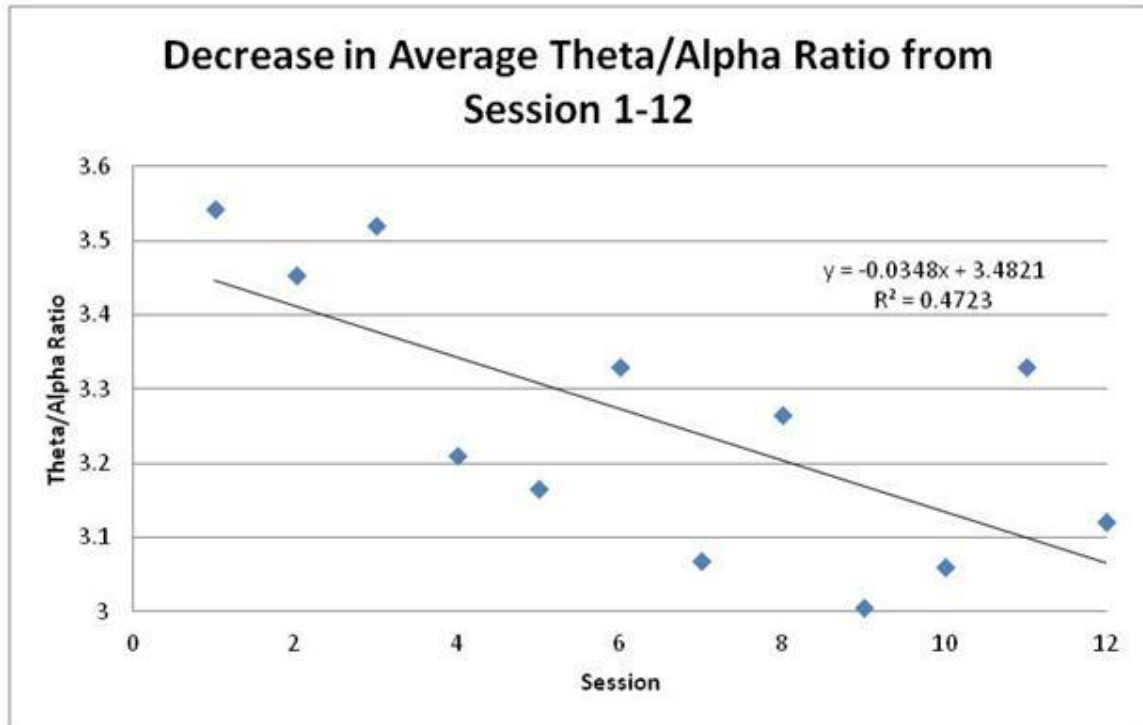


FIGURE 6: Plot of average Theta/Alpha ratio value for each session (session number 1-12) indicating a decrease in the value of Theta/Alpha ratio as session number increases. R^2 value and equation for linear relationship included on the plot.

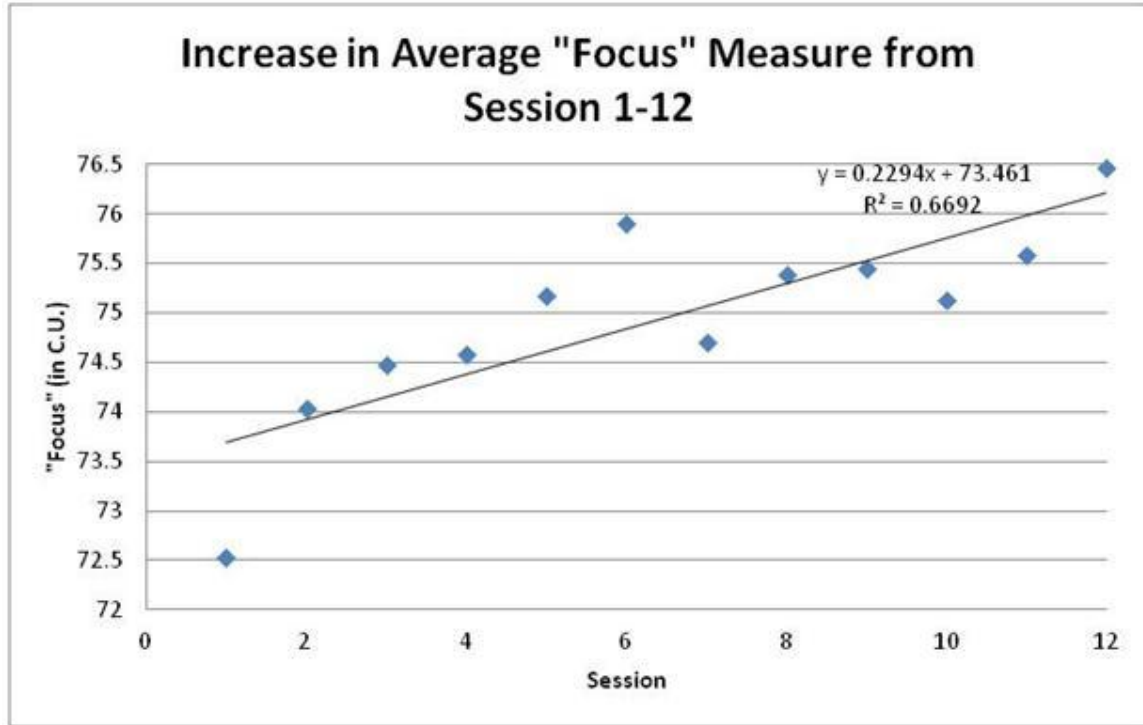


FIGURE 7: Plot of average "Focus" value for each session (session number 1-12) indicating an increase in the value of "Focus" as session number increases. R^2 value and equation for linear relationship included on the plot.

B. EEG Measures changes by Minute

The ANOVA supported that there were main effects of minute for some interested EEG measures. Specifically, the effect of minute was determined to not be significant for Theta relative power [$F(24,264) = 0.98, p = .493$] or Low Beta relative power [$F(24,264) = 0.88, p = .633$]. However, the Theta/Low Beta ratio [$F(24,264) = 2.12, p = 0.002$], Theta/Alpha ratio [$F(24,264) = 2.05, p = 0.003$], and "Focus" measure [$F(24,264) = 4.35, p < 0.001$] were shown to change significantly according to minute. The full summary of the ANOVA results for changes in EEG measures from minute 1-25 are presented in Table 2.

TABLE II

SUMMARY OF ANOVA RESULTS FOR CHANGES IN EEG MEASURES FROM MINUTE 1-25 OF NFB WITHIN A SESSION (P<0.05 SIGNIFICANT)

EEG Measure	Degrees of Freedom	F Statistic	p-value	Direction of Change
Delta Relative Power	24	1.64	0.032	Decrease
Theta Relative Power	24	0.98	0.493	NS
Alpha Relative Power	24	0.710	0.841	NS
Low Beta Relative Power	24	0.88	0.633	NS
High Beta Relative Power	24	1.58	0.045	Increase
Gamma Relative Power	24	1.66	0.029	Increase
Theta/Low Beta Ratio	24	2.12	0.002	Decrease
Theta/High Beta Ratio	24	6.11	<0.001	Decrease
Theta/Beta Ratio	24	4.82	<0.001	Decrease
Theta/Alpha Ratio	24	2.05	0.003	Decrease
"Focus" Measure	24	4.35	<0.001	Increase
"Alertness" Measure	24	4.83	<0.001	Increase

Changes were determined to be either increasing or decreasing based on the trend the data exhibited when charted. Therefore, from minute 1-25 Theta/Low Beta ratio and Theta/Alpha ratio was shown to be significantly decreasing. An increase is seen from minute 1-25 with "Focus" measure. As with the changes seen across sessions, changes in Theta/Low Beta ratio, Theta/Alpha ratio, and "Focus" measure across minute of session were of particular interest. To gain an understanding of these changes in Theta/Low Beta ratio, Theta/Alpha ratio, and "Focus" measure depending on minute of neurofeedback session, the average value for each minute of each EEG measure were plotted from minute 1-25. Figures 8-10 display the changes in average Theta/Low Beta ratio, Theta/Alpha ratio, and "Focus" measures, respectively, from minute 1-25. With regard to changes within a session of neurofeedback, a logarithmic relationship was deemed to

be a better fit than a linear relationship. For instance, in addition to visual inspection, the R^2 value for a linear relationship between "Focus" measure and minute ($R^2=0.3281$) was much lower than the R^2 value seen in Figure 10 associated with the logarithmic relationship.

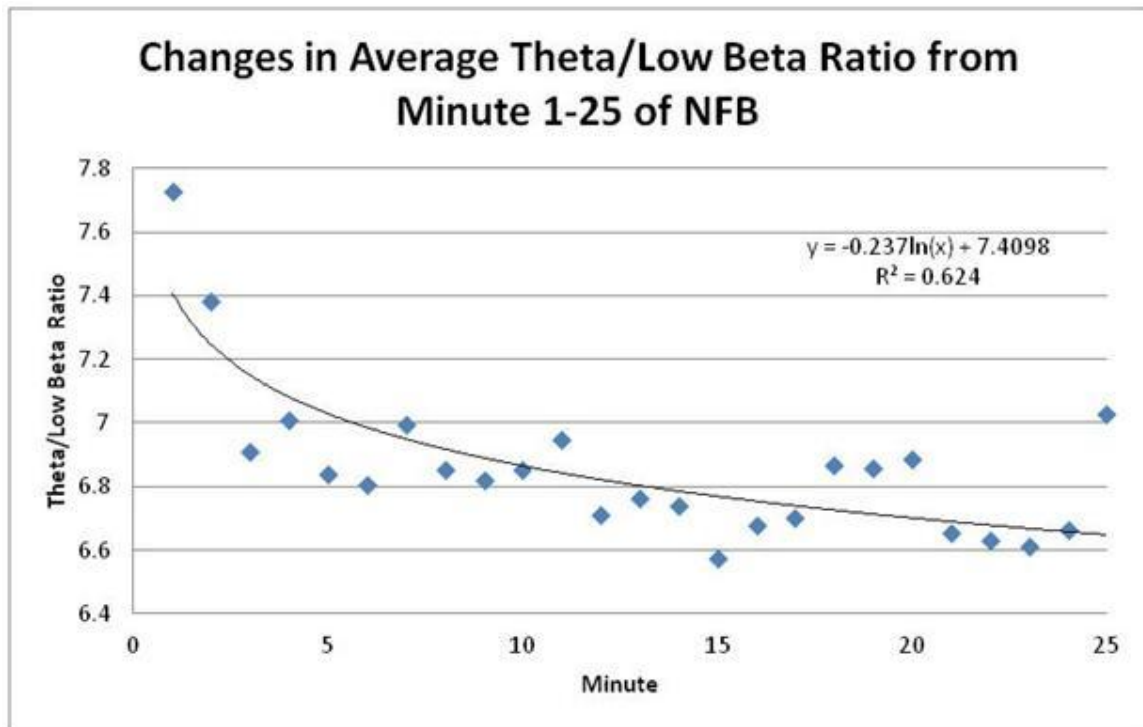


FIGURE 8: Plot of average Theta/Low Beta ratios (averaged across all sessions) for each minute of Neurofeedback (1-25) indicating a decreasing Theta/Low Beta ratio as minute of NFB within a session increases. R^2 value and equation for logarithmic relationship included on the plot.

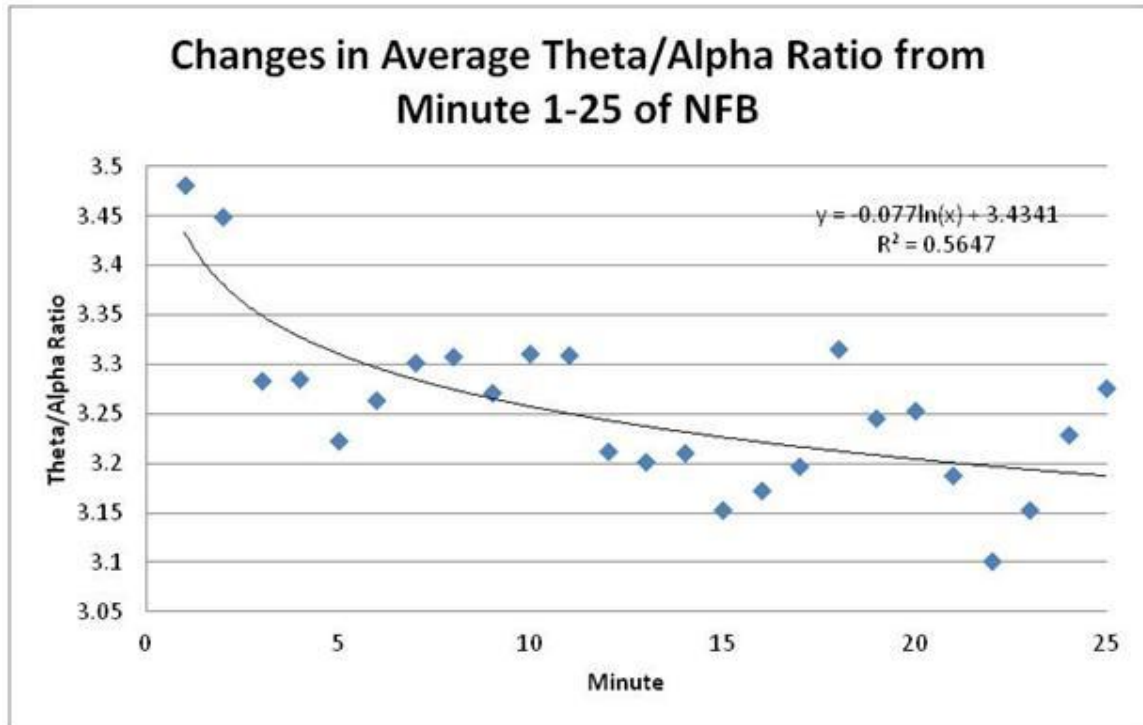


FIGURE 9: Plot of average Theta/Alpha ratios (averaged across all sessions) for each minute of Neurofeedback (1-25) indicating a decreasing Theta/Alpha ratio as minute of NFB within a session increases. R^2 value and equation for logarithmic relationship included on the plot.

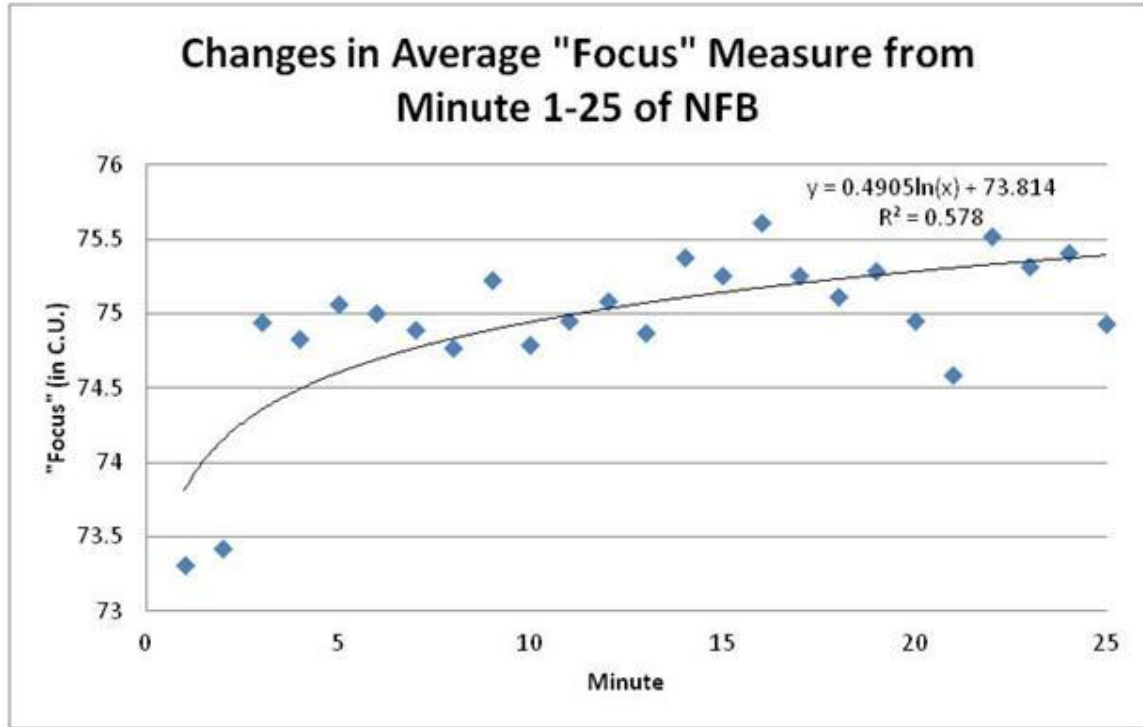


FIGURE 10: Plot of average "Focus" values (averaged across all sessions) for each minute of Neurofeedback (1-25) indicating an increasing "Focus" measure as minute of NFB within a session increases. R^2 value and equation for logarithmic relationship included on the plot.

