UNIVERSITY OF ALBERTA

COMPARING THE DYNAMIC EEG ACTIVITY OF SUCCESSFUL AND ATTENTION DEFICIT DISORDERED GRADE 5 AND 6 BOYS

by

Troy Janzen

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled COMPARING THE DYNAMIC EEG OF SUCCESSFUL AND ATTENTION DEFICIT DISORDERED GRADE 5 AND 6 BOYS, submitted by TROY JANZEN in partial fulfillment of the requirements for the degree of MASTER OF EDUCATION in COUNSELLING PSYCHOLOGY.

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Abstract

Dynamic EEG assessment was completed with eight average achieving normal male students and five males diagnosed with Attention Deficit Disorder without Hyperactivity (ADD), both between the ages of 10 and 12 years. EEG was recorded during six task/conditions: eyes open, eyes closed, reading silently, drawing complex figures, doing mental arithmetic and listening to a story. Using a Neurosearch 24, monopolar recordings for 19 brain sites were taken for each child. A minimum of one minute of data was retained for analysis after artifacting. Means and standard deviations for relative power measures were calculated for each task/condition. Changes in absolute magnitude from the eyes open condition to the different tasks were also calculated. Results are discussed in terms of initial baseline estimates of normal brain functioning on-task at this developmental period. Predominant differences between the ADD and normal groups were observed in the frequency ranges of 4-8 Hz and 12-20 Hz. The ADD group had more relative power in the 4-8 Hz band while the controls tended to have more relative power in the 12-20 Hz band. Changes in absolute magnitude were also observed from the eyes open condition to the on-task conditions. For both groups, 4-8 Hz magnitudes were larger while 8-12 Hz and 12-16 Hz magnitudes were smaller on-task than during the eyes open condition.

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CHAPTER 1

The Problem

Introduction

The use of the electroencephalogram (EEG) in examining cognitive function has undergone some remarkable changes since it was first introduced. From the beginning, researchers were excited about the possibilities of deciphering underlying neurological function by examining the electrical activity as measured by the EEG. In addition, many hoped that the EEG would provide a quick and accurate diagnostic tool. However, many factors existed which made the utility of the EEG suspect. Such factors as age, development, personality, intelligence, and many technical considerations all had to be taken into account when looking at EEG's. Much work has been done in terms of establishing EEG developmental norms at rest (for review see Lairy 1975), examining the discriminative or diagnostic power of the EEG, and utilizing the EEG as a biofeedback training tool. However, many of the earlier studies, with some exceptions, were using technically poor equipment, limited brain sites or were only examining at-rest EEG's. With the advent of new and more powerful computer technology and new statistical methods for examining EEG data, it became feasible as well as necessary to start looking at the EEG of subjects while they are performing cognitive tasks.

The purpose of this study was to examine the EEG's of normal achieving and Attention Deficit Disordered (ADD) students while they were performing various cognitive tasks.

Nature of the Problem

The inclusion of cognitive tasks while measuring raw EEG's was first tried by researchers such as Hanley and Sklar in 1976. However, the nature of the equipment being used by researchers at that time lacked processing speed and ability. Also the fact that raw waves had to be visually inspected and analyzed did not allow for any recordings of tasks that involved facial movements or other gross muscle movements. Even today, EEG's in research and medicine are typically recorded while the subject is in a resting state. That is, the EEG is recorded while the subject is sitting or lying down, with their eyes open or closed. Some EEG's are recorded after a subject is hyperventilated or after they have received photic stimulation. These methods were used to avoid the abundant muscle artifacts that can interfere with the brain signal. However, with these sorts of recordings it is not surprising that researchers have had limited success in using the EEG as a diagnostic tool.

Today with the advent of high speed computer processors, more sensitive filters and amplifiers and with other technological breakthroughs, it has become more feasible to examine the 'working' brain. Duffy (1985) was one of the first to examine the working brain with the BEAM (Brain Electrical Activity Mapping) method. Duffy focused his research on the EEG of children with behavior disorders and learning problems.

Researchers have reported limited EEG differences between populations of learning disabled (LD), Attention Deficit Disordered (ADD), Hyperactive children (ADHD) and normal children. Since the differences between these groups of children arises primarily in their approach to cognitive and behavioral tasks, it seems likely that it is during cognitive tasks that these children will show the most significant differences in brain functioning.

Part of the difficulty in trying to find EEG differences among learning disordered populations may be due to the interrelationships among the various disorders. It has been argued that ADD, ADHD, Conduct disorder and LD's can either be independent of one another or interrelated. Thus, a child may fall into any one or combination of these disorders (Lubar 1991). Differential diagnosis of these disorders becomes of utmost importance in terms of examining EEG differences, as subgroups of learning disordered children may have EEG's that appear differently on-task.

To date, what has been neglected in the majority of the literature is the examination of the on-task EEG. Those who have examined the on-task EEG have reported clear differences between learning disordered groups and normals. However, there has still been a lack of studies that have described the on-task EEG within various populations.

Purpose of the Study

The purpose of this study was to establish baseline estimates of what ADD and normal achieving children's brains look like while they were performing cognitive tasks. The intent of this study was not only to confirm the differences between the two groups, but to describe the nature of the EEG within each of the groups. By establishing these baselines at a particular developmental period, it was hoped that a means of comparison would then exist for matched populations. It was possible that inter-individual variation within the normal subjects would impede the ability to determine what a 'typical' brain does when performing a task. However, it was expected that, with some developmental variation, most subject's brains would activate similar brain regions in similar frequency bands. It was hypothesized that if this was the case, it would be possible to establish a baseline in order to compare ADD children and normally achieving children of the same age group. Thus, this study may serve as an initial study to establish new diagnostic criteria based on-task. In turn, it might be possible to train ADD children to alter their brain wave patterns to more closely match the brain of the average achieving child. Thus, the possibilities for diagnosis and treatment are profound.

CHAPTER 2

Literature Review

This chapter includes a review of the relevant literature as it relates to the EEG. This chapter will begin with a brief history on the EEG and a definition of terms. Following this, there will be a discussion on the current knowledge of the EEG of learning disordered populations. In addition, a review of the literature describing the normal EEG will ensue. Finally, the conclusions from the literature and the research questions for this thesis will be presented.

A Brief EEG History

The history of the EEG can be described as having passed through a number of peaks and troughs (Gale and Edwards, 1983). In 1929, Hans Berger published his pioneering research on the alpha wave. This began a far reaching enthusiasm about EEG's throughout the 1930's and 1940's. The 1940's and 1950's saw the widespread development and use of the EEG as a clinical and diagnostic tool. The 1960's saw a focus on sleep research and altered states of consciousness and meditation. It was during this time that EEG work was cast into a shadow of romanticism because of the 'mystics' and metaphysicians who jumped on the EEG bandwagon. In the 1970's there began an emphasis on the use of the EEG in biofeedback. In the 1980's and today there has been an increased move toward using EEG for biofeedback as well as a diagnostic tool. Areas of focus have included: Sensorimotor Rhythm (SMR) epilepsy, hyperactivity (Lubar and Lubar, 1984; Lubar and Shouse,1976; Shouse and Lubar, 1979; Tansey and Bruner, 1983) sports performance (Landers 1991), Attention Deficit Disorder (ADD) (Lubar, Bianchini, Calhoun, Lambert, Brody and Shasbin, 1985; Lubar and Lubar, 1984; Lubar 1985a; Lubar, 1985b; Lubar, 1991; Tansey, 1984 and 1985), dyslexia (Duffy, 1985; Duffy, Denckla, Bartels, and Sandini 1980; Duffy, Denckla, Bartels, Sandini and Kiesling, 1980; Hanley and Sklar, 1976; Rebert, Wexler and Sproul, 1978; Symann-Louett, Gascon, Matsumiya, and Lombroso, 1977; Yingling, Galin, Fein, Peltzman and Davenport, 1986) and now preliminary work has begun on the use of EEG in the treatment of alcoholism (Penniston and Kulkoski, 1989).

Definition of Terms

Before beginning a formal review of the literature there are several terms used throughout this chapter that need to be defined and clarified. First, frequency, magnitude, amplitude and power need to be clarified. The frequency of an EEG wave refers to the number of cycles per second in which that wave is oscillating. Magnitude and amplitude are both used to refer to the size or height of a wave. These terms are synonymous and can be used interchangeably. The power of a wave is calculated by squaring the magnitude at each recording point and summing these values over time.