C. Correlation between "Focus" Measure and EEG Band Relative Powers/Ratios

The results of the Pearson Correlation, using the corresponding average values for any interested EEG measures (Theta relative power, Alpha relative power, Low Beta relative power, High Beta relative power, Theta/Low Beta ratio, Theta/High Beta ratio, Theta/Beta ratio, and Theta/Alpha ratio) and for "Focus" calculated for changes in minute 1-25 and session 1-12, showed possible correlations in multiple EEG band relative power and EEG band ratios with the "Focus" measure. Specifically, a significant correlation existed between "Focus" and the Theta/Low Beta ratio (Pearson Correlation Coefficient =

-0.633, $p < 0.001$, $R^2 = 0.401$). Additionally, a significant correlation existed between "Focus" and the Theta/Alpha ratio (Pearson Correlation Coefficient = -0.676, $p < 0.001$, $R^2 = 0.457$). Table 3 fully summarizes the results of the Pearson Correlation test and gives the linear regression equation of the correlation between all significant measures and the "Focus" measure with appropriate R^2 values.

TABLE III

SUMMARY OF RESULTS OF PEARSON CORRELATION TEST USING CORRESPONDING AVERAGE VALUES OF EEG BAND RELATIVE POWERS AND EEG BAND RATIOS WITH "FOCUS" MEASURE ($P < 0.05$ SIGNIFICANT)

		Theta Relative Power	Alpha Relative Power	Low Beta Relative Power	High Beta Relative Power	Theta/ Low Beta Ratio	Theta/ High Beta Ratio	Theta/ Beta Ratio	Theta/ Alpha Ratio
"Focus"	<i>Pearson Correlation Coefficient</i>	-0.197	0.444	0.423	0.373	-0.633	-0.577	-0.612	-0.676
	<i>p-value</i>	0.242	0.006	0.009	0.023	<0.001	<0.001	<0.001	<0.001
	<i>Equation</i>	y = -68.179x + 80.618	y = 194.17x + 69.304	y = 283.31x + 70.576	y = 76.68x + 72.227	y = -1.5496x + 85.584	y = -1.2722x + 80.056	y = -2.7701x + 81.765	y = -3.9262x + 87.736
	<i>R² Value</i>	0.0389	0.1968	0.1792	0.1388	0.4005	0.3334	0.3742	0.4573

Additionally, Figure 11 plots the correlation for the Theta/Low Beta ratio vs. "Focus," while Figure 12 plots the correlation for the Theta/Alpha ratio vs. "Focus."

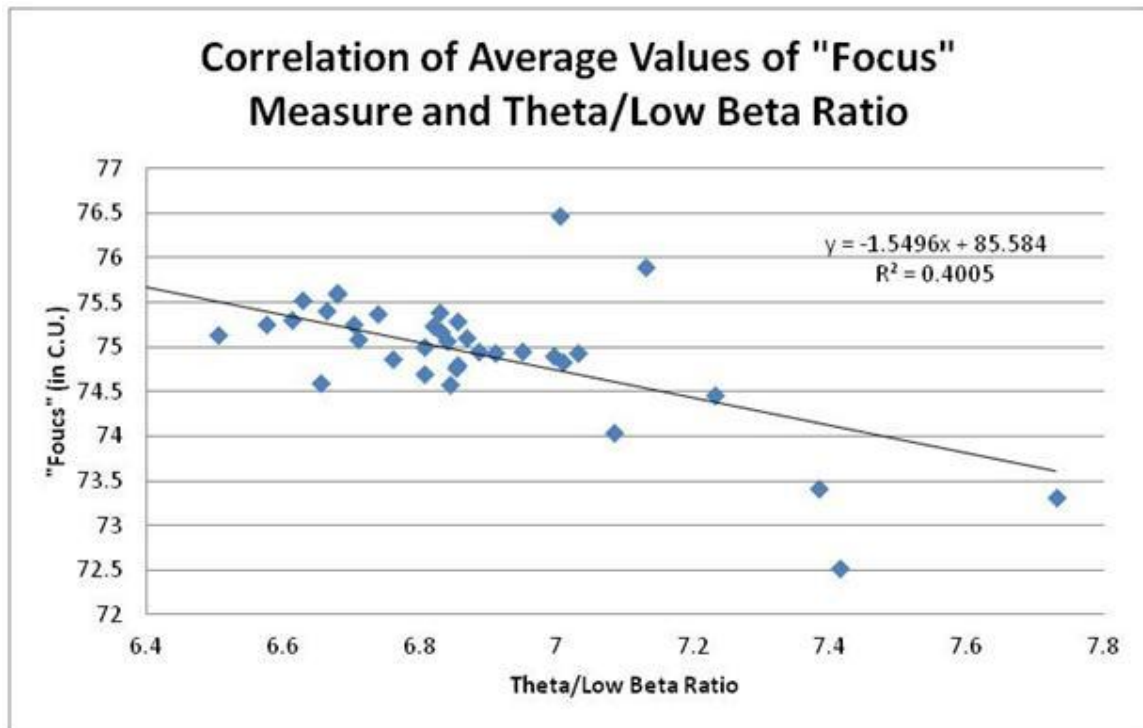


FIGURE 11: Plot of correlation between corresponding average "Focus" values and Theta/Low Beta ratios for Sessions 1-12 and Minute 1-25 of NFB within a session.

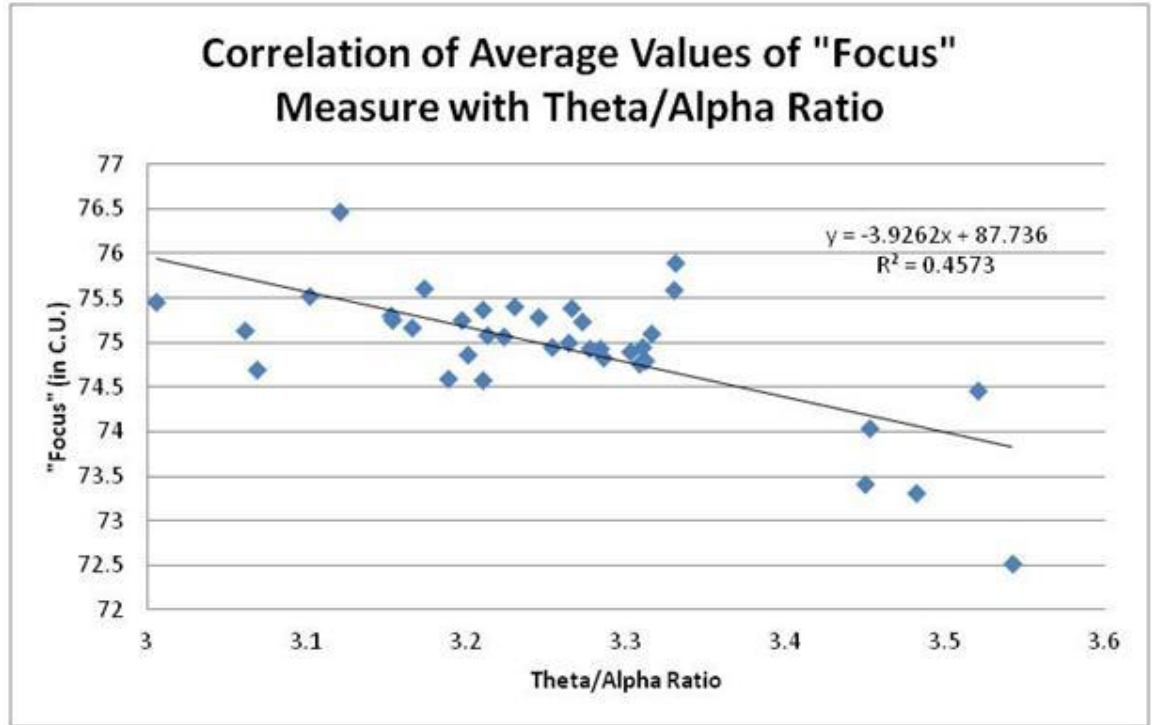


FIGURE 12: Plot of correlation between corresponding average "Focus" values and Theta/Alpha ratios for Sessions 1-12 and Minute 1-25 of NFB within a session.

D. IVA+ and ABC Survey – Pre- and Post-Neurofeedback

The student t-test performed on the results of the IVA+ yielded multiple measures showing a significant change from pre- to post-neurofeedback for each subject. The Attention Quotient showed a significant change from pre-neurofeedback (78.00 ± 6.33) to post-neurofeedback (87.22 ± 5.68); $t(17) = -2.576$, $p = 0.020$. The Attention Quotient – Visual showed a significant change from pre-neurofeedback (89.89 ± 4.40) to post-neurofeedback (97.89 ± 3.31); $t(17) = -2.285$, $p = 0.035$. The Sustained Visual Attention Quotient showed a significant change from pre-neurofeedback (83.44 ± 5.64) to post-neurofeedback (97.83 ± 4.92); $t(17) = -2.721$, $p = 0.015$. The Visual Reaction Time (ms) showed a significant change from pre-neurofeedback (490.78 ± 22.87) to post-

neurofeedback (468.94 ± 19.45); $t(17) = 2.379$, $p = 0.029$. Table 4 fully summarizes the IVA+ t-test results.

TABLE IV

SUMMARY OF SIGNIFICANT CHANGES WITHIN THE IVA+PLUS TEST FROM COMPARING PRE- AND POST- NEUROFEEDBACK ($P < 0.05$ SIGNIFICANT)

Measure	Pre-NFB Mean \pm SE	Post-NFB Mean \pm SE	t-statistic	p-value	Change from Pre-NFB to Post-NFB
Attention Quotient	78.00 \pm 6.33	87.22 \pm 5.68	-2.576	0.020	Increase
Attention Quotient – Auditory	70.39 \pm 7.62	79.06 \pm 7.94	-2.012	0.060	NS
Attention Quotient – Visual	89.89 \pm 4.40	97.89 \pm 3.31	-2.285	0.035	Increase
Sustained Auditory Attention Quotient	60.83 \pm 9.44	74.11 \pm 9.41	-2.009	0.061	NS
Sustained Visual Attention Quotient	83.44 \pm 5.64	97.83 \pm 4.92	-2.721	0.015	Increase
Auditory Reaction Time (ms)	735.56 \pm 30.54	699.00 \pm 31.98	1.812	0.088	NS
Visual Reaction Time (ms)	490.78 \pm 22.87	468.94 \pm 19.45	2.379	0.029	Decrease

All ABC survey measures showed significant changes from pre- to post-neurofeedback. Specifically, Hyperactivity and Inappropriate Speech showed the most

significant changes. Hyperactivity showed a significant change from pre-neurofeedback (15.28 ± 3.24) to post-neurofeedback (10.83 ± 2.44); $t(17) = 3.189$, $p = 0.005$.

Inappropriate Speech showed a significant change from pre-neurofeedback (2.94 ± 0.75) to post-neurofeedback (1.94 ± 0.64); $t(17) = 4.675$, $p < 0.001$. Table 5 fully summarizes the results of the t-test for the ABC outcomes.

TABLE V

SUMMARY OF SIGNIFICANT CHANGES IN CLINICAL MEASURE AS INDICATED BY THE ABBERANT BEHAVIOR CHECKLIST SURVEY FROM COMPARING DATA FROM PRE- AND POST- NEUROFEEDBACK ($P < 0.05$ SIGNIFICANT)

Measure	Pre-NFB Mean \pm SE	Post-NFB Mean \pm SE	t-statistic	p-value	Change from Pre-NFB to Post-NFB
Irritability	11.67 ± 2.16	8.33 ± 2.01	3.602	0.002	Decrease
Lethargy	8.00 ± 2.04	3.94 ± 1.25	2.366	0.030	Decrease
Stereotypy	3.89 ± 1.37	2.56 ± 1.01	2.515	0.022	Decrease
Hyperactivity	15.28 ± 3.24	10.83 ± 2.44	3.189	0.005	Decrease
Inappropriate Speech	2.94 ± 0.75	1.94 ± 0.64	4.675	<0.001	Decrease

V. CONCLUSIONS

The results outlined in Tables 1 and 2 indicate outcomes which were primarily expected with regards to changes in the relative power of interested bands and the change in ratios. For instance, the Theta band is shown to decrease across sessions and minute within a session, while the Alpha band is shown to increase for both criteria. Therefore, it would appear that the Theta/Alpha band should decrease for both session and minute within a session. This is evidenced in Figure 6 and 9. However, several bands (High Beta and Gamma) and “Alertness” measure show what appear to be counterintuitive results at first glance. Upon further inspection of the protocol and the changes within each band though, this discrepancy can be rationalized and explained. The High Beta band shows an increase in relative power within session, but a decrease from session to session. However, the session to session changes indicate a very low correlation. Additionally, neurofeedback doesn't specifically target the 18-30 Hz range encompassed by the High Beta designation in this protocol. The Gamma measure is also not noted for being specifically targeted by this application. However, the increase within session observed in the Gamma range could be the result of an increase in a subjective sense of achievement attained through mastery of the assigned skill (i.e. increasing ability to focus attention). It has been suggested that an increase in the prefrontal Gamma activity could be tied to emotional responses and the effort associated with learning (Rubik 2011). Therefore, the decrease in Gamma activity from session to session could be the result of the subject

having a lower effort to mastering this skill of concentration of attention. Finally, "Alertness" indicates a decrease from session 1-12, while indicating an increase from minute 1-25 within a session. This is not unexpected since "Alertness" was not to be enhanced or suppressed in this protocol, but simply maintained within a broad range. In the later stages of the neurofeedback training course the ability to focus attention does not require general arousal, resulting in dissociation of two measures and lower correlation of "Focus" and "Alertness".

As evidenced in Tables 1-2 and Figures 5, 6, 8, and 9 the most notable indications of this analysis are a decrease in the Theta/Low Beta and Theta/Alpha proportions from session to session and from minute 1 to minute 25 within a session. These results show consistency with the overall aims and goals of neurofeedback which have been described earlier (Monastra 2005). Specifically, this claim can be made regarding the decrease in the Theta/Low Beta ratio. A net reduction in Theta/Low Beta ratio was seen across both sessions and minute within a session. These findings support the treatment of EEG irregularities within the ADHD population (Barry, Clarke, and Johnstone 2003) with neurofeedback techniques. Figure 13 provides visual illustration of the observed changes, as a result of session number and minute within a session, through utilization of a surface chart representing a three dimensional view of the data.

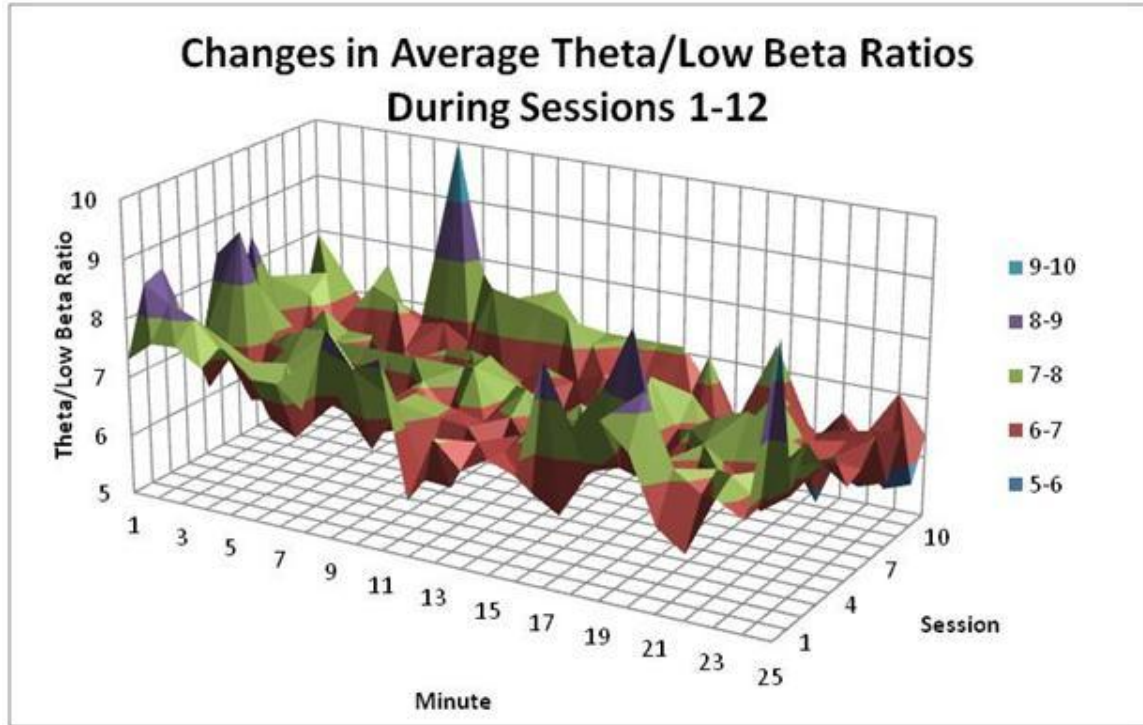


FIGURE 13: The surface chart provides evidence supporting the decrease in the Theta/Low Beta ratio with regards to increasing session number and increasing minute of each session. As is consistent with the results of the ANOVA, Session trends, and Minute trend analysis, a general decrease is seen from (Session 1, Minute 1) through (Session 12, Minute 25) for the Theta/Low Beta ratio. The legend on the right side of the figure gives the color-coded ranges for the Theta/Low Beta ratio, as seen in the chart.

In this study, the Theta band was characterized by the EEG signals collected between 4-8 Hz whereas the Alpha signal was characterized via the signals collected between 8-13 Hz. A reduction in the Theta/Alpha proportion was seen across both sessions and minute within a session. As with the evidence provided for changing Theta/Low Beta ratio values, visual illustration of a decrease in Theta/Alpha ratio as a function of session number and minute within a session is provided in Figure 14.

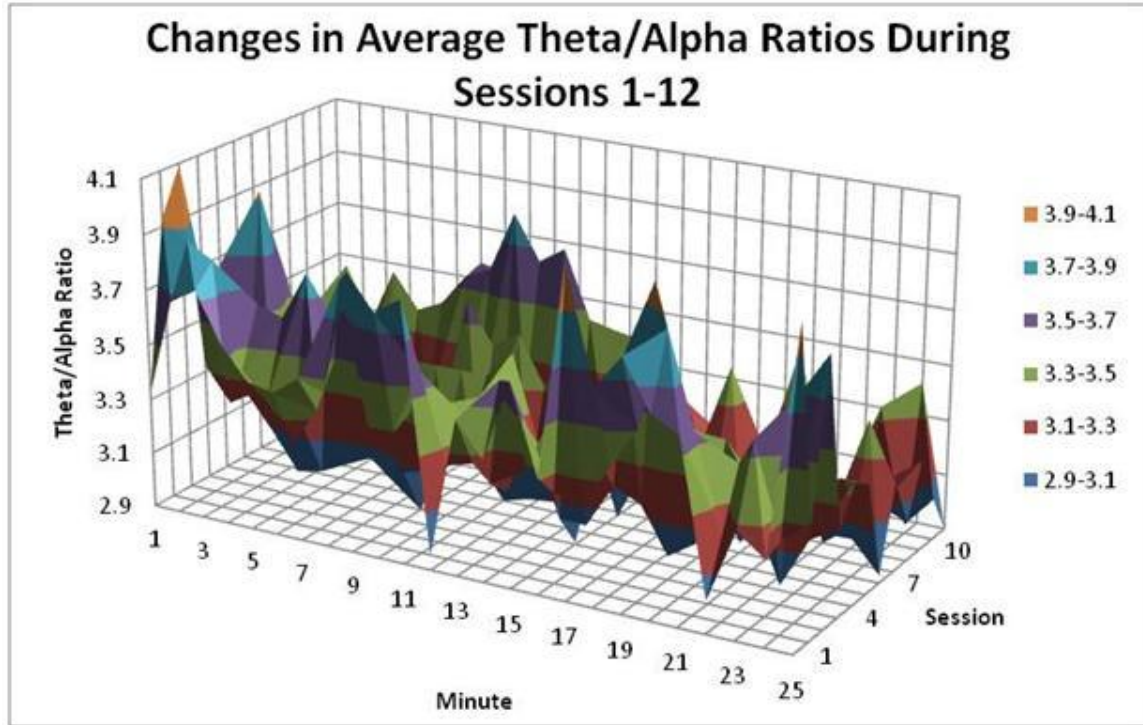


FIGURE 14: The surface chart provides evidence supporting the decrease in the Theta/Alpha ratio with regards to increasing session number and increasing minute of each session. As is consistent with the results of the ANOVA, Session trends, and Minute trend analysis, a general decrease is seen from (Session 1, Minute 1) through (Session 12, Minute 25) for the Theta/Alpha ratio. The legend on the right side of the figure gives the color-coded ranges for the Theta/Alpha ratio, as seen in the chart.

Also, the decrease of Theta/Alpha and Theta/Low Beta ratios indicate a potential link between these ratios and the targeted desynchronized measure of "Focus" recorded at the prefrontal site, since "Focus" showed an increase across session number and minute within a session (Fig. 15).

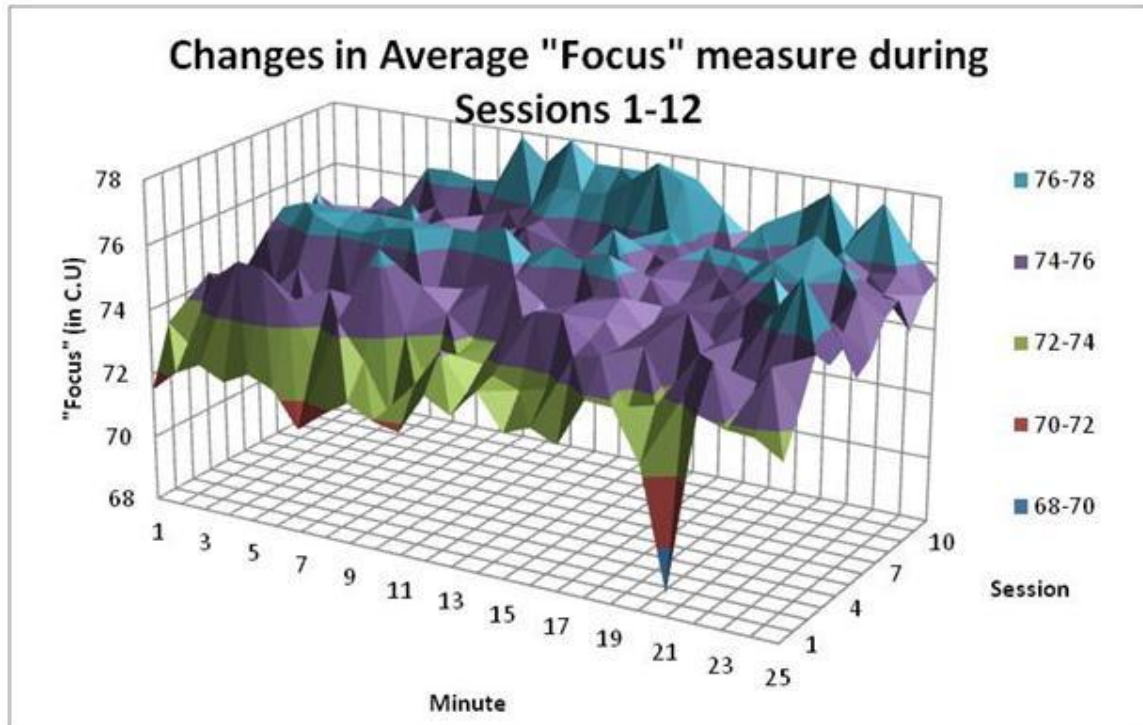


FIGURE 15: The surface chart provides anecdotal evidence supporting the increase in the "Focus" measure with regards to increasing session number and increasing minute of each session. As is consistent with the results of the ANOVA, Session trends, and Minute trend analysis, a general increase is seen from (Session 1, Minute 1) through (Session 12, Minute 25) for the "Focus" measure. The legend on the right side of the figure gives the color-coded ranges for the "Focus" measure, as seen in the chart.

As previously mentioned, ADHD subjects, especially subjects presenting with Inattentive ADHD subtype, have similar expressions of EEG characteristics. This is specifically evident in the Theta/Beta proportion being similar in the first session to that encountered in other studies involving ADHD subjects (Barry et al. 2009; Lansbergen et al. 2011; Ogrim, Kropotov, and Hestad 2012). In this analysis, the average session one value for the Theta/Low Beta proportion was 7.4, which is similar to the baseline value of 6.4-6.6 reported by Monastra (2008) for Theta/Beta values encompassing similar frequencies

current data of Ogrim, Kropotov, and Hestad (2012) (7.02-7.08 for young ADHD group and 6.21for adult ADHD group).

Due to the improvements in clinical and functional outcomes indicated through IVA+Plus and ABC, there is also discussion to be held as to whether training of the "Focus" measure or the Theta/Beta and Theta/Alpha ratios are more fundamental to functional improvement. Determination of the measure more fundamental to treatment of ADHD would increase the efficiency and aid in the delivery of neurofeedback treatment methods.

Similar to prior work in the treatment of ADHD with neurofeedback, this study indicates the efficacy of neurofeedback for altering the EEG characteristics associated with the disorder (Arns et al. 2009; Gevensleben et al. 2009; Holtmann and Stadler 2006; Monastra 2005; Sherlin et al. 2010a, 2010b; Sokhadze 2012). The positive effects of the increase in "Focus" during neurofeedback corresponded to an improvement in the clinical measures and functional outcomes seen in the IVA+Plus test and the ABC survey. Since this exploratory study did not use a controlled design we are not claiming any clinical efficiency results, but rather consider it as an investigation of EEG bands' relative powers and their ratios across 12 session neurofeedback training course aimed to enhance focused attention. This is a methodological study that uses EEG analysis in ADHD children enrolled in neurofeedback treatment using a specialist device and software.

However, this analysis differs from those prior studies in the consideration of what is transpiring not only from session to session, but also within each session. Therefore, improvement can be indicated within a shorter number of sessions (i.e. 12) compared to previous protocols that required 30-40 sessions per subject to statistically

indicate significant improvement either in EEG or clinical behavioral measures (Gevensleben et al. 2009). Probably more than 12 sessions might contribute to better consolidation of results of operant conditioning using neurofeedback and currently we have study in progress that will compare outcomes of 12 vs. 18 sessions of neurofeedback using the same protocol.

VI. FUTURE WORK AND APPLICATIONS

Based on the application developed for more efficiently processing data from neurofeedback sessions, a great deal of future research is brought to the forefront of discussion. The first extension of this research involves the use of a controlled study to demonstrate these changes. In this study, the results clearly demonstrated changes in certain bands and band ratios during neurofeedback even though specific bands were not targeted in the protocol. Therefore, a study incorporating a control group of non-ADHD subjects contrasted with a group consisting of ADHD subjects with each group undergoing neurofeedback sessions to increase "Focus" would be beneficial. The ADHD group could be further broken down into positive and negative for comorbid diagnosis, or medicated vs. non-medicated subjects. Additionally, one shortcoming of the current study involved the use of a neurofeedback system without a calibration measure. In a controlled study, a system with calibration capabilities would increase the ability for a wide-ranging analysis. Assumptions based on resistance, derived from general electrical principles, could be bypassed and the true total power of the EEG signal could be calculated and compared across different subjects with regard to session and minute of neurofeedback. Other measures such as relative amplitude of the signal in bands and band ratios could also be more accurately considered.

This study also utilized band-pass filtering to analyze the differences and changes within EEG bands and band ratios. Band-pass filtering, although with its advantages, does have larger affinity for error due to multiple filters being necessary to develop the interested relative powers and band ratios. A spectral analysis of each could produce

results with greater accuracy than seen with a band-pass based analysis. Spectral analysis would involve only filtering the signal from 2-45 Hz and then calculating power of measures from the integration of the results expressed in the frequency domain following a fast Fourier transform (FFT).

In addition to changing the form of analysis, there is also a viable extension of this protocol to a different patient population. Many neurophysiological disorders present with abnormal EEG patterns (Pliszka 1998). As a result, an extension of this protocol to autistic subjects seems logical. Such a study would be the first of its kind to examine the EEG changes occurring within neurofeedback treatment of autistic subjects. Results of this analysis would be integral to determine any efficacy or benefit of treatment of autism with neurofeedback protocols.

REFERENCES

- Aman, M.G. and Singh, N.N. (1994). *Aberrant Behavior Checklist - Community. Supplementary Manual*. East Aurora, NY: Slosson Ed. Publications.
- American Psychiatric, A. and D.-I. American Psychiatric Association. Task Force on (2000). Diagnostic and statistical manual of mental disorders : DSM-IV-TR. Washington, DC, American Psychiatric Association.
- Arns, M., de Ridder, S., Strehl, U., Breteler, M., and Coenen, A. 2009. Efficacy of neurofeedback treatment in ADHD: The effects on inattention, impulsivity and hyperactivity: A meta-analysis. *Clinical EEG & Neuroscience* 40(3): 180-189.
- Banaschewski, T., Coghill, D., Santosh, P., Zuddas, A., et al. 2006. Long-acting medications for the hyperkinetic disorders. *European Child & Adolescent Psychiatry* 15(8): 476-495.
- Barry, R. J., Clarke, A. R. , and Johnstone, S.J.. 2003. A review of electrophysiology in attention-deficit/hyperactivity disorder: I. Qualitative and quantitative electroencephalography. *Clinical Neurophysiology* 114(2): 171-183.
- Barry, R. J., Clarke, A.R., Johnstone, S.J., McCarthy, R., and Selikowitz, M. 2009. Electroencephalogram theta/beta ratio and arousal in attention-deficit/hyperactivity disorder: evidence of independent processes. *Biological Psychiatry* 66(4): 398-401.
- Biederman, J., Milberger, S., Faraone, S.V., Kiely, K., et al. 1995. Family-environment risk factors for attention-deficit hyperactivity disorder: a test of Rutter's indicators of adversity. *Archives of General Psychiatry* 52(6): 464-470.
- Biederman, J. 2005. Attention-deficit/hyperactivity disorder: a selective overview. *Biological Psychiatry* 57(11): 1215-1220.
- Clarke, A. R., Barry, R. J., McCarthy, R., and Selikowitz, M. 1998. EEG analysis in attention-deficit/hyperactivity disorder: a comparative study of two subtypes. *Psychiatry Research* 81(1): 19-29.
- Clarke, A. R., Barry, R. J., McCarthy, R., and Selikowitz, M. 2001. EEG-defined subtypes of children with attention-deficit/hyperactivity disorder. *Clinical Neurophysiology* 112(11): 2098-2105.
- Clarke, A. R., Barry, R. J., McCarthy, R., Selikowitz, M., and Brown, C.R. 2002. EEG evidence for a new conceptualisation of attention deficit hyperactivity disorder. *Clinical Neurophysiology* 113(7): 1036-1044.

Clarke, A. R., Barry, R.J., Dupuy, F.E., McCarthy, R., et al. 2010. Childhood EEG as a predictor of adult attention-deficit/hyperactivity disorder. *Clinical Neurophysiology* 122(1): 73-80.

Clarke, A. R., Barry, R.J., Irving, A.M., McCarthy, R., and Selikowitz, M. 2011a. Children with attention-deficit/hyperactivity disorder and autistic features: EEG evidence for comorbid disorders. *Psychiatry Research* 185(1-2): 225-231.

Clarke, A. R., Barry, R.J., Dupuy, F.E., Heckel, L.D., et al. 2011b. Behavioural differences between EEG-defined subgroups of children with attention-deficit/hyperactivity disorder. *Clinical Neurophysiology* 122(7): 1333-1341.

Cortese, S. 2012. The neurobiology and genetics of attention-deficit/hyperactivity disorder (ADHD): What every clinician should know. *European Journal of Paediatric Neurology* doi:10.1016/j.ejpn.2012.01.009.