The major types of EEG activity include delta, theta, alpha, Sensorimotor Rhythm (SMR) and beta waves. Delta waves refer to low frequency EEG activity between 0 and 4 Hertz (Hz). Delta waves can reach magnitudes of 100 to 200 uV and are commonly associated with sleep in the normal human (Ray, 1990). Theta waves refer to frequency ranges between 4 and 8 Hz and is abundant during early stages of sleep or drowsiness (Lubar, 1989). Theta has also been associated with conditions of low levels of alertness such as hypnagogic imagery (Ray, 1990). Alpha waves have been defined as the "rhythm at 8-13 Hz occurring during wakefulness over the posterior region of the head ... Best seen with eyes closed or under conditions of physical relaxation and relative mental inactivity. Blocked or attenuated by attention, especially visual and mental effort." (Fuller, 1978, p.45). SMR waves refer to frequency ranges of 12 to 15 Hz and are typically recorded over the central cortex. SMR waves have been found to be blocked with movement and are produced when the subject is sitting quietly (Lubar, 1989). Finally, beta waves refer to frequency ranges of 13 hz to as high as 50 Hz. Beta has been said to represent cortical activation and is associated with tension, states of anxiety and with the presentation of novel stimuli (Ray, 1990). Ray and Cole (1985) suggested that beta reflects the processing of positive and negative emotional stimuli.

Many terms have been used to describe people with learning disorders. These terms include: LD, minimal brain dysfunction, educationally handicapped, specific LD, dyslexic, ADD and ADHD. For the purposes of this paper, the general term of "learning disordered" will be used to represent all of the above terms. Where researchers have specified the group under investigation their term for that group will be used.

EEG Abnormalities

From as early as 1938 to the present, much of the EEG work has focused on the presence of EEG abnormalities in learning disordered populations. There are three broad categories of EEG abnormalities. These include fast transient spikes, focal slow waves of moderate to high amplitude, and generalized slow waves (Hanley and Sklar, 1976). Findings have been variable in terms of the incidence of abnormal EEG's in learning disordered populations. Estimates of the incidence of abnormal EEG's in learning disordered populations have ranged from 19% to 71% with a majority of studies reporting around 60% (Becker, Velasco, Harmony, Marosi and Landazuri, 1987; Hughes and

Park, 1969; Jasper, Solomon and Bradley, 1938; Muehl, Knott and Benton, 1969; Murdoch, 1974; Satterfield, 1973; Torres and Ayers, 1968; Wikler, Dixon, and Parker, 1970). The most commonly reported EEG abnormality in learning disordered populations has been the presence of excessive slow wave activity and focal spike patterns (Jasper, 1938; Muehl et. al., 1969; Satterfield, 1973). Although the incidence of abnormal EEG's in learning disordered populations have often been reported as significantly different from normals, the incidence has not been high enough to support the use of the EEG diagnostically. It should be pointed out that all of these studies have examined populations that may have been diagnosed as LD, ADD, or ADHD. Thus, the generic term learning disordered was employed here. It is also important to note that even among normal children the incidence of EEG abnormalities has been reported to be 17% to 29% (Murdoch, 1974; Torres and Ayers, 1968).

Without exception, all of the above cited studies have searched for EEG abnormalities in the resting brain. That is, all of the EEG's were recorded while the subject was either sitting or lying down, with their eyes open or closed. Sometimes the subject was hyperventilated or given photic stimulation to help elicit the abnormalities. Many researchers recognized the need for examining the EEG of a cognitively challenged brain rather than the resting brain. As Fuller (1977) stated,

> Thus, it is essential to explore disturbances of attention in LD children in relationship to EEG parameters while they are actively performing tasks. Furthermore, the meaning of the results may be enhanced when stimuli analogous to those that are difficult in the school learning environment are used. A search for anomalous responses to stimuli might be expected to yield better results than the search for abnormalities in the resting EEG. (p.154)

The technological advances that made examining on-task EEG's possible will be explored in a later section.

Alpha and Attention

Many researchers during the 1930's were particularly interested in alpha as it related to attention. Berger (1933), proposed that thalamic inhibition blocks alpha rhythms during attention. In the 1970's and 1980's many studies focused on alpha as it related to attention in children with learning disabilities (Fuller 1977 and 1978, Mulholland 1974, O'Malley and Conners 1972, Ray and Cole 1985). A majority of these studies found that alpha tends to attenuate when the brain is required to sustain attention (Mulholland 1974, Fuller 1978). Fuller (1977, 1978) found that LD boys tended to show less alpha attenuation than normals during tasks like recall and arithmetic. A later study by Ray and Cole (1985) confirmed the role of alpha in attentional processes but added that beta may be a useful measure of appropriate cognitive and emotional processes. It should be pointed out that all of these studies were limited to 2 combinations of bipolar recordings. At that time Fuller (1978) concluded that the attention deficits in the LD children could be a result of either a specific neurological dysfunction, a maturational lag, a psychological origin or some combination of these. What was important about these studies by Fuller (1977, 1978) and Ray and Cole (1985) was that researchers were beginning to study how performing cognitive tasks effected the EEG.

<u>BEAM and Neurometrics</u>

Two major diagnostic techniques were also being developed during the 1970's and 1980's. One of these was called neurometrics (Alverez, Valdes and Pascual, 1987; John et. al., 1977; Princhep, John, Ahn and Kaye 1983; Senf 1988), which utilized multivariate statistics and discriminant analysis to successfully discriminate between learning disabled groups and normals. Neurometrics has built large databases of normal and abnormal functioning populations for statistical comparisons. In this way groups of behaviorally similar people can be compared and differentiated according to brain function. In terms of the discriminative accuracy of this technique for LD populations John et. al. (1977) reported 93% accuracy as compared to 76% accuracy for psychometric indices. Ahn, Princhep, John and Baird (1980), even used this technique to make developmental equations that predicted 32 parameters of the EEG recorded from normals as a function of age. When these equations were tested in neurological, LD and specific LD groups, 54 to 58 percent of the LD and neurological groups were classified as dysfunctional. These equations were even confirmed for 2 different cultures from which the equations were based (Ahn et. al., 1980; Alverez, Valdes, and Pascual, 1987). Although the validity of these equations have been criticized (McCauley and Ciesielski, 1982; Yingling et. al., 1986), neurometric evaluation has continued to be investigated.

The other technique was the development of Brain Electrical Activity Mapping, or BEAM, by Duffy in 1979. Essentially, BEAM is a computer which performs the spectral analysis of EEG data and provides a topographic display of the spatial distribution of the different frequency ranges. An extension of BEAM is significance probability mapping where a subject's data is replaced by a Z or t transformation, thus displaying the deviation from the norm (Duffy, 1985; Duffy, Bartels, and Burchfiel, 1981). Using this technique, Duffy et. al. (1980) were able to correctly identify 12 of 13 normal and 9 of 11 dyslexic children who had been preselected for the study. The utility of the BEAM technique has been demonstrated with tumour patients, dyslexics, and brain lesion patients (Duffy, Burchfiel and Lombroso, 1979; Duffy, Denckla, Bartels, and Sandini, 1980; Duffy et. al, 1980; Duffy, Jensen, Erba, Burchfiel, and Lombroso, 1984). Research has also been conducted with covert epilepsy, schizophrenia, presenile and senile dementia and the brain function of premature infants (Duffy, 1985).

The most important advantage of both the BEAM and neurometrics technique was that it allowed the examination of the EEG while the subject performed cognitive tasks. In addition, the computer freed the researcher from carrying out the complex analyses of wave forms. Up until this time, little to no studies had examined the EEG while subjects performed cognitive tasks as the EEG could be distorted by gross and fine muscle activity. With the invention of more powerful filters these problems could be effectively eliminated. However, to date, researchers using neurometrics have limited their analyses to resting EEG states, and BEAM has been utilized predominantly with dyslexic populations. Further, the developmental equations by Ahn et. al. (1980) were developed from the eyes closed condition. Thus, there remains a lack of research with on-task EEG's even though the technology permits it.