Cowan J.D. and Albers, S. Manual for The Peak Achievement Trainer. Goshen, KY: NeuroTek LLC; 2008.

Faraone, S.V., Sergeant, J., Gillberg, C., and Biederman, J. 2003. The worldwide prevalence of ADHD: is it an American condition? *World Psychiatry* 2:104 –113.

Faraone, S. V., Perlis, R.H., Doyle, A.E., and Smoller, J.W., et al. 2005. Molecular Genetics of attention-deficit/hyperactivity disorder. *Biological Psychiatry* 57(11): 1313-1323.

Faraone, S. V. and Mick, E. 2010. Molecular genetics of attention deficit hyperactivity disorder. *The Psychiatric Clinics of North America* 33(1): 159-180.

Ferguson, J. H. 2000. National Institutes of Health consensus development conference statement: diagnosis and treatment of attention-deficit/hyperactivity disorder (ADHD). *Journal of the American Academy of Child & Adolescent Psychiatry* 39(2): 182-193.

Fuchs, T., Birbaumer, N., Lutzenberger, W., Gruzelier, J.H., and Kaiser, J. 2003. Neurofeedback treatment for attention-deficit/hyperactivity disorder in children: a comparison with methylphenidate. *Applied Psychophysiology and Biofeedback* 28(1): 1-12.

Gevensleben, H., Holl, B., Albrecht, B., Vogel, C., et al. 2009. Is neurofeedback an efficacious treatment for ADHD? A randomised controlled clinical trial. *Journal of Child Psychology and Psychiatry* 50(7): 780-789.

Gillberg, C., Gillberg, I.C., Rasmussen, P., Kadesjö, B., et al. 2004. Co-existing disorders in ADHD – implications for diagnosis and intervention. *European Child & Adolescent Psychiatry* 13(0): 80-92.

Greenhill, L. L., Halperin, J. M., and Abikoff, H. 1999. Stimulant medications. *Journal of the American Academy of Child & Adolescent Psychiatry* 38(5): 503-512.

Greenhill, L. L., Swanson, J.M., Vitiello, B., Davies, M., et al. 2001. Impairment and department responses to different methylphenidate doses in children with ADHD: the MTA titration trial. *Journal of the American Academy of Child & Adolescent Psychiatry* 40(2): 180-187.

Holtmann, M. and Stadler, C. 2006. Electroencephalographic biofeedback for the treatment of attention-deficit hyperactivity disorder in childhood and adolescence. *Expert Review of Neurotherapeutics* 6(4): 533-540.

Lansbergen, M. M., Arns, M., van Dongen-Boomsma, M., Spronk, D., and Buitelaar, J.K. 2011. The increase in theta/beta ratio on resting-state EEG in boys with attention-deficit/hyperactivity disorder is mediated by slow alpha peak frequency. *Progress in Neuro-Psychopharmacology and Biological Psychiatry* 35(1): 47-52.

Linden, M., Habib, T., and Radojevic, V. 1996. A controlled study of the effects of EEG biofeedback on cognition and behavior of children with attention deficit disorder and learning disabilities. *Biofeedback and Self-regulation* 21(1): 35-49.

Lofthouse, N., Arnold, L. E. and Hurt, E. 2010 A Comment on Sherlin, Arns, Lubar, and Sokhadze, 2010. *Journal of Neurotherapy* 14(4): 301-306.

Lubar, J.F. and Shouse, M. N. 1976. EEG and behavioral changes in a hyperkinetic child concurrent with training of the sensorimotor rhythm (SMR): A preliminary report. *Biofeedback and Self-regulation*, 1(3), 293-306.

Mick, E., Biederman, J., Faraone, S.V., Sayer, J., and Kleinman, S. 2002. Case-control study of attention-deficit hyperactivity disorder and maternal smoking, alcohol use, and drug use during pregnancy. *Journal of the American Academy of Child & Adolescent Psychiatry* 41(4): 378-385.

Miller, R. 2007. Theory of the normal waking EEG: from single neurones to waveforms in the alpha, beta and gamma frequency ranges. *International Journal of Psychophysiology* 64(1): 18-23.

Monastra, V. J. 2005. Electroencephalographic biofeedback (neurotherapy) as a treatment for attention deficit hyperactivity disorder: rationale and empirical foundation. *Child and Adolescent Psychiatric Clinics of North America* 14(1): 55-82.

Monastra, V.J. 2008. Quantitative electroencephalography and attention-deficit/hyperactivity disorder: implications for clinical practice. *Current Psychiatry Reports* 10(5): 432-438.

Neale, B. M., Medland, S.E., Ripke, S., Asherson, P., et al. 2010. Meta-analysis of genome-wide association studies of attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child & Adolescent Psychiatry* 49(9): 884-897.

Ogrim, G., Kropotov, J., and Hestad, K. 2012. The QEEG theta/beta ratio in ADHD and normal Performance Tests. *Psychiatry Research* doi: 10.1016/j.psychres.2011.12.041

Pliszka, S. R. 1998. Comorbidity of attention-deficit/hyperactivity disorder with psychiatric disorder: an overview. *The Journal of Clinical Psychiatry* 59 Suppl 7: 50-8.

Rossiter, D. and La Vaque, T.J. 1995. A comparison of EEG biofeedback and psychostimulants in treating attention deficit/hyperactivity disorders. *Journal of Neurotherapy* 1(1): 48-59.

Rubik, B. 2011. Neurofeedback-enhanced gamma brainwaves from the prefrontal cortical region of meditators and non-meditators and associated subjective experiences. *Journal of Alternative & Complementary Medicine* 17(2): 109-115.

Sandford, J.A. IVA+ Plus IVA-AE. Integrated Visual and Auditory Continuous Performance Test (CPT).

Sherlin, L., Arns, M., Lubar, J., and Sokhadze, E. 2010a. A position paper on neurofeedback for the treatment of ADHD. *Journal of Neurotherapy* 14(2): 66-78.

Sherlin, L., Arns, M., Lubar, J., and Sokhadze, E. 2010b. A reply to Lofthouse, Arnold, and Hurt (2010). *Journal of Neurotherapy* 14(4): 307-311.

Sokhadze E. 2012. Peak performance training using prefrontal EEG biofeedback. *Biofeedback* 40 (in press).

Taylor, E., Döpfner, M., Sergeant, J., Asherson, P., et al. 2004. European clinical guidelines for hyperkinetic disorder – first upgrade. *European Child & Adolescent Psychiatry* 13(0): 7-30.

The MTA Cooperative Group. 1999. A 14-month randomized clinical trial of treatment strategies for attention-deficit/hyperactivity disorder. *Archives of General Psychiatry* 56(12): 1073-1086.

Van den Bergh, W. 2010. *Neurofeedback and State Regulation in ADHD: A Therapy Without Medication*. BMED Press.

Wood, A.C., Buitelaar, J., Rijdsdijk, F., Asherson, P., and Kuntai, J. 2009. Rethinking shared environment as a source of variance underlying attention-deficit/hyperactivity disorder symptoms: comment on Burt. *Psychological Bulletin* 2010;136:331e40.

Wyrwicka, W. and Serman, M. B. 1968. Instrumental conditioning of sensorimotor cortex EEG spindles in the waking cat. *Physiology and Behavior* 3(5): 703-707.

Zhou, K., Dempfle, A., Arcos-Burgos, M., Bakker, S.C., et al. 2008. Meta-analysis of genome-wide linkage scans of attention deficit hyperactivity disorder. *American Journal of Medical Genetics Part B: Neuropsychiatric Genetics* 147B(8): 1392-1398.

APPENDIX I: MATLAB CODES

A. EEG Signal Processing Main Code

```
clear
close all
clc

mkdir('Output_Excel_Files');
xlsDir_Input = [cd '\Converted\']; % Input data folder
xlsDir_Output=[cd '\Output_Excel_Files\']; % Output data folder

allXls_Files = dir(xlsDir_Input); %Structure with all files in the specified dir.
FL = length(allXls_Files); %Total # of files inncludes hidden ones
for file_number =1:FL
    if strcmp(allXls_Files(file_number).name, '.') ||
        strcmp(allXls_Files(file_number).name, '..') ||
        strcmp(allXls_Files(file_number).name, 'Thumbs.db')
        continue; % Avoid all hidden files in folder
    end
    curFile = allXls_Files(file_number).name;

    Input_Chgs = dlmread([xlsDir_Input, '\ curFile ], ',', 2, 0);
    Input_Chgs = Input_Chgs(:,1:7);
    if size(Input_Chgs,1)>=25*256*60 %To only look at first 25 minutes of file
        Raw_Signal = Input_Chgs(1:25*256*60,1);
    else
        Raw_Signal = Input_Chgs(:,1);
    end
    max_value = max(max(Raw_Signal));
    min_value = min(min(Raw_Signal));

    c = cwt(Raw_Signal,[1:1:128],'morl'); %Continuous Wavelet Transformation
    Inp_S_2_45 = Input_Signal_2_45(c); %Input Signal 2-45 Hz Function
    for k = 1:1:length(Inp_S_2_45)
        if Inp_S_2_45(k)>max_value
            Inp_S_2_45(k) = max_value;
        end

        if Inp_S_2_45(k)<min_value
            Inp_S_2_45(k) = min_value;
        end
    end
end
```



```

        end
    end

    Delta_Signal = Input_Chgs(:,2);
    Theta_Signal = Input_Chgs(:,3);
    Alpha_Signal = Input_Chgs(:,4);
    Low_Beta = Input_Chgs(:,5);
    High_Beta = Input_Chgs(:,6);
    Gamma_Signal = Input_Chgs(:,7);

    No_Minutes = fix((length(Inp_S_2_45))/15360)
    for k = 1:1:No_Minutes
        Start_In = (k-1).*15360 + 1;
        End_In = k.*15360;
        D_S = Delta_Signal(Start_In:1:End_In);
        T_S = Theta_Signal(Start_In:1:End_In);
        A_S = Alpha_Signal(Start_In:1:End_In);
        L_B = Low_Beta(Start_In:1:End_In);
        H_B = High_Beta(Start_In:1:End_In);
        G_S = Gamma_Signal(Start_In:1:End_In);
        I_S = Inp_S_2_45(Start_In:1:End_In);

        R_D_S(k) = sum(D_S.^2)./sum(I_S.^2);
        R_T_S(k) = sum(T_S.^2)./sum(I_S.^2);
        R_A_S(k) = sum(A_S.^2)./sum(I_S.^2);
        R_L_B(k) = sum(L_B.^2)./sum(I_S.^2);
        R_H_B(k) = sum(H_B.^2)./sum(I_S.^2);
        R_G_S(k) = sum(G_S.^2)./sum(I_S.^2);

        Ratio_T_L_B(k) = R_T_S(k)./R_L_B(k);
        Ratio_T_H_B(k) = R_T_S(k)./R_H_B(k);
        Ratio_T_B(k) = R_T_S(k)./(R_L_B(k) + R_H_B(k));
        Ratio_T_A(k)=R_T_S(k)./R_A_S(k)
    end
    Start_In = 1;
    End_In = No_Minutes.*15360;
    D_S = Delta_Signal(Start_In:1:End_In);
    T_S = Theta_Signal(Start_In:1:End_In);
    A_S = Alpha_Signal(Start_In:1:End_In);
    L_B = Low_Beta(Start_In:1:End_In);
    H_B = High_Beta(Start_In:1:End_In);
    G_S = Gamma_Signal(Start_In:1:End_In);
    I_S = Inp_S_2_45(Start_In:1:End_In);
    R_D_S(No_Minutes + 1) = sum(D_S.^2)./sum(I_S.^2);
    R_T_S(No_Minutes + 1) = sum(T_S.^2)./sum(I_S.^2);

```

```

R_A_S(No_Minutes + 1) = sum(A_S.^2)./sum(I_S.^2);
R_L_B(No_Minutes + 1) = sum(L_B.^2)./sum(I_S.^2);
R_H_B(No_Minutes + 1) = sum(H_B.^2)./sum(I_S.^2);
R_G_S(No_Minutes + 1) = sum(G_S.^2)./sum(I_S.^2);
Ratio_T_L_B(No_Minutes + 1) = R_T_S(No_Minutes + 1)./R_L_B(No_Minutes + 1);
Ratio_T_H_B(No_Minutes + 1) = R_T_S(No_Minutes + 1)./R_H_B(No_Minutes + 1)
Ratio_T_B(No_Minutes + 1) = R_T_S(No_Minutes + 1)./(R_L_B(No_Minutes + 1) +
    R_H_B(No_Minutes + 1));
Ratio_T_A(No_Minutes + 1)=R_T_S(No_Minutes +1)./R_A_S(No_Minutes + 1);

X = [R_D_S' R_T_S' R_A_S' R_L_B' R_H_B' R_G_S' Ratio_T_L_B' Ratio_T_H_B'
    Ratio_T_B' Ratio_T_A'];
curFile = curFile(1:end-4);
xlswrite([ xlsDir_Output '\Result_' curFile '.xlsx'],X)
end

```

B. Input Signal Filtering Function

Input Signal 2_45

```
function Filtered_Wav = Input_Signal_2_45(coefs)
```

```
fs = 256;
```

```
[h w] = size(coefs);
```

```
    for iter_index = 1:h
```

```
        xnoisy = coefs(iter_index,:);
```

```
        Filtered_Signal = BPF_2_45(xnoisy,fs);
```

```
        Filtered_Wav_coef(iter_index,1:w) = Filtered_Signal(1:w);
```

```
    end
```

```
Filtered_Wav = sum(Filtered_Wav_coef)./128;
```

C. 2-45 Hz Band-pass Filter Function

BPF_2_45

```
function Filtered_Signal = BPF_2_45(x,fs)
```

```
% BPF Parameters
```

```
Fp1= 2./fs;
```

```
Fp2 = 45./fs;
```

```
Fs1 = 0.5./fs;
```

```
Fs2 = 46.5./fs;
```

```
F0 = (Fp1 + Fp2)./2;
```

```
Fp = 0.5.*(Fp2 - Fp1);
```

```
Fs = 0.5.*(Fs2 - Fs1);
```

```
Fc = (Fp + Fs)./2;
```

```
C = 7.96; % Assuming Harris Window
```

```
Number_of_Samples = round(C./Fc);
```

```
% To check that the number of samples are odd
```

```
if ((Number_of_Samples./2)==fix(Number_of_Samples./2))
```

```
    Number_of_Samples = Number_of_Samples + 1;
```

```
end
```

```
N = [-(Number_of_Samples-1)./2:1:(Number_of_Samples-1)./2];
```

```
w_n = Harris_W_7(Number_of_Samples); %Harris Window Function
```

```
%Calculate the impulse response of LPF
```

```
h_LPF = Impulse_Response_LPF(w_n,Fc); %Impulse Response Function
```

```
h_BPF = 2.*cos(2.*F0.*pi.*N).*h_LPF;
```

```
Y_C = conv(h_BPF,x);
```

```
% To remove the transition time
```

```
Filtered_Signal = Y_C(fix(Number_of_Samples./2):1:length(Y_C)-
```

```
fix(Number_of_Samples./2+1));
```

D. Harris Window Function

```
function w_n = Harris_W_7(Number_of_Samples)

b0 = 0.355768;
b1 = 0.487396;
b2 = 0.144232;
b3 = 0.012604;

i=0;
for n = 0:1:(Number_of_Samples)-1
    i = i+1;
    w_n(i) = b0 - b1.*cos(2.*n.*pi./(Number_of_Samples-1)) +
             b2.*cos(4.*n.*pi./(Number_of_Samples-1)) -
             b3.*cos(6.*n.*pi./(Number_of_Samples-1));
end
```

E. Impulse Response LPF Function

```
function h_LPF = Impulse_Response_LPF(w_n,Fc)

n=0;
N = length(w_n);

    for i = -(N-1)./2:1:(N-1)./2
        n = n+1;
        if (i==0)
            h(n) = 2.*Fc; %To calculate h[n]
        else
            h(n) = ((2.*Fc).*(sin(2.*Fc*pi*i)))/(2.*Fc.*pi.*i);
        end
    end
h_LPF = h.*w_n;
```

F. Main Analysis Code

```
%=====
clc;
clear all;
close all;
%=====
mkdir('Outputs')
parentDir=cd;
allData_dir =[cd '\allData\'];
OutDir = [cd '\Outputs\'];      % Output directory to save results

dataFolders = dir(allData_dir);
FL = length(dataFolders);      % Total # of subjects (Includes hidden folders)

Ks =0;
    for file_number1 =1 : FL          %To determine # of subjects
        % take care of hidden files
        if strcmp(dataFolders(file_number1).name, '.') ||
            strcmp(dataFolders(file_number1).name, '..')
            continue;
        end
        Ks = Ks+1;
    end

patientCount = 0;

allSelected_Sessions = cell(12, Ks); %Create Cell Array for 12 Sessions and Ks number
                                     %of subjects

    for file_number2 = 1 : FL      % To move from subject to subject for each session
        % take care of hidden files
        if strcmp(dataFolders(file_number2).name, '.') ||
            strcmp(dataFolders(file_number2).name, '..')
            continue;
        end
        patientCount = patientCount + 1;
        % Current Data Set Directory and its Output Directory
        curFolder = dataFolders(file_number2).name;
        curData_dir = [allData_dir, curFolder ];
        %=====
        sessionFiles = dir(curData_dir);
```

```

FL2 = length(sessionFiles); % Total # of Sessions (Includes hidden
                             %folders)
Ks2 = 0;
for file_number3 = 1 : FL      %To move from subject to subject while
                               %getting FL2 session file
    % take care of hidden files
    if strcmp(sessionFiles(file_number3).name, '.') ||
        strcmp(sessionFiles(file_number3).name, '..')
        continue;
    end
    Ks2 = Ks2 + 1;
end

allSessions = cell(1,Ks2);
sessionCount = 0;
for file_number4 = 1 : FL2    %To move from session to session across all
                              %subjects
    % take care of hidden files
    if strcmp(sessionFiles(file_number4).name, '.') ||
        strcmp(sessionFiles(file_number4).name, '..')
        continue;
    end
    sessionCount = sessionCount + 1;
    % Current Data Set Directory and its Output Directory
    curFile = sessionFiles(file_number4).name;
    curData = xlsread([curData_dir '\' curFile]);
    allSessions{sessionCount} = curData;
end
%=====
%=====
allSelected_Sessions{1,patientCount} = allSessions{1};
allSelected_Sessions{2,patientCount} = allSessions{2};
allSelected_Sessions{3,patientCount} = allSessions{3};
allSelected_Sessions{4,patientCount} = allSessions{4};
allSelected_Sessions{5,patientCount} = allSessions{5};
allSelected_Sessions{6,patientCount} = allSessions{6};
allSelected_Sessions{7,patientCount} = allSessions{7};
allSelected_Sessions{8,patientCount} = allSessions{8};
allSelected_Sessions{9,patientCount} = allSessions{9};
allSelected_Sessions{10,patientCount} = allSessions{10};
allSelected_Sessions{11,patientCount} = allSessions{11};
allSelected_Sessions{12,patientCount} = allSessions{12};
end

```

%The First Session


```

-----
first_Ses_Mean = zeros(25,10);
firstIndices = zeros(25,1);

for cc = 1 : Ks
    curPatient = allSelected_Sessions{1,cc};
    [rows cols] = size(curPatient);
    %remove the summary row for each file
    if rows>=26
        curPatient(26:end,:) = [];
    elseif rows<26
        curPatient(end,:) = [];
    end
    curIndx = ones(25,1);
    [rows cols] = size(curPatient);
    if rows<25
        numLines= 25-rows;
        curPatient(rows+1:rows+numLines,:) = 0;
        curIndx(rows+1:rows+numLines,:) = 0;
    end
    first_Ses_Mean = first_Ses_Mean+curPatient;
    firstIndices = firstIndices + curIndx;
end
XX_01 = repmat(firstIndices,1,size(first_Ses_Mean,2));
first_Ses_Mean = first_Ses_Mean./XX_01 ;
xlswrite([OutDir '\first_Ses_Mean.xls'],first_Ses_Mean)

% The Second Session
%-----
second_Ses_Mean = zeros(25,10);
secondIndices = zeros(25,1);

for cc = 1 : Ks
    curPatient = allSelected_Sessions{2,cc};
    [rows cols] = size(curPatient);
    if rows>=26
        curPatient(26:end,:) = [];
    elseif rows<26
        curPatient(end,:) = [];
    end
    curIndx = ones(25,1);
    [rows cols] = size(curPatient);
    if rows<25
        numLines= 25-rows;
        curPatient(rows+1:rows+numLines,:) = 0;

```

```

        curIndx(rows+1:rows+numLines,:) = 0;
    end

    second_Ses_Mean = second_Ses_Mean+curPatient;
    secondIndices = secondIndices + curIndx;
end
XX_02 = repmat(secondIndices,1,size(second_Ses_Mean,2));
second_Ses_Mean = second_Ses_Mean./XX_02 ;
xlswrite([OutDir '\second_Ses_Mean.xls'],second_Ses_Mean)

% The Third Session
%-----
third_Ses_Mean = zeros(25,10);
thirdIndices = zeros(25,1);

for cc = 1 : Ks
    curPatient = allSelected_Sessions{3,cc};
    [rows cols] = size(curPatient);
    if rows>=26
        curPatient(26:end,:) = [];
    elseif rows<26
        curPatient(end,:) = [];
    end
    curIndx = ones(25,1);
    [rows cols] = size(curPatient);
    if rows<25
        numLines= 25-rows;
        curPatient(rows+1:rows+numLines,:) = 0;
        curIndx(rows+1:rows+numLines,:) = 0;
    end
    third_Ses_Mean = third_Ses_Mean+curPatient;
    thirdIndices = thirdIndices + curIndx;
end
XX_03 = repmat(thirdIndices,1,size(third_Ses_Mean,2));
third_Ses_Mean = third_Ses_Mean./XX_03 ;
xlswrite([OutDir '\third_Ses_Mean.xls'],third_Ses_Mean)

% The Fourth Session
%-----
fourth_Ses_Mean = zeros(25,10);
fourthIndices = zeros(25,1);

for cc = 1 : Ks
    curPatient = allSelected_Sessions{4,cc};
    [rows cols] = size(curPatient);

```

```

        if rows>=26
            curPatient(26:end,:) = [];
        elseif rows<26
            curPatient(end,:) = [];
        end
        curIndx = ones(25,1);
        [rows cols] = size(curPatient);
        if rows<25
            numLines= 25-rows;
            curPatient(rows+1:rows+numLines,:) = 0;
            curIndx(rows+1:rows+numLines,:) = 0;
        end
        fourth_Ses_Mean = fourth_Ses_Mean+curPatient;
        fourthIndices = fourthIndices + curIndx;
    end
    XX_04 = repmat(fourthIndices,1,size(fourth_Ses_Mean,2));
    fourth_Ses_Mean = fourth_Ses_Mean./XX_04 ;
    xlswrite([OutDir 'fourth_Ses_Mean.xls'],fourth_Ses_Mean)

% The Fifth Session
%-----
fifth_Ses_Mean = zeros(25,10);
fifthIndices = zeros(25,1);

for cc = 1 : Ks
    curPatient = allSelected_Sessions{5,cc};
    [rows cols] = size(curPatient);
    if rows>=26
        curPatient(26:end,:) = [];
    elseif rows<26
        curPatient(end,:) = [];
    end
    curIndx = ones(25,1);
    [rows cols] = size(curPatient);
    if rows<25
        numLines= 25-rows;
        curPatient(rows+1:rows+numLines,:) = 0;
        curIndx(rows+1:rows+numLines,:) = 0;
    end
    fifth_Ses_Mean = fifth_Ses_Mean+curPatient;
    fifthIndices = fifthIndices + curIndx;
end
XX_05 = repmat(fifthIndices,1,size(fifth_Ses_Mean,2));
fifth_Ses_Mean = fifth_Ses_Mean./XX_05 ;
xlswrite([OutDir 'fifth_Ses_Mean.xls'],fifth_Ses_Mean)

```

```

% The Sixth Session
%-----
sixth_Ses_Mean = zeros(25,10);
sixthIndices = zeros(25,1);

    for cc = 1 : Ks
        curPatient = allSelected_Sessions{6,cc};
        [rows cols] = size(curPatient);
        if rows>=26
            curPatient(26:end,:) = [];
        elseif rows<26
            curPatient(end,:) = [];
        end
        curIndx = ones(25,1);
        [rows cols] = size(curPatient);
        if rows<25
            numLines= 25-rows;
            curPatient(rows+1:rows+numLines,:) = 0;
            curIndx(rows+1:rows+numLines,:) = 0;
        end
        sixth_Ses_Mean = sixth_Ses_Mean+curPatient;
        sixthIndices = sixthIndices + curIndx;
    end
XX_06 = repmat(sixthIndices,1,size(sixth_Ses_Mean,2));
sixth_Ses_Mean = sixth_Ses_Mean./XX_06 ;
xlswrite([OutDir '\sixth_Ses_Mean.xls'],sixth_Ses_Mean)

```

```

% The Seventh Session
%-----
seventh_Ses_Mean = zeros(25,10);
seventhIndices = zeros(25,1);

    for cc = 1 : Ks
        curPatient = allSelected_Sessions{7,cc};
        [rows cols] = size(curPatient);
        if rows>=26
            curPatient(26:end,:) = [];
        elseif rows<26
            curPatient(end,:) = [];
        end
        curIndx = ones(25,1);
        [rows cols] = size(curPatient);
        if rows<25
            numLines= 25-rows;

```

```

        curPatient(rows+1:rows+numLines,:) = 0;
        curIndx(rows+1:rows+numLines,:) = 0;
    end
    seventh_Ses_Mean = seventh_Ses_Mean+curPatient;
    seventhIndices = seventhIndices + curIndx;
end
XX_07 = repmat(seventhIndices,1,size(seventh_Ses_Mean,2));
seventh_Ses_Mean = seventh_Ses_Mean./XX_07 ;
xlswrite([OutDir '\seventh_Ses_Mean.xls'],seventh_Ses_Mean)

```

% The Eighth Session

%-----

```

eighth_Ses_Mean = zeros(25,10);
eighthIndices = zeros(25,1);

```

```

    for cc = 1 : Ks
        curPatient = allSelected_Sessions{8,cc};
        [rows cols] = size(curPatient);
        if rows>=26
            curPatient(26:end,:) = [];
        elseif rows<26
            curPatient(end,:) = [];
        end
        curIndx = ones(25,1);
        [rows cols] = size(curPatient);
        if rows<25
            numLines= 25-rows;
            curPatient(rows+1:rows+numLines,:) = 0;
            curIndx(rows+1:rows+numLines,:) = 0;
        end
        eighth_Ses_Mean = eighth_Ses_Mean+curPatient;
        eighthIndices = eighthIndices + curIndx;
    end
    XX_08 = repmat(eighthIndices,1,size(eighth_Ses_Mean,2));
    eighth_Ses_Mean = eighth_Ses_Mean./XX_08 ;
    xlswrite([OutDir '\eighth_Ses_Mean.xls'],eighth_Ses_Mean)

```

% The Ninth Session

%-----

```

ninth_Ses_Mean = zeros(25,10);
ninthIndices = zeros(25,1);

```

```

    for cc = 1 : Ks
        curPatient = allSelected_Sessions{9,cc};
        [rows cols] = size(curPatient);

```

```

        if rows>=26
            curPatient(26:end,:) = [];
        elseif rows<26
            curPatient(end,:) = [];
        end
        curIndx = ones(25,1);
        [rows cols] = size(curPatient);
        if rows<25
            numLines= 25-rows;
            curPatient(rows+1:rows+numLines,:) = 0;
            curIndx(rows+1:rows+numLines,:) = 0;
        end
        ninth_Ses_Mean = ninth_Ses_Mean+curPatient;
        ninthIndices = ninthIndices + curIndx;
    end
    XX_09 = repmat(ninthIndices,1,size(ninth_Ses_Mean,2));
    ninth_Ses_Mean = ninth_Ses_Mean./XX_09 ;
    xlswrite([OutDir \'ninth_Ses_Mean.xls'],ninth_Ses_Mean)

% The Tenth Session
%-----
tenth_Ses_Mean = zeros(25,10);
tenthIndices = zeros(25,1);

for cc = 1 : Ks
    curPatient = allSelected_Sessions{ 10,cc };
    [rows cols] = size(curPatient);
    if rows>=26
        curPatient(26:end,:) = [];
    elseif rows<26
        curPatient(end,:) = [];
    end
    curIndx = ones(25,1);
    [rows cols] = size(curPatient);
    if rows<25
        numLines= 25-rows;
        curPatient(rows+1:rows+numLines,:) = 0;
        curIndx(rows+1:rows+numLines,:) = 0;
    end
    tenth_Ses_Mean = tenth_Ses_Mean+curPatient;
    tenthIndices = tenthIndices + curIndx;
end
XX_10 = repmat(tenthIndices,1,size(tenth_Ses_Mean,2));
tenth_Ses_Mean = tenth_Ses_Mean./XX_10 ;
xlswrite([OutDir \'tenth_Ses_Mean.xls'],tenth_Ses_Mean)

```

```

% The Eleventh Session
%-----
eleventh_Ses_Mean = zeros(25,10);
eleventhIndices = zeros(25,1);

    for cc = 1 : Ks
        curPatient = allSelected_Sessions{ 11,cc };
        [rows cols] = size(curPatient);
        if rows>=26
            curPatient(26:end,:) = [];
        elseif rows<26
            curPatient(end,:) = [];
        end
        curIndx = ones(25,1);
        [rows cols] = size(curPatient);
        if rows<25
            numLines= 25-rows;
            curPatient(rows+1:rows+numLines,:) = 0;
            curIndx(rows+1:rows+numLines,:) = 0;
        end
        eleventh_Ses_Mean = eleventh_Ses_Mean+curPatient;
        eleventhIndices = eleventhIndices + curIndx;
    end
XX_11 = repmat(eleventhIndices,1,size(eleventh_Ses_Mean,2));
eleventh_Ses_Mean = eleventh_Ses_Mean./XX_11 ;
xlswrite([OutDir '\eleventh_Ses_Mean.xls'],eleventh_Ses_Mean)

```

```

% The Twelfth Session
%-----
twelfth_Ses_Mean = zeros(25,10);
twelveIndices = zeros(25,1);

    for cc = 1 : Ks
        curPatient = allSelected_Sessions{ 12,cc };
        [rows cols] = size(curPatient);
        if rows>=26
            curPatient(26:end,:) = [];
        elseif rows<26
            curPatient(end,:) = [];
        end
        curIndx = ones(25,1);
        [rows cols] = size(curPatient);
    end

```

```

        if rows<25
            numLines= 25-rows;
            curPatient(rows+1:rows+numLines,:)= 0;
            curIndx(rows+1:rows+numLines,:)= 0;
        end
        twelfth_Ses_Mean = twelfth_Ses_Mean+curPatient;
        twelveIndices = twelveIndices + curIndx;
    end
    XX_12 = repmat(twelveIndices,1,size(twelfth_Ses_Mean,2));
    twelfth_Ses_Mean = twelfth_Ses_Mean./XX_12 ;
    xlswrite([OutDir 'twelfth_Ses_Mean.xls'],twelfth_Ses_Mean)