On-task EEG Studies

Of the studies that have examined on-task EEG's, there are several different findings of importance. First, a majority of the studies that have examined learning disordered populations in comparison to normals have found a difference in the EEG response to cognitive challenges. Hanley and Sklar (1976) were some of the first researchers to examine the differences in on-task EEG's when comparing normal children to dyslexic children. They found that the most recurring difference between dyslexic and normal children is higher activity in the 3-7 Hz or theta band. Lubar, Bianchini, Calhoun, Lambert, Brody and Shasbin (1985) also found that for tasks like reading, math, and puzzles, LD children had significantly more activity in the theta band than controls. From the previous section it was shown that LD children do not attenuate alpha as greatly as normals when presented with a task like mental arithmetic (Fuller, 1977). Using multivariate statistical techniques it was found that hyperactive, LD and hyperactive/LD children could be differentiated using a complex visual search task (Dykman, Holcomb, Ogelsby, and Ackerman, 1982). Further, principle component analysis revealed a component with the highest loadings centrally and parietally in the frequency ranges from 16-20 Hz and 7-10 Hz. This component best differentiated the four groups. One of the most recent studies to examine on-task EEG differences in ADHD and normal children was conducted by Mann, Lubar, Zimmerman, Miller and Muenchen (in press). Mann et. al. (in press) confirmed that ADHD children have less beta and more theta than normal children on-task. Further, these differences tended to occur in frontal and parietal areas of the brain.

Further evidence that on-task differences exist between learning disordered and normal children comes from evoked potential (EP) studies. An EP a distinctive wave that is recorded from the cortex in response to some stimuli, whether auditory or visual. The most common difference found between LD and normal children has been a low amplitude P300 response in the LD children (Trommer, Bernstein, Roserberg and Armstrong, 1988). The P300 component indicates not only detection of a stimulus, but also comprehension of the meaning of the stimulus (Lubar, 1989). A majority of the EP studies that have shown differences between LD and normal children have used some kind of auditory or visual task, sometimes with complex semantic content (Lubar, Gross, Shively and Mann, 1990; Lubar, Mann, Gross, and Shively, 1992; Symann-Louett, Gascon, Matsumiya, and Lombroso, 1977). This suggests that LD children differ in how they process complex auditory or visual semantic stimuli. Thus, there is evidence of on-task differences between learning disordered and normal populations in both EP and EEG studies.

A second conclusion that can be drawn from on-task studies is that subgroups within the LD population can have on-task EEG differences. Rebert, Wexler, and Sproul (1978) found that dyslexics and dysphasics differed in their theta power in the right and left hemispheres during reading and drawing. As mentioned previously, Dykman et. al. (1982) showed that LD, hyperactive and mixed children differed in their component scores for the 16-20 Hz and 7-10 Hz ranges. The fact that subgroups of LD children can differ in their EEG response patterns has important implications for future studies examining on-task differences. Subject selection and diagnostic procedures must be carefully outlined to ensure that groups under investigation are relatively uniform or homogeneous.

What has been lacking from on-task EEG studies has been information on what normal children's EEG's look like when performing cognitive tasks. On-task EEG studies to date have examined the differences between some LD population and normals. None of the studies have reported descriptive EEG data within normal, LD or ADD groups. Rather, the focus of the on-task research has been to find differences between these groups.

Normal EEG Studies

Much work has been done to describe how the resting EEG changes throughout the lifespan (for review see Lairy 1975). Many studies have been carried out which describe the relative changes in the power of the different frequency bands over the years. Matousek and Petersen (1973) have examined the resting EEG in normal children from the ages of 1 to 16. In general they found that delta activity decreases with age, theta and alpha1 (7.5-9.5 Hz) increase and culminate at about 4 to 8 years then decrease again, alpha2 (9.5-12.5 Hz) increases continuously during childhood and does not change in adolescence, and beta decreases from age 1 to age 16. These same authors also examined inter and intra-individual differences and found that the inter-individual variability is lowest in the theta band and highest in the alpha1 band. Also the inter-individual variability increased significantly with increasing age. Intra-individual variability was lowest in the beta band and highest in the alpha frequency bands.

Other studies have confirmed and extended these findings. For example, Gasser, Jennen-Steinmetz, Sroka, Verleger and Mocks (1988) examined normal children between the ages of 6 and 17 years. They found that for the theta and alpha bands, maturation over this entire age span starts posteriorly and ends anteriorly. The development of the beta band matures in the cortex in the following order: CZ, PZ, occipital sites, lateral sites, central sites, and frontal sites. In another study, Gasser, Verleger, Bacher and Sroka (1988) found that over the age span all bands except alpha2 decrease in absolute power whereas the fast bands increased and slow bands decreased in relative power.

It has been shown in studies of the development of the EEG throughout the life span that significant changes in terms of the dominant frequency band occurs around the age of 9 years (Lairy 1975). It is at the age of 9 years when alpha activity becomes dominant as opposed to the once dominant slow wave theta rhythm and alpha remains dominant throughout adulthood. Developmentally, it is roughly between the ages of 7 to 11 years that a child is thought to undergo cognitive changes from pre-operational thought to concrete operational thought (Miller 1989). Thatcher, Walker and Guidice (1987) found that the EEG within the hemispheres developed at different rates with growth spurts corresponding to these major developmental stages described by Piaget. Diaz de Leon, Harmony, Marosi, Landazuri, Becker and Banuelos (1985) confirmed that normal children's EEG's appear to be age dependant.

Normal EEG's have even been described in healthy men 30 to 80 years of age (Duffy, Albert, McAnulty, and Garvey,

1984) and Evoked Potentials (EP) in normals have also been examined (Fenwick, Brown and Hennesey, 1981).

The extent of our knowledge about normal EEG throughout the lifespan is considerable. However, there has been no effort to develop age norms for EEG's recorded while performing cognitive tasks. All of the normative studies to date have examined the resting brain, with some using hyperventilation or photic stimulation. Thus, the problem remains that little is understood about the on-task EEG in normal populations.

Conclusions from the Literature

In general, most studies have been unsuccessful in discriminating various learning disordered groups from normals on the basis of an abnormal EEG. The incidence of abnormalities within learning disordered populations is higher than normal groups but not to the extent that it can be used diagnostically. However, it has been pointed out repeatedly that all of the EEG abnormality studies were limited to an examination of the resting EEG.

Those studies which have examined on-task differences have repeatedly shown that differences between learning disordered and normal groups exist. However, by only examining the on-task EEG differences between groups these studies have not provided descriptive EEG information on the individual groups. While we now have some idea of how a normal achieving child differs from an learning disordered child on the EEG we do not have the normative information for either of these groups.

The information we do have on the normal functioning brain is quite extensive. Changes in the EEG appear to be age dependant. However, generalizations of the normative studies to date are limited as they have only examined the resting brain.

Research Questions

The review of the literature was intended to convey the lack of studies providing descriptive on-task EEG information on individual groups. As previously mentioned, the purpose of the present study is to describe the on-task EEG within ADD and successful children. Thus the research questions for the present study are twofold. First, what do ADD and successful children's EEG look like when they are performing cognitive tasks? Second, do the two groups perform differently from task to task? To examine these two questions the EEG's of two samples of children were examined while performing various cognitive tasks.

CHAPTER 3

Method

Overview

This study involved the collection of EEG data from several subjects while they were performing various cognitive tasks. In this chapter the method for acquiring the EEG is described. This will include a discussion of the sample selection, equipment specifications, experimental design, and data analysis.

Sample Selection

The subjects who participated in this experiment were 13 right handed males between the ages of 10-12. Subjects were 5 ADD children, ages 9 years, 7 months to 12 years 1 months; and 8 normal achieving students, ages 9 years, 10 months to 12 years, 6 months. Subjects were chosen at this age range as EEG's have been shown to be stable for up to 3 years in boys between the ages of 9 and 13 (Fein, Galin, Yingling, Johnstone and Nelson, 1984).

The ADD children were selected from the EEG biofeedback treatment program run by Dr. George Fitzsimmons at the University of Alberta. All children referred to the University treatment program had been previously diagnosed as ADD by a neurologist, psychologist or paediatrician according to DSM III-R classification (American Psychiatric Association, 1987). A majority of the ADD children were experiencing concomitant difficulties in several school subjects. However, none of the children selected for this study displayed clinical symptoms of hyperactivity or conduct disorder.