```


APPENDIX II: DATA TABLES

A. Raw Data for Analysis

TABLE VI

RAW DATA FOR SESSION 1

Minute	Delta Relative Power	Theta Relative Power	Alpha Relative Power	Low Beta Relative Power	High Beta Relative Power	Gamma Relative Power	Theta/ Low Beta Ratio	Theta/ High Beta Ratio	Theta/ Beta Ratio	Theta/ Alpha Ratio	"Focus"	"Alertness"
1	0.145	0.084	0.027	0.013	0.027	0.026	7.306	4.501	2.73	3.323	71.501	38.594
2	0.15	0.082	0.024	0.012	0.029	0.027	7.655	4.846	2.858	3.676	72.178	38.133
3	0.138	0.079	0.023	0.012	0.025	0.027	7.682	4.672	2.809	3.733	72.58	38.2
4	0.137	0.084	0.026	0.013	0.029	0.033	7.407	4.576	2.739	3.552	72.196	38.913
5	0.141	0.087	0.031	0.015	0.032	0.031	7.807	4.701	2.86	3.44	72.603	39.189
6	0.135	0.078	0.024	0.012	0.03	0.04	7.405	4.025	2.545	3.42	72.286	38.884
7	0.136	0.084	0.027	0.014	0.036	0.047	7.418	4.23	2.617	3.491	71.214	38.864
8	0.133	0.081	0.026	0.014	0.035	0.046	7.058	3.96	2.473	3.459	71.838	38.243
9	0.143	0.085	0.023	0.014	0.036	0.047	8.504	4.83	3	3.903	72.352	38.541
10	0.141	0.08	0.023	0.012	0.027	0.031	7.925	4.375	2.761	3.778	71.956	38.364
11	0.137	0.091	0.026	0.013	0.03	0.032	8.169	4.81	2.92	3.843	71.789	37.127
12	0.125	0.075	0.027	0.016	0.039	0.045	5.931	3.376	2.095	2.95	73.068	38.462
13	0.14	0.082	0.026	0.015	0.032	0.035	7.06	3.87	2.435	3.46	72.64	38.115
14	0.142	0.084	0.028	0.017	0.032	0.033	6.622	3.972	2.439	3.339	73.527	38.376
15	0.134	0.081	0.026	0.015	0.037	0.041	6.895	4.486	2.634	3.634	72.438	38.631
16	0.139	0.09	0.029	0.017	0.042	0.043	6.724	3.932	2.417	3.316	72.763	39.227
17	0.138	0.08	0.02	0.011	0.029	0.033	8.682	4.645	2.943	4.068	72.414	37.487
18	0.142	0.08	0.023	0.013	0.033	0.035	7.721	4.434	2.744	3.669	73.895	38.324
19	0.142	0.081	0.023	0.015	0.037	0.039	7.908	4.476	2.761	3.793	73.846	40.133
20	0.136	0.074	0.022	0.014	0.033	0.036	7.489	3.576	2.326	3.616	72.337	39.841
21	0.135	0.082	0.025	0.016	0.045	0.057	6.394	3.326	2.114	3.565	68.69	40.593
22	0.136	0.082	0.029	0.016	0.047	0.061	6.071	3.377	2.077	3.017	74.133	40.317
23	0.126	0.079	0.024	0.014	0.043	0.053	7.044	3.561	2.285	3.281	73.867	40.64
24	0.125	0.076	0.026	0.016	0.051	0.063	6.806	3.454	2.241	3.203	73.799	39.199
25	0.144	0.087	0.03	0.016	0.044	0.047	9.698	6.307	3.704	4.02	73.28	37.095

TABLE VII

RAW DATA FOR SESSION 2

Minute	Delta Relative Power	Theta Relative Power	Alpha Relative Power	Low Beta Relative Power	High Beta Relative Power	Gamma Relative Power	Theta/ Low Beta Ratio	Theta/ High Beta Ratio	Theta/ Beta Ratio	Theta/ Alpha Ratio	"Focus"	"Alertness"
1	0.142	0.081	0.022	0.011	0.026	0.03	8.449	5.57	3.279	3.93	73.338	37.982
2	0.146	0.084	0.025	0.013	0.031	0.039	8.2	5.461	3.191	3.864	72.687	39.025
3	0.145	0.076	0.022	0.011	0.023	0.026	8.049	4.71	2.928	3.811	75.021	38.235
4	0.149	0.083	0.029	0.016	0.042	0.047	7.607	4.26	2.677	3.412	75.681	40.102
5	0.138	0.079	0.025	0.013	0.03	0.028	7.464	4.287	2.663	3.336	75.598	38.192
6	0.158	0.082	0.028	0.015	0.037	0.043	6.57	3.675	2.268	3.199	74.726	38.942
7	0.139	0.079	0.027	0.015	0.041	0.045	6.339	3.504	2.166	3.341	73.283	39.594
8	0.154	0.084	0.025	0.014	0.033	0.038	7.861	4.618	2.808	3.825	74.421	39.404
9	0.146	0.082	0.027	0.015	0.041	0.046	6.97	3.617	2.306	3.32	73.367	39.614
10	0.157	0.101	0.033	0.021	0.056	0.071	6.428	3.762	2.282	3.32	71.871	38.956
11	0.157	0.095	0.032	0.019	0.053	0.064	7.306	5.044	2.816	3.561	72.961	39.804
12	0.145	0.08	0.027	0.016	0.04	0.044	6.104	3.627	2.225	3.24	74.146	39.329
13	0.142	0.083	0.027	0.017	0.042	0.057	6.076	3.429	2.135	3.268	73.025	40.039
14	0.144	0.085	0.026	0.016	0.047	0.053	6.931	3.591	2.302	3.583	73.708	40.203
15	0.14	0.081	0.026	0.017	0.049	0.059	6.86	3.53	2.275	3.303	73.416	40.315
16	0.138	0.082	0.027	0.016	0.046	0.067	6.273	3.496	2.197	3.225	73.629	39.284
17	0.141	0.083	0.028	0.018	0.043	0.058	6.004	3.373	2.098	3.202	74.729	39.347
18	0.135	0.078	0.025	0.014	0.031	0.038	6.753	4.139	2.507	3.353	74.914	38.782
19	0.137	0.08	0.027	0.016	0.04	0.05	7.194	4.309	2.644	3.509	73.477	38.667
20	0.142	0.079	0.024	0.013	0.03	0.037	8.297	5.062	3.084	3.871	73.793	38.146
21	0.146	0.087	0.027	0.015	0.04	0.043	7.16	4.258	2.618	3.538	74.263	38.38
22	0.146	0.082	0.028	0.017	0.042	0.051	6.846	3.964	2.452	3.211	75.356	38.04
23	0.152	0.084	0.028	0.016	0.04	0.046	7.251	4.334	2.644	3.555	73.652	37.042
24	0.141	0.089	0.031	0.018	0.046	0.051	6.887	4.318	2.559	3.23	75.513	36.348
25	0.14	0.086	0.029	0.015	0.035	0.041	7.207	4.197	2.574	3.311	74.453	36.102

TABLE VIII

RAW DATA FOR SESSION 3

Minute	Delta Relative Power	Theta Relative Power	Alpha Relative Power	Low Beta Relative Power	High Beta Relative Power	Gamma Relative Power	Theta/ Low Beta Ratio	Theta/ High Beta Ratio	Theta/ Beta Ratio	Theta/ Alpha Ratio	"Focus"	"Alertness"
1	0.148	0.091	0.024	0.011	0.021	0.022	8.579	6.309	3.514	4.094	73.712	34.095
2	0.136	0.083	0.025	0.013	0.027	0.029	7.537	4.473	2.72	3.544	74.791	36.5
3	0.138	0.094	0.029	0.014	0.028	0.026	7.642	4.485	2.731	3.502	74.849	37.909
4	0.141	0.083	0.026	0.013	0.031	0.032	7.138	3.763	2.371	3.64	74.001	39.879
5	0.13	0.081	0.027	0.014	0.035	0.03	7.108	3.626	2.335	3.607	73.367	39.215
6	0.138	0.085	0.028	0.015	0.035	0.03	7.363	3.829	2.447	3.786	74.221	39.265
7	0.138	0.085	0.028	0.016	0.042	0.036	6.453	3.312	2.131	3.481	74.997	39.98
8	0.136	0.075	0.026	0.013	0.032	0.031	6.895	3.393	2.199	3.454	73.072	38.831
9	0.132	0.079	0.027	0.014	0.033	0.026	6.523	3.457	2.185	3.458	76.504	36.843
10	0.135	0.084	0.039	0.014	0.033	0.031	6.69	3.184	2.09	3.359	74.125	36.388
11	0.137	0.085	0.028	0.013	0.03	0.04	7.297	3.972	2.45	3.401	72.526	37.482
12	0.133	0.083	0.027	0.015	0.034	0.035	6.967	3.781	2.397	3.386	73.727	38.771
13	0.136	0.082	0.035	0.017	0.046	0.071	6.919	3.848	2.409	3.158	73.604	38.985
14	0.14	0.078	0.027	0.013	0.028	0.027	6.44	3.79	2.314	3.21	75.019	37.82
15	0.132	0.081	0.028	0.015	0.029	0.024	6.97	4.172	2.559	3.308	75.497	37.498
16	0.141	0.089	0.029	0.016	0.034	0.028	7.4	4.467	2.722	3.585	75.56	38.46
17	0.134	0.083	0.036	0.016	0.04	0.033	7.381	4.34	2.651	3.33	74.934	37.648
18	0.132	0.09	0.029	0.016	0.038	0.036	8.029	4.55	2.805	3.736	74.807	38.332
19	0.146	0.1	0.032	0.017	0.038	0.039	9.059	5.339	3.31	3.984	75.077	39.12
20	0.136	0.081	0.032	0.016	0.042	0.041	6.99	4.074	2.494	3.499	73.442	38.528
21	0.131	0.086	0.032	0.018	0.043	0.048	6.408	4.247	2.457	3.133	75.173	38.69
22	0.131	0.082	0.03	0.016	0.036	0.03	7.077	4.45	2.665	3.416	74.617	38.491
23	0.127	0.087	0.03	0.015	0.03	0.03	6.855	3.978	2.44	3.403	74.636	38.872
24	0.122	0.079	0.028	0.015	0.035	0.036	7.271	4.29	2.593	3.693	73.784	38.417
25	0.133	0.087	0.028	0.014	0.031	0.029	7.781	4.737	2.843	3.847	75.727	38.108

TABLE IX

RAW DATA FOR SESSION 4

Minute	Delta Relative Power	Theta Relative Power	Alpha Relative Power	Low Beta Relative Power	High Beta Relative Power	Gamma Relative Power	Theta/ Low Beta Ratio	Theta/ High Beta Ratio	Theta/ Beta Ratio	Theta/ Alpha Ratio	"Focus"	"Alertness"
1	0.132	0.084	0.026	0.013	0.027	0.028	7.675	5.348	3.091	3.322	71.642	35.893
2	0.137	0.08	0.027	0.015	0.035	0.04	6.437	4.034	2.41	3.201	71.305	38.589
3	0.141	0.078	0.026	0.013	0.03	0.035	7.077	4.399	2.63	3.326	73.45	38.523
4	0.135	0.081	0.028	0.015	0.033	0.033	7.007	4.24	2.604	3.306	74.448	38.279
5	0.132	0.082	0.029	0.016	0.037	0.035	6.789	4.198	2.554	3.165	75.154	39.355
6	0.134	0.079	0.025	0.014	0.035	0.035	7.807	4.847	2.892	3.508	73.932	38.947
7	0.136	0.08	0.027	0.015	0.038	0.035	7.85	4.992	2.992	3.491	74.597	39.313
8	0.144	0.082	0.029	0.016	0.043	0.039	7.28	4.457	2.695	3.313	74.326	40.145
9	0.132	0.081	0.028	0.014	0.04	0.044	6.762	3.512	2.252	3.076	74.468	39.863
10	0.129	0.079	0.029	0.016	0.044	0.041	6.693	3.575	2.281	3.11	75.251	40.297
11	0.132	0.079	0.026	0.015	0.035	0.032	6.387	3.429	2.193	3.187	74.58	39.94
12	0.141	0.08	0.025	0.013	0.032	0.03	6.946	3.77	2.386	3.417	73.92	39.062
13	0.14	0.077	0.028	0.015	0.044	0.042	6.838	3.614	2.302	3.092	73.962	39.108
14	0.136	0.077	0.025	0.014	0.041	0.035	7.004	4.093	2.544	3.303	74.454	38.51
15	0.133	0.078	0.027	0.015	0.054	0.087	6.753	3.932	2.422	3.033	72.996	39.488
16	0.128	0.083	0.029	0.016	0.038	0.042	5.866	3.227	2.037	3.031	75.623	40.239
17	0.132	0.088	0.029	0.016	0.042	0.039	6.38	3.899	2.358	3.193	75.26	38.83
18	0.125	0.082	0.028	0.015	0.036	0.035	6.534	3.989	2.38	3.15	73.979	38.815
19	0.132	0.081	0.028	0.015	0.033	0.041	6.4	3.676	2.277	2.985	75.626	37.926
20	0.141	0.082	0.029	0.016	0.04	0.041	6.265	3.818	2.312	3.052	75.968	39.135
21	0.143	0.092	0.03	0.016	0.036	0.046	7.211	4.28	2.616	3.442	75.196	37.58
22	0.128	0.091	0.029	0.015	0.036	0.055	6.895	4.681	2.713	3.208	75.505	37.346
23	0.129	0.079	0.028	0.014	0.034	0.045	6.311	4.036	2.407	2.97	76.38	35.761
24	0.13	0.089	0.03	0.015	0.03	0.024	6.647	4.409	2.577	3.155	77.544	35.07
25	0.138	0.075	0.024	0.012	0.026	0.023	7.291	4.615	2.733	3.212	75.154	37.609

TABLE X

RAW DATA FOR SESSION 5

Minute	Delta Relative Power	Theta Relative Power	Alpha Relative Power	Low Beta Relative Power	High Beta Relative Power	Gamma Relative Power	Theta/ Low Beta Ratio	Theta/ High Beta Ratio	Theta/ Beta Ratio	Theta/ Alpha Ratio	"Focus"	"Alertness"
1	0.139	0.104	0.035	0.02	0.034	0.036	6.976	4.948	2.819	3.67	73.445	37.632
2	0.146	0.088	0.031	0.018	0.035	0.036	6.869	4.567	2.693	3.194	74.314	37.077
3	0.144	0.083	0.029	0.017	0.033	0.031	6.147	3.838	2.316	3.074	75.721	37.527
4	0.138	0.092	0.036	0.02	0.047	0.056	6.23	3.629	2.228	2.942	75.974	38.003
5	0.132	0.083	0.032	0.018	0.046	0.054	6.231	3.65	2.245	2.963	76.56	40.897
6	0.133	0.08	0.031	0.016	0.036	0.034	6.399	3.414	2.17	3.01	76.234	39.863
7	0.141	0.089	0.036	0.019	0.042	0.043	6.268	3.593	2.22	3.054	76.213	39.384
8	0.129	0.083	0.031	0.017	0.038	0.036	6.011	3.329	2.102	2.976	76.488	39.943
9	0.129	0.076	0.029	0.015	0.031	0.03	6.158	3.529	2.193	2.884	76.63	39.462
10	0.142	0.085	0.03	0.015	0.039	0.049	7.098	4.022	2.513	3.161	74.935	38.993
11	0.137	0.09	0.033	0.018	0.054	0.076	6.669	3.868	2.376	3.239	75.059	39.409
12	0.14	0.073	0.024	0.014	0.038	0.042	7.507	4.537	2.779	3.463	75.371	39.727
13	0.142	0.08	0.029	0.016	0.037	0.035	6.958	4.206	2.555	3.193	75.709	38.924
14	0.13	0.081	0.028	0.016	0.041	0.052	7.309	4.531	2.74	3.108	75.13	38.699
15	0.137	0.079	0.03	0.017	0.042	0.048	6.512	4.063	2.433	2.908	74.121	38.314
16	0.137	0.086	0.028	0.016	0.042	0.046	7.25	4.631	2.759	3.311	75.551	38.842
17	0.136	0.082	0.03	0.019	0.056	0.07	6.529	4.052	2.45	3.283	75.662	39.252
18	0.149	0.086	0.027	0.016	0.042	0.058	7.167	4.377	2.663	3.545	74.708	38.977
19	0.131	0.08	0.031	0.017	0.047	0.055	6.721	4.116	2.486	3.132	74.628	39.241
20	0.139	0.083	0.029	0.015	0.04	0.05	7.188	4.683	2.761	3.224	74.307	39.331
21	0.133	0.085	0.031	0.017	0.047	0.067	7.499	4.418	2.718	3.049	72.788	38.651
22	0.141	0.086	0.03	0.016	0.046	0.046	7.66	4.534	2.788	3.213	74.279	39.8
23	0.13	0.084	0.032	0.018	0.047	0.059	7.488	4.707	2.832	3.081	75.226	38.113
24	0.135	0.085	0.036	0.02	0.052	0.056	6.697	3.789	2.377	3.134	75.032	38.533
25	0.135	0.081	0.027	0.015	0.038	0.045	7.212	4.134	2.581	3.338	75.375	39.098