Following acceptance from an ethics review committee, normal subjects were chosen from several Edmonton Public Elementary schools out of the grade 5 and 6 classrooms. Teachers were asked to choose several students whose academic performance and classroom behavior they believed would fall in the normal range and who did not display any attentional or hyperactivity problems. To verify that the control children fell within the normal limits of attentional problems and hyperactivity the Swanson teacher questionnaire was administered. The Swanson teacher questionnaire is a checklist where teachers are asked to rate a student on a 3 point scale in terms of difficulties with inattention, impulsivity, hyperactivity and peer interactions. Age norms for the SNAP are available for ages 8 to 12. Controls chosen for this study fell within one standard deviation of their age group on all of the scales.

Parents were given a history form which included birth information, developmental milestones, medical history and emotional functioning (see Appendix A). Based on this history form, children who had a previous history of birth injury, developmental delays or neurological problems were excluded from the study.

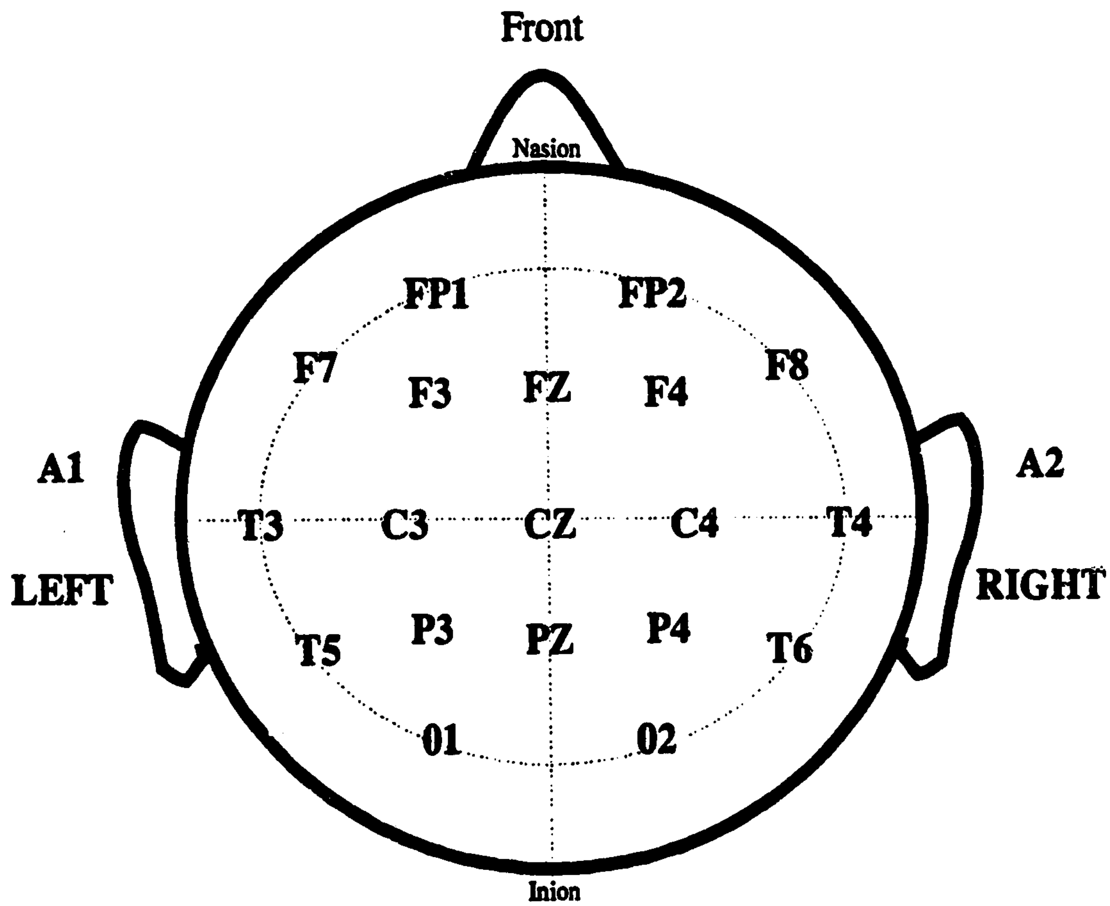
Equipment Description

The present study utilized new equipment recently developed by Lexicor Corporation called the Neurosearch 24. This equipment allows for up to 20 channels and 4 auxiliary channels of topographic brain mapping. Electrode caps are provided with standard electrodes sewn into a nylon cap so that the electrodes are situated according to the International 10-20 system (Jasper, 1958). The International 10-20 sites are displayed in Figure 1. Monopolar recordings referenced to linked ear lobes can be read from the cap. From there the signal is relayed to a microcomputer that records the data on disk and subsequently performs a Fast Fourier Transform (FFT) on the raw data (Dummermouth and Keller, 1973). Conventional bipolar montages of any desired electrode combination can be constructed subsequently by computer simulation.

Procedure

For each subject, recording took place either in the morning between 9 a.m. and 12 p.m. or in the afternoon between 1 p.m. and 4 p.m. For the ADD group, all recordings took place at the University of Alberta biofeedback training clinic. For the normal group, 6 children had their EEG's recorded at the school and the remaining two were recorded

Figure 1



Legend

F = Frontal
C = Central
T = Temporal
P = Parietal
O = Occipital

odd numbers = left hemisphere

even numbers = right hemisphere

Z = midline

at the University biofeedback training clinic. Subjects were initially familiarized with the laboratory setting and all the procedures were explained and consent forms signed.

Psychometric Measures

All subjects were administered three different psychometric tests. These included the Wechsler Intelligence Scale for Children-Revised (WISC-R), the Wide Range Achievement Test-Revised (WRAT-R) and the Woodcock Reading Mastery Test-Revised, Form G (WRMT-R).

Neurometric Measures

All EEG recordings were taken from the Neurosearch 24 which was previously described. Subjects were comfortably seated in a high backed chair while five to six minutes of raw EEG data were recorded for each of the conditions. A linked ear referenced monopolar montage was used for recording. Sites were prepared with Electo-gel and all impedances measured below 5 KOhms. The sampling rate was set at 128 samples per second and the gain was set at 32K. Simultaneous recordings were taken from muscle electrodes placed over the frontalis and masseter muscles. This was done to assist in the visual inspection of the EEG for muscle and eye movement artifacts. Following hookup, EEG data was collected for the following tasks:

Eyes Open - Subject were asked to fix their eyes on an X placed 3 feet in front of them.

Eyes Closed - Subject were requested to close their eyes but to keep their eyes stationary as if they were fixated on the X.

Drawing - Subjects were asked to copy a series of drawings from the Bender Gestalt Visual Motor Test. Each of the nine figures were presented individually at the top of a separate page. Drawings were made on a lap desk placed across the arms of the chair. These procedures were followed in order to reduce artifacts caused by arm and hand movements. Verbal instructions to the subjects were the same as outlined by the test manual (Koppitz, 1975).

Reading Silently - Subject were required to read silently grade appropriate materials. Selection of material was based on the test results of the WRAT-R and the WRMT-R. Subjects were told that it was not a test but they would be required to tell what the story was about. Following the recording of the task, subjects were asked about general and specific details of the story to be sure they were able to read it. Reading material was selected from the Canadian Achievement Test. Reading materials were presented on a music stand and the pages were turned by the experimenter. This was done to try to reduce muscle artifact.

Listening to a Story - Subjects were required to sit quietly with their eyes open and fixated on the X, three feet away while a story was read to them. The Little Fisherman was read to all subjects and they were told that they would be asked what the story was about afterwards. This story was chosen for its low vocabulary, high interest content. Most subjects reported having enjoyed the story at the completion of the recording session.

Raven's Progressive Matrices-Revised - Subjects were required to complete the psychometric test called Ravens Progressive Matrices-Revised. This task involves pattern analysis and requires subjects to complete a pattern. For this task, subjects were given 2-3 seconds to examine a matrix and then provide a whispered response upon request. Each pattern was presented on a music stand placed 1 foot away from the subject. The pages were turned by the experimenter.

Arithmetic - Each subject was required to give a whispered verbal response to a series of grade level arithmetic problems. The grade level for each subject was based on their individual results on the WRAT-R and on the arithmetic portion of the WISC-R. Most material was simple addition, subtraction, or multiplication so that subjects were able to perform the operation cognitively without needing to do any written figuring. Subjects were asked to whisper the correct responses to each of the problems. Arithmetic materials were also chosen from the Canadian Achievement Test.

For each condition every effort was made to reduce artifact due to eye blinks and muscle movement. The rationale for choosing these particular tasks was twofold. First, the tasks were chosen to reflect cognitive activities which are thought to involve particular brain areas or hemispheric activity. Thus, tasks like reading would be expected to show activity in areas shown to be involved in language functioning (eg. Wernicke's and Broca's area) perhaps with a predominance of left hemispheric activity. Drawing, on the other hand, may be expected to show more right hemisphere involvement especially in frontal and parietal-occipital areas. Thus, with a variety of cognitive tasks many different brain areas in both hemispheres can be sampled for expected activity. A second rationale for choosing these particular tasks was to match those tasks used by Lubar and associates in their studies.

The EEG records were carefully examined for eye movement and muscle artifact. Another qualified individual blind to the condition or group performed artifact rejection on randomly chosen subjects. Agreement on the rejection or inclusion of epochs was 83%. Following the removal of artifacts, at least 1 minute of raw EEG remained for each condition. The Raven's Progressive Matrices task was eliminated from the analysis at this point as insufficient data was available due to artifact. Thus, only six tasks remained for data analysis.

Data then underwent Fast Fourier Transform and the absolute and relative power in the different frequency bands were calculated. Absolute measures represent the amplitude or magnitude of the waves in a specific frequency band. Relative measures represent the percentage of the power in as specific frequency band as compared with the total power across all bands. To examine the first research question of this study the relative measure was chosen. The relative measure has been used by researchers such as Mann et. al. (in press). Thus the frequency bands were selected to match those used by Mann et. al. (in press). These band passes included; delta1 (0-2 Hz), delta2 (2-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta1 (12-20 Hz) and beta2 (20-32 Hz). To examine the second research question of what happens to the EEG from a resting state to on-task the absolute measures were used. These measures were chosen because the values in the frequency bands are not as interdependent as for the relative measure. Thus, it was felt that the absolute measure would more accurately reflect EEG changes on-task. Nineteen channels of EEG data were recorded across 8 band passes for the absolute measure; Delta (0-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), SMR (12-16 Hz), beta1 (16-20 Hz), beta2 (20-24 Hz), EMG1 (24-28 Hz) and EMG2 (28-32 Hz). Band passes of equal length were chosen in order to accurately compare the changes in the different bands.

Data Analysis

Once the data had been artifacted, it was then possible to carry out several types of statistical analysis. Basic descriptive statistics were carried out on the relative measures providing means and standard deviations for each frequency band in each of the 19 sites. Following this, changes in magnitude from the eyes open condition to the different tasks were calculated.

It has been pointed out by Oken and Chiappa (1986) that significance of results in not necessarily meaningful when you are potentially comparing thousands of variables. With 8 subjects by 19 electrodes by 8 frequency bands by 7 tasks you are looking at a potential of over 7000 data cells. Thus, inferential statistics would have little statistical power with such a large amount of data points and a small sample size. For this reason, the present study did not endeavour to do any inferential statistical analyses on the neurometric data. Rather the present study was intended to serve as a baseline estimate of what the brain of successful and ADD children looks like when performing various tasks. Inferential statistics were performed on the psychometric data, as the assumptions of parametric analysis are more closely met. However, with the small sample size statistical power on the psychometric results will be small.

Chapter 4

Results

In the present study, EEG data was analyzed using descriptive statistics. This chapter is divided into three major sections. The first section deals with the psychometric data describing the two groups. T-tests were used to compare the ADD group to the control group for differences in age, IQ and achievement. The second section deals with the neurometric data. Basic means and standard deviations for the two groups are described and compared below. The final section includes a discussion of inter-task comparisons which will be limited to the absolute measures.

Psychometric Analysis

There were no significant differences between the two groups for age (See Table 1). There were no significant differences between the ADD and control group as measured by the WISC-R. However, an analysis of the individual subtests of the WISC-R revealed that one subtest, coding, showed a significant difference between the groups, with the ADD group scoring lower than the controls. An analysis of the achievement results revealed that the ADD group scored significantly lower than the control group on all achievement measures with the exception of the reading

Table 1

Psychometric Differences Between Subjects with ADD (n=5) and Controls (n=8)

Measure	ADD Mean (SD)	Control Mean (SD)
Age*	126.4 (11.1)	134.1 (9.7)
Range	115 - 145	118 - 150
WISC-R Verbal	109 (2.9)	105.1 (6.2)
Range	107 - 114	98 - 115
WISC-R Performance	103.6 (11.5)	114.1 (5.8)
Range	85 - 112	108 - 124
WISC-R Full Scale	107.2 (6.5)	110.5 (4.7)
Range	96 - 112	102 - 116
WRMT-R Basic**	94.3 (10.6)	108.1 (7.9)
Range	83 - 104	100 - 119
WRMT-R Comp	91.7 (12.7)	99.9 (4.5)
Range	77 - 99	95 - 107
WRMT-R Full Scale	93 (11.4)	104.4 (8.2)
Range	80 - 101	95 - 115
WRAT-R Reading**	96 (9.9)	109.1 (6.3)
Range	81 - 105	99 - 118
WRAT-R Spelling**	87.8 (15.5)	105.3 (7.7)
Range	68 - 109	97 - 116
WRAT-R Math**	84.4 (16)	99.9 (9.3)
Range	71 - 112	91 - 116

Note: All scores are standard scores.

* Ages are given in months

** $p<.05$ 2 tailed

comprehension and full scale score on the WRMT-R. For both groups mean IQ and achievement scores fell within one standard deviation of the population mean. One notable exception to this was that the ADD group scored just below one standard deviation on the math subtest of the WRAT-R.

These results suggest that the ADD group was having significantly greater academic difficulties than the control group at the time of testing. In addition the significant difference on the coding subtest suggests that the ADD group may have greater difficulty in learning a new task that requires attention and concentration.

Neurometric Data

Due to the large amount of data that was analyzed and reported, each task/condition will be reported on separately. In addition to describing the relative power of the different frequency bands within the individual groups, the groups were compared and contrasted.

Relative Measure

Eyes Open

Means percentages of total power and the average total power in microvolts (uV) for the ADD group and control group are presented in Tables 2 and 3 respectively. As can be seen from these tables deltal and delta 2 account for a large percentage of the total power in both groups. For

Table 2
Mean Percent Power for the Eyes Open Condition in the ADD Group

	Frequency bands						
Sites	delta1	delta2	theta	alpha	beta1	beta2	total
F7	27.1	20.3	18.1	10.1	12.1	12.2	264.3
T3	21.6	18.9	20.0	11.9	13.6	14.0	193.8
T5	21.2	15.3	12.6	11.5	12.6	11.5	330.2
FP1	31.3	22.7	20.6	10.7	8.7	6.0	268.4
F3	25.2	23.2	24.6	13.0	9.3	4.8	365.7
C3	20.4	20.4	23.1	24.1	8.7	3.3	460.9
P3	23.8	21.7	22.9	20.0	8.8	2.9	384.1
O1	24.4	21.6	17.8	19.3	10.9	5.9	401.0
FZ	25.5	22.9	27.3	13.0	8.1	3.3	376.1
CZ	23.1	22.2	25.9	19.5	7.2	2.2	504.6
PZ	25.7	21.2	22.6	20.1	8.2	2.1	441.6
FP2	28.7	21.4	20.0	10.4	9.6	9.8	255.7
F4	26.2	21.7	23.9	13.3	9.5	5.5	375.9
C4	22.6	21.3	22.7	22.3	8.1	3.0	438.7
P4	24.6	21.0	21.6	21.4	8.6	2.7	415.5
O2	24.5	22.6	18.0	19.4	9.9	5.6	370.9
F8	28.7	21.5	18.8	11.3	10.3	9.4	247.5
T4	22.2	19.4	18.2	14.1	14.4	11.7	215.1
T6	23.6	20.6	19.1	22.5	10.2	4.0	348.7