TABLE XI

RAW DATA FOR SESSION 6

Minute	Delta Relative Power	Theta Relative Power	Alpha Relative Power	Low Beta Relative Power	High Beta Relative Power	Gamma Relative Power	Theta/ Low Beta Ratio	Theta/ High Beta Ratio	Theta/ Beta Ratio	Theta/ Alpha Ratio	"Focus"	"Alertness"
1	0.128	0.08	0.023	0.011	0.021	0.02	8.406	5.886	3.361	3.665	73.686	35.895
2	0.133	0.081	0.022	0.01	0.019	0.019	8.858	5.455	3.282	3.931	73.381	35.593
3	0.125	0.083	0.029	0.014	0.028	0.023	6.989	4.29	2.571	3.301	76.244	37.257
4	0.133	0.09	0.05	0.027	0.061	0.053	6.787	3.988	2.439	3.258	77.404	36.773
5	0.14	0.098	0.071	0.041	0.094	0.083	6.585	3.686	2.306	3.215	77.11	36.064
6	0.137	0.098	0.067	0.04	0.096	0.086	6.74	3.597	2.282	3.265	77.008	36.609
7	0.132	0.098	0.065	0.041	0.097	0.087	6.298	3.406	2.156	3.164	76.549	36.425
8	0.143	0.107	0.083	0.047	0.109	0.093	6.583	3.647	2.296	2.97	77.073	35.959
9	0.14	0.092	0.075	0.043	0.102	0.097	6.374	3.199	2.072	3.14	76.545	37.138
10	0.134	0.097	0.066	0.039	0.091	0.083	6.628	3.534	2.25	3.116	76.33	37.193
11	0.153	0.109	0.102	0.054	0.127	0.107	7.529	3.947	2.515	3.486	75.906	35.741
12	0.134	0.087	0.029	0.014	0.031	0.026	7.547	4.451	2.695	3.511	76.827	36.59
13	0.14	0.094	0.033	0.016	0.034	0.026	7.129	4.169	2.579	3.19	76.158	38.245
14	0.125	0.078	0.028	0.015	0.035	0.034	6.619	3.714	2.313	3.204	76.541	39.349
15	0.139	0.082	0.028	0.015	0.033	0.031	6.691	3.729	2.346	3.292	76.222	38.987
16	0.126	0.08	0.03	0.016	0.034	0.028	6.453	3.779	2.335	2.983	76.532	39.245
17	0.13	0.08	0.027	0.015	0.031	0.026	6.813	3.771	2.392	3.185	75.117	37.639
18	0.142	0.084	0.027	0.015	0.029	0.025	7.708	4.489	2.814	3.418	75.282	37.044
19	0.136	0.089	0.032	0.017	0.039	0.038	6.933	3.936	2.459	3.148	75.362	38.658
20	0.129	0.09	0.034	0.018	0.045	0.045	6.701	3.919	2.401	3.238	75.35	38.478
21	0.126	0.078	0.028	0.016	0.035	0.035	6.93	3.879	2.443	3.224	75.722	38.551
22	0.13	0.082	0.031	0.017	0.04	0.04	6.12	3.797	2.294	2.931	76.739	39.297
23	0.136	0.094	0.033	0.018	0.044	0.044	6.76	4.111	2.498	3.217	75.972	38.48
24	0.127	0.091	0.03	0.017	0.043	0.043	6.883	4.085	2.497	3.294	75.778	39.364
25	0.134	0.084	0.029	0.016	0.036	0.036	6.545	3.827	2.366	3.292	74.213	37.304

TABLE XII

RAW DATA FOR SESSION 7

Minute	Delta Relative Power	Theta Relative Power	Alpha Relative Power	Low Beta Relative Power	High Beta Relative Power	Gamma Relative Power	Theta/ Low Beta Ratio	Theta/ High Beta Ratio	Theta/ Beta Ratio	Theta/ Alpha Ratio	"Focus"	"Alertness"
1	0.139	0.079	0.028	0.013	0.024	0.022	7.126	4.947	2.873	3.098	72.748	36.313
2	0.14	0.088	0.025	0.013	0.025	0.024	7.751	5.219	3.067	3.64	73.173	36.783
3	0.138	0.08	0.027	0.014	0.027	0.025	6.461	4.086	2.434	3.09	74.488	37.943
4	0.126	0.087	0.033	0.016	0.037	0.038	6.777	3.943	2.437	2.99	74.597	38.22
5	0.138	0.08	0.026	0.014	0.029	0.029	7.011	4.215	2.58	3.232	74.746	39.239
6	0.146	0.088	0.031	0.016	0.032	0.036	6.368	3.845	2.316	3.053	74.429	39.284
7	0.141	0.083	0.029	0.015	0.031	0.032	7.037	4.391	2.638	3.282	74.458	39.486
8	0.139	0.09	0.04	0.021	0.043	0.044	6.916	3.784	2.369	2.942	74.384	39.947
9	0.136	0.089	0.034	0.019	0.044	0.05	6.072	3.505	2.124	2.997	74.853	40.275
10	0.14	0.094	0.035	0.02	0.048	0.05	5.756	3.462	2.079	3.035	74.602	40.1
11	0.137	0.079	0.033	0.017	0.042	0.042	6.337	3.681	2.262	2.776	74.897	40.422
12	0.138	0.09	0.044	0.022	0.052	0.055	6.568	3.819	2.355	2.927	74.354	39.321
13	0.135	0.081	0.035	0.017	0.035	0.031	6.817	4.116	2.487	2.937	74.769	38.788
14	0.135	0.09	0.039	0.021	0.049	0.051	6.419	3.563	2.238	2.886	75.575	40.341
15	0.13	0.086	0.036	0.019	0.045	0.044	6.817	3.77	2.373	3.036	74.947	40.026
16	0.133	0.078	0.03	0.016	0.031	0.03	7.078	4.009	2.503	3.142	75.477	40.025
17	0.138	0.091	0.039	0.02	0.045	0.041	6.869	3.829	2.43	2.924	75.733	39.954
18	0.141	0.084	0.032	0.019	0.038	0.041	6.67	4.105	2.496	3.098	75.097	40.532
19	0.136	0.084	0.031	0.016	0.033	0.03	7.343	4.141	2.614	3.266	75.021	37.839
20	0.156	0.086	0.033	0.018	0.033	0.026	6.801	4.3	2.604	2.935	75.665	36.801
21	0.141	0.091	0.035	0.018	0.031	0.026	7.163	4.591	2.757	3.09	74.755	38.404
22	0.153	0.088	0.029	0.015	0.026	0.023	7.645	5.529	3.142	3.335	74.479	38.932
23	0.138	0.079	0.029	0.017	0.029	0.026	6.955	4.515	2.702	3.033	74.532	38.434
24	0.142	0.084	0.033	0.018	0.031	0.03	6.751	4.378	2.593	3.038	75.1	38.911
25	0.13	0.088	0.035	0.019	0.033	0.03	6.662	4.456	2.606	2.928	74.549	38.54

TABLE XIII

RAW DATA FOR SESSION 8

Minute	Delta Relative Power	Theta Relative Power	Alpha Relative Power	Low Beta Relative Power	High Beta Relative Power	Gamma Relative Power	Theta/ Low Beta Ratio	Theta/ High Beta Ratio	Theta/ Beta Ratio	Theta/ Alpha Ratio	"Focus"	"Alertness"
1	0.135	0.101	0.028	0.013	0.019	0.017	8.448	6.36	3.545	3.7	74.524	35.839
2	0.136	0.071	0.022	0.011	0.019	0.018	7.118	4.421	2.691	3.377	74.264	36.606
3	0.13	0.075	0.026	0.012	0.027	0.024	6.817	3.733	2.362	3.158	76.237	38.611
4	0.143	0.073	0.024	0.011	0.023	0.02	7.379	4.28	2.642	3.195	75.235	38.588
5	0.139	0.086	0.028	0.014	0.033	0.03	7.078	4.039	2.473	3.298	75.949	38.345
6	0.142	0.078	0.025	0.013	0.028	0.026	7.078	3.97	2.422	3.435	76.118	38.102
7	0.135	0.081	0.028	0.014	0.033	0.028	6.354	3.568	2.197	3.122	76.369	39.232
8	0.134	0.073	0.025	0.012	0.03	0.028	6.796	3.556	2.255	3.188	75.015	40.697
9	0.136	0.087	0.028	0.015	0.039	0.04	7.089	3.487	2.253	3.582	74.378	41.524
10	0.14	0.081	0.026	0.013	0.036	0.032	7.159	3.39	2.226	3.43	74.63	40.809
11	0.14	0.07	0.021	0.011	0.028	0.025	7.025	3.24	2.147	3.495	74.365	40.434
12	0.148	0.076	0.024	0.012	0.031	0.026	6.804	3.716	2.281	3.318	74.625	39.972
13	0.139	0.073	0.022	0.011	0.026	0.025	7.096	3.562	2.3	3.467	74.143	40.606
14	0.143	0.083	0.028	0.014	0.033	0.027	6.948	3.737	2.349	3.333	74.987	40.206
15	0.138	0.084	0.031	0.016	0.035	0.028	6.066	3.208	2.05	3	76.677	39.033
16	0.139	0.086	0.03	0.013	0.027	0.022	7.472	4.658	2.794	3.149	75.181	38.515
17	0.128	0.082	0.029	0.015	0.03	0.028	6.926	3.922	2.441	3.087	75.92	39.034
18	0.134	0.079	0.027	0.013	0.031	0.028	6.698	3.146	2.097	3.221	75.471	39.191
19	0.138	0.077	0.026	0.013	0.029	0.023	6.475	3.299	2.136	3.106	75.769	39.031
20	0.138	0.08	0.031	0.018	0.038	0.034	5.887	3.338	2.074	3.036	76.002	39.597
21	0.131	0.076	0.029	0.016	0.038	0.031	5.932	3.463	2.117	2.996	76.554	41.447
22	0.139	0.073	0.028	0.015	0.032	0.027	6.441	3.412	2.193	3.231	76.011	38.774
23	0.135	0.073	0.026	0.014	0.032	0.028	5.741	2.956	1.919	3.073	74.782	40.507
24	0.146	0.079	0.025	0.013	0.03	0.03	6.864	3.626	2.314	3.427	76.025	41.262
25	0.147	0.076	0.028	0.014	0.033	0.032	7.019	4.561	2.676	3.221	75.415	40.442

TABLE XIV

RAW DATA FOR SESSION 9

Minute	Delta Relative Power	Theta Relative Power	Alpha Relative Power	Low Beta Relative Power	High Beta Relative Power	Gamma Relative Power	Theta/ Low Beta Ratio	Theta/ High Beta Ratio	Theta/ Beta Ratio	Theta/ Alpha Ratio	"Focus"	"Alertness"
1	0.15	0.092	0.03	0.013	0.025	0.024	7.586	4.712	2.854	3.345	73.691	36.066
2	0.149	0.093	0.034	0.019	0.034	0.033	6.18	3.952	2.337	3.169	73.835	37.678
3	0.145	0.091	0.032	0.017	0.03	0.029	6.027	3.563	2.164	3.186	75.605	37.669
4	0.145	0.091	0.033	0.017	0.031	0.029	6.121	3.666	2.221	3.156	74.44	38.222
5	0.135	0.101	0.041	0.021	0.043	0.039	5.595	3.239	1.992	2.896	74.53	38.177
6	0.132	0.098	0.043	0.022	0.04	0.035	5.377	3.203	1.959	2.68	74.972	37.909
7	0.133	0.096	0.04	0.02	0.035	0.034	5.557	3.202	1.992	2.804	75.475	38.897
8	0.134	0.1	0.042	0.023	0.045	0.051	5.632	3.203	1.989	3.01	74.718	38.917
9	0.13	0.085	0.032	0.018	0.042	0.04	5.901	3.267	2.068	2.973	75.289	38.38
10	0.138	0.084	0.028	0.015	0.038	0.036	6.333	3.28	2.12	3.228	74.886	38.929
11	0.124	0.082	0.033	0.02	0.043	0.039	5.41	2.805	1.816	2.752	75.933	39.897
12	0.132	0.084	0.033	0.02	0.041	0.035	5.526	3.158	1.97	2.796	75.639	39.531
13	0.133	0.089	0.034	0.021	0.046	0.043	5.527	3.008	1.898	2.858	75.41	39.187
14	0.134	0.087	0.032	0.019	0.042	0.041	5.866	3.462	2.114	3.011	75.612	38.895
15	0.127	0.081	0.029	0.018	0.039	0.039	5.388	2.919	1.856	2.969	76.096	39.199
16	0.143	0.083	0.03	0.019	0.048	0.049	6.196	3.377	2.127	3.154	75.796	39.286
17	0.133	0.086	0.035	0.019	0.047	0.042	5.926	3.301	2.039	3.045	75.801	38.165
18	0.129	0.071	0.026	0.015	0.031	0.028	6.122	3.22	2.058	3.074	76.309	37.985
19	0.126	0.078	0.032	0.019	0.041	0.036	5.748	3.05	1.95	2.87	76.242	38.135
20	0.131	0.078	0.034	0.017	0.033	0.028	5.98	3.246	2.079	2.874	76.121	37.865
21	0.137	0.099	0.032	0.017	0.033	0.028	7.288	4.635	2.779	3.358	75.939	38.393
22	0.131	0.081	0.033	0.017	0.037	0.032	5.946	3.228	2.061	2.839	77.192	38.635
23	0.136	0.084	0.034	0.02	0.05	0.05	6.103	3.314	2.108	2.975	76.434	38.973
24	0.129	0.084	0.032	0.02	0.047	0.047	5.926	3.247	2.061	3.08	74.686	38.132
25	0.136	0.08	0.031	0.018	0.044	0.04	6.085	3.059	2.011	3.04	75.696	38.676

TABLE XV

RAW DATA FOR SESSION 10

Minute	Delta Relative Power	Theta Relative Power	Alpha Relative Power	Low Beta Relative Power	High Beta Relative Power	Gamma Relative Power	Theta/ Low Beta Ratio	Theta/ High Beta Ratio	Theta/ Beta Ratio	Theta/ Alpha Ratio	"Focus"	"Alertness"
1	0.137	0.088	0.029	0.014	0.024	0.028	7.46	5.052	2.936	3.33	74.341	34.761
2	0.133	0.078	0.035	0.012	0.022	0.024	7.186	4.601	2.778	3.068	73.64	36.375
3	0.128	0.092	0.034	0.017	0.038	0.035	6.622	3.964	2.419	3.062	75.155	37.737
4	0.128	0.085	0.032	0.016	0.036	0.033	6.189	3.627	2.238	3.05	75.42	38.159
5	0.12	0.081	0.028	0.015	0.031	0.032	6.086	3.413	2.158	2.956	75.031	37.754
6	0.14	0.095	0.033	0.017	0.031	0.028	6.52	3.896	2.382	3.057	74.71	37.738
7	0.138	0.088	0.034	0.016	0.032	0.028	6.066	3.67	2.222	3.052	75.427	38.281
8	0.122	0.076	0.028	0.014	0.032	0.034	6.094	3.009	1.982	2.993	74.714	38.244
9	0.131	0.083	0.029	0.015	0.03	0.03	6.325	3.539	2.204	3.065	74.831	37.76
10	0.139	0.09	0.03	0.015	0.029	0.027	6.557	4.068	2.426	3.136	75.565	38.257
11	0.13	0.086	0.03	0.015	0.032	0.029	6.288	3.804	2.287	3.205	75.937	38.762
12	0.131	0.088	0.033	0.017	0.038	0.038	6.114	3.353	2.104	2.952	75.24	38.007
13	0.133	0.086	0.029	0.015	0.031	0.028	6.567	4.075	2.43	3.22	74.864	37.519
14	0.128	0.083	0.032	0.015	0.032	0.035	6.762	4.116	2.503	2.999	75.226	37.231
15	0.133	0.081	0.03	0.015	0.031	0.028	6.253	3.551	2.188	2.948	74.854	38.923
16	0.129	0.087	0.035	0.018	0.039	0.036	6.042	3.601	2.189	2.874	76.314	39.037
17	0.124	0.087	0.031	0.016	0.034	0.031	6.339	3.889	2.355	2.986	75.691	38.261
18	0.131	0.085	0.026	0.014	0.027	0.022	7.431	4.601	2.744	3.434	75.737	37.944
19	0.127	0.089	0.032	0.017	0.035	0.034	6.348	4.054	2.425	3.02	75.267	38.763
20	0.146	0.101	0.085	0.049	0.112	0.097	6.056	3.541	2.182	2.928	75.586	38.693
21	0.137	0.096	0.071	0.042	0.094	0.085	6.32	3.882	2.346	3.158	76.042	37.917
22	0.146	0.103	0.095	0.053	0.12	0.101	6.627	4.141	2.509	3.107	74.892	36.537
23	0.131	0.077	0.028	0.014	0.028	0.025	6.607	4.092	2.434	2.983	74.993	37.768
24	0.132	0.085	0.028	0.015	0.03	0.029	6.69	3.693	2.352	3.15	75.435	37.654
25	0.123	0.072	0.026	0.014	0.029	0.025	6.783	3.877	2.4	3.228	74.483	37.552