Table 3
Mean Percent Power for the Eyes Open Condition in the Control Group

	Frequency Bands						
Sites	delta1	delta2	theta	alpha	beta1	beta2	total
F7	26.8	19.7	17.0	10.7	14.1	11.7	204.4
T3	19.9	17.5	16.4	13.6	18.5	14.0	180.9
T5	16.6	18.0	14.9	6.7	14.9	6.7	241.7
FP1	28.4	21.2	17.7	12.1	13.0	7.4	183.3
F3	23.5	22.1	22.5	12.9	13.4	5.6	292.6
C3	20.8	18.5	19.7	25.8	11.7	3.4	386.3
P3	25.8	20.2	17.7	21.0	12.2	3.1	375.8
O1	24.4	20.4	15.5	21.0	13.8	4.9	372.8
FZ	23.4	23.0	24.1	12.9	12.2	4.5	302.2
CZ	24.4	21.6	24.6	16.8	9.5	3.2	399.2
PZ	27.0	20.5	18.4	20.1	11.3	2.7	417.8
FP2	27.8	20.2	17.1	11.8	13.9	9.3	182.0
F4	24.5	22.4	21.6	12.9	12.6	6.1	311.5
C4	22.4	18.8	20.6	23.6	10.9	3.7	382.8
P4	25.4	19.7	18.3	20.9	12.5	3.3	392.6
O2	24.0	20.1	15.2	22.3	13.0	5.3	381.9
F8	25.6	19.7	18.0	12.0	14.2	10.6	198.7
T4	20.9	16.2	14.7	14.6	19.8	13.8	211.4
T6	23.3	18.8	16.4	21.0	15.0	5.6	287.2

both groups, roughly 40-50% of the total power in all channels comes from this 4Hz frequency range. Further inspection revealed that, with some exceptions, the ADD group tended to have more relative delta.

In the theta band, ADD's had greater relative power than controls in all brain sites. For both groups F3, F4, FZ and CZ showed the greatest relative power in the theta band. In general, all sites accounted for about 18-26% of the total power in the ADD group and 14-25% in the control group. Parietal sites showed the greatest differences between groups in relative theta power.

In the alpha band, the control group showed more relative power in 11 of 18 sites than the ADD's. However, differences between the groups were very small. In both groups the alpha band accounted for about 10-25% of the total power. Those channels that accounted for greater than 20% of the total power included C3, C4, PZ, P4 and T6. The control group had greater than 20% total power in the additional sites of O1, O2 and P3.

In the beta1 band, controls had more relative power than ADD's for all sites. On the average, about 10% of the total power was accounted for in all of the brain sites for the ADD group. Conversely, beta1 accounted for 13% of the total power in the control group across all sites. In both groups, the temporal channels (T3,T4,T5, and T6) accounted for the most relative beta1 power. The difference in relative beta1 power between the groups was greatest in T3, T4, and T6.

The beta2 band accounted for the smallest percentage of total power in all channels and in both groups. In both groups the beta2 band accounted for an average of 6% of the total power across all the sites. In both groups the percentages ranged from 2-15%. Sites that showed greater than 11% of the total power included F7, F8, T3, and T4. These large beta2 percentages may be accounted for due to muscle tension in the masseter muscle.

In terms of the total power for the eyes open condition, both groups showed considerable variation from one site to the next. However, the ADD group consistently had greater total power than the control group. On the average, across all sites, ADD's had about 350 uV2 while the controls had only 300 uV2. The one exception to this was in channel O2 where controls had greater total power.

Eyes Closed

Means percent power for the ADD group are presented in Table 4 and mean percent power for the controls are presented in Table 5. Once again the delta1 and delta2 bands account for the largest percentage of total power in both groups. Typically the frontal channels showed the largest percentage of delta in both groups.

Table 4
Mean Percent Power for the Eyes Closed Condition in the ADD Group

	Frequency Bands						
Sites	delta1	delta2	theta	alpha	beta1	beta2	total
F7	28.8	22.5	19.8	15.0	8.1	5.8	276.4
T3	20.2	22.0	22.1	20.6	9.3	5.8	216.4
T5	17.8	18.1	24.6	29.1	7.7	2.6	414.5
FP1	30.2	23.1	19.6	13.7	7.7	5.7	311.0
F3	23.4	22.4	24.6	17.6	8.3	3.7	414.2
C3	17.5	18.2	24.0	29.8	7.6	2.7	569.5
P3	17.9	16.7	24.8	31.8	6.9	1.8	649.8
O1	13.6	14.5	20.2	41.2	7.4	3.0	1037.5
FZ	22.0	23.6	26.3	17.8	7.7	2.7	430.7
CZ	18.2	20.7	29.2	23.3	6.5	2.1	584.2
PZ	18.3	17.7	26.6	29.6	6.2	1.5	729.0
FP2	30.1	24.4	19.9	13.3	7.5	4.8	299.7
F4	22.6	23.8	23.9	18.1	8.2	3.4	431.7
C4	18.0	20.2	25.4	26.1	7.6	2.7	554.6
P4	17.4	17.8	24.5	31.6	7.0	1.8	719.6
O2	14.3	15.7	23.8	37.4	7.0	1.8	782.2
F8	26.7	22.4	21.5	16.0	8.3	5.1	277.1
T4	17.6	20.6	22.4	22.2	11.2	5.9	227.9
T6	14.5	16.4	21.1	39.1	7.0	1.9	719.4

Table 5
Mean Percent Power for the Eyes Closed Condition in the Control Group

	Frequency Bands						
Sites	delta1	delta2	theta	alpha	beta1	beta2	total
F7	27.4	20.3	16.8	16.4	11.7	7.5	246.6
T3	21.4	19.1	20.0	20.4	13.6	5.6	186.1
T5	18.6	16.7	16.8	30.4	13.4	4.2	341.4
FP1	29.7	22.1	16.6	15.0	10.3	6.3	270.8
F3	20.9	20.5	21.2	19.3	12.9	5.4	347.1
C3	17.8	17.4	19.2	30.4	11.8	3.4	452.5
P3	18.9	17.1	16.1	32.9	12.1	2.9	518.3
O1	14.2	12.5	10.9	48.0	11.4	3.1	1068.1
FZ	20.2	21.5	22.2	19.5	12.3	4.4	356.4
CZ	19.5	21.0	22.3	24.3	9.9	3.1	464.2
PZ	18.4	16.2	15.8	36.5	10.7	2.4	656.0
FP2	30.3	22.0	16.2	14.5	10.6	6.4	267.6
F4	21.0	21.4	19.9	19.0	13.0	5.7	355.5
C4	18.1	18.7	18.9	29.8	11.2	3.3	456.6
P4	18.4	15.7	14.6	37.7	11.0	2.6	685.2
O2	12.9	11.8	10.6	50.3	10.7	3.6	1036.8
F8	24.8	20.6	17.9	17.1	12.1	7.5	236.9
T4	19.6	17.7	16.8	23.0	15.4	7.5	210.5
T6	16.4	13.8	13.8	41.0	12.0	3.0	618.7

For the theta band, the same trend was found in the eyes closed condition as for the eyes open condition. That is, the ADD group showed greater relative theta in all sites. Further, the largest percentage of relative theta was found in the central sites along the midline (FZ,CZ,PZ) for both groups.

In the alpha band there was considerable variation from one site to another. Typically the channels from the posterior half of the brain had the greatest relative alpha for both groups. Controls consistently had greater relative power in the alpha band than ADD's. This difference was greatest in the occipital sites of O1, O2 and PZ. The difference was most augmented in channel O2 where controls had up to 13% more relative alpha than the ADD's. Thus, there appears to be a more dominant shift to alpha in a resting eyes closed state for controls than for ADD's.

Once again, controls had more relative beta1 power than ADD's in all channels. However, in both groups, there was less relative power than in the eyes open condition (refer to Tables 1 & 2). The ADD group's relative beta1 power ranged from 6.2 to 11.2% while the controls ranged from 10.3 to 15.4%. Sites with the greatest relative beta1 power for both groups were T3 and T4, however the controls also had a large relative beta1 power in T5.

In the beta2 band, the ADD group ranged from 1.5 to 5.9% while the controls ranged from 2.4 to 7.5%. Sites with the greatest relative beta2 power were F3, F7, T3, and T4 for the ADD group. For the control group sites FP2, F3, F7, F8 and T4 had the greatest relative beta2 power. The control group had more beta2 power in all sites except T3. However, the differences between the groups were small, on the average controls had 1% more relative beta2 than ADD's.