TABLE XVI

RAW DATA FOR SESSION 11

Minute	Delta Relative Power	Theta Relative Power	Alpha Relative Power	Low Beta Relative Power	High Beta Relative Power	Gamma Relative Power	Theta/ Low Beta Ratio	Theta/ High Beta Ratio	Theta/ Beta Ratio	Theta/ Alpha Ratio	"Focus"	"Alertness"
1	0.164	0.089	0.031	0.015	0.027	0.022	6.803	4.66	2.698	3.141	74.025	34.773
2	0.14	0.081	0.026	0.014	0.031	0.031	7.446	4.822	2.84	3.502	73.925	37.519
3	0.136	0.075	0.026	0.013	0.031	0.029	6.67	3.921	2.394	3.299	74.799	39.197
4	0.157	0.083	0.027	0.014	0.03	0.028	7.358	4.037	2.542	3.509	74.649	39.11
5	0.148	0.086	0.026	0.014	0.029	0.028	7.179	4.094	2.51	3.38	74.358	38.859
6	0.142	0.078	0.025	0.013	0.03	0.026	6.841	3.496	2.26	3.424	75.455	39.009
7	0.132	0.085	0.026	0.014	0.036	0.033	6.938	3.247	2.134	3.543	73.967	38.914
8	0.143	0.08	0.025	0.014	0.037	0.034	6.68	3.26	2.092	3.587	75.452	38.707
9	0.141	0.079	0.022	0.011	0.025	0.025	7.711	4.102	2.623	3.814	75.727	36.127
10	0.141	0.077	0.022	0.011	0.024	0.025	7.618	4.037	2.572	3.652	76.038	36.539
11	0.137	0.072	0.022	0.012	0.03	0.034	7.546	3.874	2.519	3.715	76.735	36.883
12	0.137	0.072	0.023	0.012	0.029	0.031	7.396	3.345	2.252	3.466	76.695	37.787
13	0.136	0.077	0.025	0.014	0.035	0.037	7.053	3.268	2.195	3.443	76.798	37.696
14	0.134	0.073	0.025	0.013	0.031	0.033	6.838	3.518	2.284	3.425	77.363	36.802
15	0.132	0.073	0.026	0.014	0.033	0.033	6.61	3.805	2.374	3.286	78.498	37.545
16	0.129	0.073	0.026	0.014	0.034	0.035	6.292	3.354	2.147	3.178	77.522	37.317
17	0.135	0.076	0.027	0.014	0.036	0.038	6.081	3.318	2.07	2.954	75.218	38.298
18	0.136	0.078	0.027	0.016	0.035	0.04	5.668	3.235	2.001	3.076	75.253	38.338
19	0.141	0.084	0.031	0.018	0.041	0.041	5.838	3.22	2.028	3.059	76.636	39.676
20	0.14	0.078	0.025	0.014	0.034	0.045	7.626	4.653	2.833	3.493	74.279	37.926
21	0.14	0.076	0.027	0.017	0.032	0.029	5.47	2.845	1.831	3.077	73.256	39.237
22	0.142	0.072	0.028	0.014	0.029	0.029	5.872	3.304	2.052	2.897	76.213	36.81
23	0.137	0.071	0.023	0.012	0.026	0.025	6.194	3.171	2.077	3.347	75.702	36.689
24	0.134	0.073	0.026	0.014	0.03	0.033	5.532	3.214	1.976	2.932	75.832	40.381
25	0.128	0.073	0.025	0.014	0.032	0.032	5.707	2.899	1.893	3.046	75.309	39.848

TABLE XVII

RAW DATA FOR SESSION 12

Minute	Delta Relative Power	Theta Relative Power	Alpha Relative Power	Low Beta Relative Power	High Beta Relative Power	Gamma Relative Power	Theta/ Low Beta Ratio	Theta/ High Beta Ratio	Theta/ Beta Ratio	Theta/ Alpha Ratio	"Focus"	"Alertness"
1	0.139	0.094	0.032	0.013	0.022	0.02	7.946	5.649	3.198	3.163	73.05	35.957
2	0.141	0.078	0.026	0.012	0.025	0.025	7.371	5.349	3.033	3.225	73.601	37.421
3	0.127	0.076	0.031	0.016	0.038	0.04	6.745	3.96	2.446	2.856	75.182	38.424
4	0.135	0.08	0.029	0.015	0.042	0.043	7.623	4.305	2.675	3.265	74.866	38.131
5	0.13	0.077	0.03	0.016	0.047	0.041	6.472	3.44	2.189	2.999	76.354	38.984
6	0.125	0.073	0.028	0.016	0.046	0.044	6.693	3.928	2.41	3.186	76.394	37.611
7	0.133	0.081	0.029	0.015	0.041	0.038	10.4	6.774	4.022	3.564	76.236	37.986
8	0.139	0.082	0.025	0.013	0.035	0.03	7.743	4.099	2.616	3.549	76.331	37.577
9	0.129	0.076	0.029	0.016	0.042	0.036	6.692	3.426	2.208	3.024	77.845	35.372
10	0.132	0.073	0.029	0.015	0.041	0.034	6.727	4.166	2.467	3.129	77.134	36.59
11	0.131	0.091	0.034	0.016	0.038	0.035	7.694	4.46	2.726	3.143	78.148	36.715
12	0.128	0.087	0.043	0.031	0.08	0.093	6.309	3.488	2.167	3.086	77.634	37.735
13	0.148	0.093	0.046	0.031	0.076	0.078	6.972	4.833	2.672	3.454	76.471	36.781
14	0.155	0.105	0.069	0.04	0.096	0.093	7.679	5.611	3.076	3.333	77.645	35.519
15	0.14	0.103	0.073	0.042	0.099	0.091	6.38	4.256	2.446	2.972	77.604	35.658
16	0.14	0.101	0.078	0.045	0.106	0.093	6.632	4.04	2.416	3.045	77.622	35.468
17	0.125	0.083	0.03	0.017	0.037	0.033	6.506	3.864	2.312	3.109	76.593	37.175
18	0.133	0.08	0.029	0.018	0.04	0.041	5.923	3.231	2.009	3.021	75.893	38.992
19	0.132	0.082	0.03	0.016	0.038	0.038	6.307	3.143	2.046	3.071	76.47	36.614
20	0.129	0.084	0.028	0.015	0.031	0.028	6.941	4.228	2.525	3.201	76.996	35.567
21	0.133	0.082	0.034	0.018	0.037	0.029	5.93	3.938	2.254	2.785	77.621	36.189
22	0.118	0.09	0.037	0.019	0.045	0.042	6.499	4.003	2.332	2.921	76.569	35.314
23	0.116	0.081	0.031	0.017	0.041	0.035	6.039	3.736	2.202	2.914	77.594	36.076
24	0.127	0.095	0.035	0.019	0.041	0.036	7.005	4.408	2.591	3.418	76.396	37.127
25	0.119	0.088	0.04	0.019	0.041	0.036	6.375	4.188	2.407	2.837	75.538	37.68

B. T-test Results for ABC and IVA+Plus Measures

TABLE XVIII

SUMMARY OF ABC T-TEST

Paired Measure	Paired Differences							
	df	Mean	Standard Deviation	Standard Error Mean	95% Confidence Interval of the Difference		t-statistic	p-value
					Lower	Upper		
Irritability	17	3.330	3.926	0.925	1.381	5.286	3.602	0.002
Lethargy	17	4.056	7.272	1.714	0.439	7.672	2.366	0.030
Stereotypy	17	1.333	2.249	0.530	0.215	2.452	2.515	0.022
Hyperactivity	17	4.444	5.913	1.394	1.504	7.385	3.189	0.005
Inappropriate Speech	17	1.000	0.907	0.214	0.549	1.451	4.675	0.000

TABLE XIX
SUMMARY OF IVA+PLUS T-TEST

Paired Measure	Paired Differences							
	df	Mean	Standard Deviation	Standard Error Mean	95% Confidence Interval of the Difference		t-statistic	p-value
					Lower	Upper		
Response Control Quotient	17	-2.5	25.025	5.899	-14.945	9.945	-0.424	0.677
Response Control Quotient Auditory	17	-5.788	22.972	5.415	-17.201	5.646	-1.067	0.301
Response Control Quotient Visual	17	1.444	24.181	5.7	-10.581	13.469	0.253	0.803
Attention Quotient	17	-9.222	15.187	3.58	-16.775	-1.67	-2.576	0.02*
Attention Quotient Auditory	17	-8.667	18.279	4.308	-17.757	0.423	-2.012	0.06
Attention Quotient Visual	17	-8	14.852	3.501	-15.386	-0.614	-2.285	0.035*
Sustained Auditory Attention Quotient	17	-13.278	28.042	6.609	-27.223	0.667	-2.009	0.061
Sustained Visual Attention Quotient	17	-14.389	22.432	5.287	-25.544	-3.234	-2.721	0.015*
Auditory Reaction Time	17	36.556	85.614	20.179	-6.019	79.13	1.812	0.088*
Visual Reaction Time	17	21.833	38.938	9.178	2.47	41.197	2.379	0.029*

*indicates $p < 0.05$

C. MiniTab ANOVA Output and Pearson Correlation Test Output

ANOVA Output

Analysis of Variance for Delta, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Minute	24	0.0015801	0.0015801	0.0000658	1.64	0.032
Session	11	0.0035372	0.0035372	0.0003216	8.03	0.000
Error	264	0.0105716	0.0105716	0.0000400		
Total	299	0.0156889				

S = 0.00632802 R-Sq = 32.62% R-Sq(adj) = 23.68%

Analysis of Variance for Theta, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Minute	24	0.0009581	0.0009581	0.0000399	0.98	0.493
Session	11	0.0031191	0.0031191	0.0002836	6.96	0.000
Error	264	0.0107493	0.0107493	0.0000407		
Total	299	0.0148265				

S = 0.00638100 R-Sq = 27.50% R-Sq(adj) = 17.89%

Analysis of Variance for Alpha, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Minute	24	0.0016410	0.0016410	0.0000684	0.71	0.841
Session	11	0.0082065	0.0082065	0.0007460	7.74	0.000
Error	264	0.0254517	0.0254517	0.0000964		
Total	299	0.0352992				

S = 0.00981875 R-Sq = 27.90% R-Sq(adj) = 18.34%

Analysis of Variance for LowBeta, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Minute	24	0.0007441	0.0007441	0.0000310	0.88	0.633
Session	11	0.0026605	0.0026605	0.0002419	6.85	0.000
Error	264	0.0093272	0.0093272	0.0000353		
Total	299	0.0127319				

S = 0.00594395 R-Sq = 26.74% R-Sq(adj) = 17.03%

Analysis of Variance for HighBeta, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Minute	24	0.0079419	0.0079419	0.0003309	1.58	0.045
Session	11	0.0130759	0.0130759	0.0011887	5.67	0.000
Error	264	0.0553263	0.0553263	0.0002096		
Total	299	0.0763442				

S = 0.0144765 R-Sq = 27.53% R-Sq(adj) = 17.92%

Analysis of Variance for Gamma, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Minute	24	0.0083055	0.0083055	0.0003461	1.66	0.029
Session	11	0.0136444	0.0136444	0.0012404	5.97	0.000
Error	264	0.0548972	0.0548972	0.0002079		
Total	299	0.0768471				

S = 0.0144203 R-Sq = 28.56% R-Sq(adj) = 19.09%

Analysis of Variance for T/LB, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Minute	24	18.7700	18.7700	0.7821	2.12	0.002
Session	11	36.5648	36.5648	3.3241	9.02	0.000
Error	264	97.2409	97.2409	0.3683		
Total	299	152.5757				

S = 0.606908 R-Sq = 36.27% R-Sq(adj) = 27.82%

Analysis of Variance for T/HB, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Minute	24	36.3625	36.3625	1.5151	6.11	0.000
Session	11	20.8368	20.8368	1.8943	7.64	0.000
Error	264	65.4268	65.4268	0.2478		
Total	299	122.6260				

S = 0.497824 R-Sq = 46.65% R-Sq(adj) = 39.57%

Analysis of Variance for T/B, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Minute	24	8.10683	8.10683	0.33778	4.82	0.000
Session	11	5.77449	5.77449	0.52495	7.49	0.000
Error	264	18.50584	18.50584	0.07010		
Total	299	32.38715				

S = 0.264760 R-Sq = 42.86% R-Sq(adj) = 35.29%

Analysis of Variance for T/A, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Minute	24	1.98883	1.98883	0.08287	2.05	0.003
Session	11	8.78168	8.78168	0.79833	19.74	0.000
Error	264	10.67722	10.67722	0.04044		
Total	299	21.44773				

S = 0.201107 R-Sq = 50.22% R-Sq(adj) = 43.62%

Analysis of Variance for Focus, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Minute	24	83.614	83.614	3.484	4.35	0.000
Session	11	285.243	285.243	25.931	32.39	0.000
Error	264	211.370	211.370	0.801		
Total	299	580.227				

S = 0.894787 R-Sq = 63.57% R-Sq(adj) = 58.74%

Analysis of Variance for Alertness, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Minute	24	92.161	92.161	3.840	3.51	0.000
Session	11	141.027	141.027	12.821	11.72	0.000
Error	264	288.891	288.891	1.094		
Total	299	522.079				

S = 1.04608 R-Sq = 44.67% R-Sq(adj) = 37.33%

Pearson Correlation Output

	Focus	T/A	T/B	T/LB	T/HB	A	LB	HB
T/A	-0.676 0.000							
T/B	-0.612 0.000	0.600 0.000						
T/LB	-0.633 0.000	0.828 0.000	0.896 0.000					
T/HB	-0.577 0.000	0.523 0.001	0.993 0.000	0.843 0.000				
A	0.444 0.006	-0.733 0.000	-0.316 0.057	-0.526 0.001	-0.248 0.138			
LB	0.423 0.009	-0.710 0.000	-0.513 0.001	-0.670 0.000	-0.463 0.004	0.846 0.000		
HB	0.373 0.023	-0.463 0.004	-0.579 0.000	-0.541 0.001	-0.573 0.000	0.465 0.004	0.795 0.000	
Theta	-0.197 0.242	-0.045 0.793	0.328 0.047	0.138 0.417	0.369 0.024	0.584 0.000	0.356 0.031	0.010 0.953

VITA

I am originally from Elizabethtown, KY and received my high school education at Central Hardin High School. I am currently completing my fifth year at the University of Louisville in the bioengineering department. During my undergraduate education, I was inducted into the engineering honor society of Tau Beta Pi and was named to the Dean's List during multiple semesters in my undergraduate studies. I received my B.S. in bioengineering from the University of Louisville in May 2011. Currently, I am completing this thesis and the other course requirements necessary for graduation with a Master of Engineering degree in Bioengineering in May of 2012. In conjunction with completion of this thesis, I have been provided additional opportunities to present the findings of this research. I presented a poster titled "Analysis of EEG Rhythms During Neurofeedback for ADHD Subjects" at Research!Louisville in the Fall of 2011 outlining the initial findings of the research. This poster was also displayed at the annual meeting for the Association for Applied Psychophysiology and Biofeedback in Baltimore, Maryland. Also, the research culminated in a submission of a journal paper titled "Neurofeedback Training Aimed to Improve Focused Attention and Alertness in Children with ADHD: A Study of Relative Power of EEG Rhythms Using Custom-Made Software Application" which was submitted to Clinical EEG and Neuroscience. This journal submission is presently waiting to be assigned for review. After completion of my Master's degree in May of 2012, I plan to attend medical school starting in the fall of 2012. I have been accepted to both the University Of Kentucky College Of Medicine and the Indiana University School of Medicine. I will make a final decision on which school I will be attending in May of 2012.