In terms of total power, the ADD group had 30 to 130 uV2 more power than controls over all the sites. The only exceptions to this were in sites O1 and O2 where controls had more power. These sites were also the sites that contained the greatest total power for both groups. Of interest was that the total powers were similar at site O1 whereas controls had substantially more overall power in O2 when compared to the ADD group.

Reading Silently

Mean percent power for the ADD group and control group are presented in Tables 6 and 7 respectively. In the delta1 and 2 bands 40 to 50% of total power was accounted for by these bands. The frontal channels (F7, FP1, FP2, F8) had the greatest relative delta1 power for both groups. Sites FZ, F4, and T5 had the greatest relative delta2 power for the ADD group, while F3, FZ, and F4 were the largest in the control group. The control group had more delta1 power than

Table 6

Mean Percent Power for the Reading Task in the ADD Group

	Frequency Bands						
Sites	delta1	delta2	theta	alpha	beta1	beta2	total
F7	26.1	21.5	21.1	10.9	11.0	9.4	270.3
T3	19.0	19.5	22.3	12.0	13.9	13.4	197.9
T5	21.6	22.9	25.4	15.6	9.4	5.1	279.6
FP1	25.7	19.8	20.6	10.8	10.9	12.2	278.0
F3	21.7	21.9	26.3	14.4	10.2	5.4	363.4
C3	18.0	20.7	25.6	24.4	8.0	3.3	452.8
P3	22.8	21.6	24.5	20.8	7.7	2.5	423.1
O1	20.3	20.3	24.9	19.6	9.9	4.9	441.9
FZ	21.2	23.3	28.7	15.3	8.2	3.4	377.4
CZ	19.2	21.8	28.9	21.1	6.6	2.3	494.1
PZ	22.6	20.6	25.0	22.8	7.0	2.0	515.7
FP2	25.4	20.3	19.6	11.3	10.8	12.7	271.1
F4	21.5	22.0	25.2	15.2	10.4	5.6	394.3
C4	20.9	21.1	24.8	22.3	7.7	3.1	453.6
P4	23.0	20.7	24.8	21.0	8.0	2.5	467.1
O2	21.9	21.4	25.0	17.8	9.8	4.2	380.7
F8	29.0	20.6	20.4	12.3	10.1	7.7	268.9
T4	19.2	19.8	19.7	15.7	13.5	12.1	213.5
T6	21.3	20.3	26.1	20.5	8.2	3.6	357.8

Table 7
Mean Percent Power for the Reading Task in the Control Group

	Frequency Bands						
Sites	delta1	delta2	theta	alpha	beta1	beta2	total
F7	28.0	21.1	18.2	9.0	12.8	11.0	220.4
T3	21.4	20.5	18.2	12.0	16.3	11.6	176.0
T5	24.5	21.2	20.9	14.3	13.6	5.4	224.0
FP1	27.2	22.1	19.3	9.3	12.6	9.6	193.8
F3	23.0	23.0	24.4	11.2	13.0	5.5	290.2
C3	21.9	19.5	21.9	21.7	11.3	3.7	357.8
P3	26.1	20.8	21.1	16.9	11.6	3.4	331.1
O1	21.3	20.9	25.4	15.5	12.1	4.8	329.9
FZ	24.1	22.7	25.3	11.1	12.4	4.3	299.2
CZ	25.0	20.4	26.0	15.8	9.7	3.2	372.3
PZ	26.6	19.7	20.7	19.0	11.1	2.9	387.1
FP2	27.8	21.0	19.2	9.2	13.1	9.7	190.3
F4	24.3	21.9	24.2	10.9	13.3	5.4	301.0
C4	23.3	19.6	23.2	18.8	11.6	3.6	330.8
P4	25.7	19.8	21.1	18.0	12.2	3.3	366.1
O2	21.0	20.5	25.4	15.3	12.1	5.8	366.7
F8	26.1	20.5	21.0	10.2	13.2	9.1	205.0
T4	22.3	19.0	18.1	13.7	17.4	9.5	182.6
T6	22.3	19.5	23.2	16.7	13.7	4.6	262.2

ADD's in all but two channels whereas the ADD's had more delta2 power in a majority of channels. The difference between the groups was typically small for delta1, however controls had 5.8% more relative power at CZ than controls. Differences in the delta2 band were usually smaller than 1%.

In the theta band, the ADD group had more relative power in all sites except O1, O2, and F8. Differences between the groups were as high as 3.7 to 4.5% higher power in the ADD group. These differences occurred at sites T3, T5, C3, PZ, and P4. In the ADD group the relative theta ranged from 19.6 to 28.9% while in the control group it ranged from 18.1 to 26%. Sites with the greatest relative theta were FZ, CZ, F3, and T6 for the ADD group. For the controls FZ, CZ, O1 and O2 had the greatest relative theta.

In the alpha band, both groups showed substantial variation in relative power from one site to another. In the ADD group relative alpha ranged from 10.8 to 22.8%, while in the control group it ranged from 9 to 21.7%. For 18 of 19 sites the ADD group had more relative alpha than controls, having 3% more power on the average.

In the beta1 band, controls had more relative power in all sites than ADD's. Relative beta1 power ranged from 9.7-17.4% in controls while ADD's ranged from 6.6-13.5%. Those sites that accounted for 13% or more of the total power in the control group were T3, T4, T5, T6, F3, F4, F8 and FP2.

These same sites, as well as FP1 and F7, accounted for 10% or more of the total power in the ADD group. The only exception was T5 and T6 where the greatest difference between the groups existed with controls having 4.2 and 5.5% more power respectively.

In the beta2 band, one can see that both groups had definite outlying values in certain sites. For the ADD group, sites F7, T3, T4, FP1 and FP2 accounted for more than 12% of the total power. In the control group these same sites accounted for 9 to 10% of the total power. High values in the beta2 band may indicate contamination of the data by muscle artifact. Therefore these sites may have spuriously increased the percentage of beta1 power in these sites. In general, differences between the groups were typically below 1%.

In terms of total power, the ADD group had more power in all sites when compared to the controls. The total power for the ADD group ranged from 197.9 to 515.7 uV2 while the controls ranged from 182.6 to 387.1 uV2. In both groups CZ and PZ had the largest total power. These are also the sites where the largest difference between the groups existed with ADD's having more than 120 uV2 more power than controls.

Drawing Bender Gestalts

Mean percent power for the ADD group and for the control group are presented in Tables 8 and 9 respectively. As can be seen from these tables delta 1 and 2 accounted for 35-50% of the total power. Further, the difference in relative power between the groups was usually very small averages less than 1% difference across all sites.

In the theta band, the ADD group ranged from 18.2 to 30.8% while the controls ranged from 17 to 26%. Sites with the greatest relative theta power were C3, CZ, and FZ for both groups. However, the ADD group had over 30% relative power in these sites while the controls had only 26%. The ADD group had more relative power than controls in all other sites as well averaging about 3% more power per site. Those sites that had greater than 4.5% power in the ADD group included T3, T5, C3, CZ, FZ and FP2.

In the alpha band, both groups produced similar relative alpha percentages. Alpha ranged from 9.1 to 18.3% in the ADD group while the controls ranged from 9.1 to 17.4%. Sites that had the greatest percentage of alpha were O1, O2 an PZ for the ADD group, which accounted for more than 18% of the total power. In contrast, the controls had the greatest in power in O2, followed by PZ and CZ respectively, which accounted for 15 to 17% of the total power.

Table 8
Mean Percent Power for the Drawing Task in the ADD Group

	Frequency Bands						
Sites	delta1	delta2	theta	alpha	beta1	beta2	total
F7	27.0	22.5	20.7	9.1	10.9	9.8	264.3
T3	19.4	19.1	22.3	11.2	14.7	13.3	219.5
T5	17.4	20.2	22.8	12.4	14.1	13.1	391.7
FP1	29.2	21.5	24.2	9.1	8.6	7.3	329.7
F3	24.7	24.1	27.7	10.6	8.1	4.8	383.9
C3	22.1	23.7	30.6	13.7	7.4	3.5	368.9
P3	23.0	24.5	26.0	15.1	7.9	3.5	355.1
O1	21.9	22.1	20.2	18.3	11.0	6.5	361.2
FZ	23.1	24.1	30.8	11.3	7.2	3.5	413.8
CZ	21.4	21.7	30.8	17.5	6.0	2.6	475.7
PZ	23.8	23.7	25.3	18.0	6.8	2.4	433.1
FP2	28.2	20.7	23.2	9.7	9.7	8.5	316.1
F4	23.2	23.4	26.1	12.9	8.8	5.6	408.6
C4	21.9	22.2	26.8	18.3	7.1	3.8	418.7
P4	24.7	24.0	23.8	15.6	7.9	3.7	383.9
O2	22.4	22.3	19.3	16.7	10.8	8.5	356.0
F8	26.2	20.8	21.4	12.1	9.9	9.6	276.2
T4	18.1	17.1	18.2	11.9	17.2	17.4	245.1
T6	22.9	21.6	18.8	14.8	11.5	10.3	326.2

Table 9
Mean Percent Power for the Drawing Task in the Control Group

	Frequency Bands						
Sites	delta1	delta2	theta	alpha	beta1	beta2	total
F7	26.8	20.3	17.6	9.1	14.1	12.0	227.6
T3	22.6	18.6	17.0	11.2	17.0	13.6	191.6
T5	22.1	19.2	18.0	11.2	17.0	12.6	248.6
FP1	27.5	22.9	19.2	10.0	12.5	8.0	238.3
F3	22.7	23.3	24.5	10.9	12.5	6.2	286.2
C3	23.7	23.4	26.0	12.8	9.7	4.5	292.2
P3	25.9	22.8	21.9	13.1	11.7	4.6	287.8
O1	21.8	20.1	18.8	13.8	14.6	11.0	315.9
FZ	22.2	24.4	26.0	10.9	11.5	4.9	301.6
CZ	22.8	23.8	26.0	15.3	8.4	3.8	350.4
PZ	25.6	23.1	21.8	15.4	10.1	4.0	323.9
FP2	27.4	23.1	18.4	9.8	12.3	9.0	237.0
F4	22.2	24.1	23.6	11.1	12.6	6.4	307.0
C4	21.7	23.4	23.1	17.4	9.8	4.7	314.1
P4	24.5	22.9	21.6	14.7	11.4	4.9	303.3
O2	20.9	20.7	17.4	13.7	14.9	12.3	330.2
F8	24.6	22.0	19.5	10.8	12.9	10.4	217.7
T4	21.0	19.5	17.5	13.1	17.0	11.9	176.5
T6	21.2	19.7	17.1	13.4	16.0	12.8	254.3

Similar to other tasks, beta1 power was greater in the controls over all the sites except T4. The ADD group ranged from 6 to 17.2% while the controls ranged from 8.4 to 17%. It seems that temporal sites had the greatest relative beta1 power for both groups. However, sites F3, FZ, T6 and O2 showed the greatest discrepancy between the two groups with controls having greater than 4% more relative beta1 than ADD's.

Of interest in the beta2 band are the several outlying values than occur in both groups. For the ADD group, all temporal sites showed substantially larger values than other sites. This same trend was observed in the controls who also had large percentages of beta2 power in F7, F8 and O2. As all of these sites are on the periphery it is possible that these large values indicate muscle artifact that was left in the analysis.

As was the case for the other tasks the ADD group had more total power in all sites than controls. While the ADD group ranged from 219.5 to 475.7 the controls ranged from 176.5 to 350.4 uV2. Sites T5, FZ, CZ, PZ, F4 and C4 all had more than 100 uV2 more power in ADD's than in controls.

Mathematics

Means for the ADD group and the controls are presented in Tables 10 and 11 respectively. In both groups, delta1 and delta2 accounted for 40 to 50% of the total power once

Table 10
<u>Mean Percent Power for the Math Task in the ADD Group</u>

	Frequency Bands						
Sites	delta1	delta2	theta	alpha	beta1	beta2	total
F7	32.6	20.7	19.8	9.3	9.3	8.3	367.3
T3	25.8	18.9	21.8	11.6	11.7	10.2	233.6
T5	21.5	20.9	25.0	14.0	11.3	7.3	296.9
FP1	28.1	23.2	21.6	8.7	8.9	9.5	243.4
F3	23.3	23.3	28.1	12.0	8.2	5.1	447.2
C3	21.7	20.6	26.5	20.6	7.2	3.3	488.7
P3	24.0	23.3	26.6	15.7	7.6	2.8	398.0
O1	20.8	23.0	24.3	16.7	10.1	5.0	405.5
FZ	22.1	24.4	31.4	11.9	7.0	3.2	434.1
CZ	22.1	23.8	28.7	16.5	6.3	2.7	471.8
PZ	23.6	24.2	27.0	16.3	6.6	2.3	452.7
FP2	27.3	22.6	21.3	8.6	10.0	11.1	390.5
F4	21.7	23.8	27.2	12.4	9.2	5.7	432.2
C4	20.9	24.3	26.7	17.6	7.1	3.5	436.1
P4	23.3	23.8	27.7	15.3	7.1	2.9	405.5
O2	21.9	22.7	25.2	16.0	9.0	5.1	390.8
F8	26.1	23.1	22.2	10.5	9.4	8.7	280.6
T4	21.4	23.6	22.8	11.6	11.4	9.2	213.2
T6	22.4	22.4	26.8	16.0	8.4	4.0	326.4

Table 11
Mean Percent Power for the Math Task in the Control Group

	Frequency Bands						
Sites	delta1	delta2	theta	alpha	beta1	beta2	total
F7	26.1	22.9	17.8	9.0	12.3	11.9	223.5
T3	22.9	23.6	19.2	12.5	13.4	8.4	159.9
T5	24.3	22.2	21.0	13.2	13.4	6.0	207.6
FP1	26.8	21.9	19.1	9.2	12.6	10.5	220.4
F3	22.6	25.4	24.0	11.0	11.4	5.7	307.6
C3	21.9	23.9	22.6	18.6	9.5	3.5	352.5
P3	25.2	22.8	22.3	15.0	11.0	3.6	297.4
O1	22.0	22.6	21.8	13.9	13.4	6.4	276.2
FZ	23.0	25.8	25.6	10.7	10.5	4.4	319.0
CZ	23.6	24.4	26.1	13.7	8.7	3.5	350.0
PZ	25.2	24.0	22.0	15.5	10.2	3.2	328.2
FP2	26.2	21.3	18.8	9.2	13.3	11.3	221.1
F4	24.4	24.7	23.9	10.3	11.2	5.6	420.9
C4	22.8	24.2	23.5	15.4	10.2	4.0	324.5
P4	24.9	23.7	21.8	15.1	11.1	3.5	319.7
O2	22.0	22.7	21.4	14.8	12.7	6.5	303.8
F8	25.0	22.7	20.4	9.9	12.4	9.6	212.2
T4	24.2	23.2	18.1	11.8	14.6	8.1	177.4
T6	23.9	22.2	20.5	14.5	13.7	5.2	238.0

again. There was little variation from one site to another and there was little difference between the groups. Two exceptions were F7, where ADD's had 6.5% more relative delta1 than controls, and T3, where controls had 4.7% more delta2 power than ADD's.

In the theta band, ADD's ranged from 19.8 to 31.4% while controls ranged from 17.8 to 26.1%. As was the case for the previous tasks, ADD's had more relative theta in all sites. Relative theta was the greatest in sites FZ and CZ for both groups. ADD's had the next greatest power in F3 and P4, while controls had substantial relative power in F3, F4, C3 and C4. Sites with the largest discrepancies between the groups were FZ, PZ, P4 and T6, where the ADD's had greater than 5% more relative theta than controls.

The ranges for relative alpha were similar for both groups and the differences between the groups were small. Sites C3 and C4 accounted for the largest percentage in both groups. However, the ADD's had additionally large values in sites O1 and CZ, while the controls had their next largest values at PZ and P4. The alpha values for both groups tended to be lower than they were for the eyes open condition.

In the beta1 band the control group had more relative power than ADD in all sites. For both groups, the sites with the greatest relative beta1 were T3, T4, T5, O1 and

FP2. However, the controls also had considerable power in site T6. This site was also the site that showed the largest discrepancy between the two groups. Other sites that showed more than 3.5% beta1 in the control group were P4, Pz, Fz and FP1.

Sites FP1 and FP2 had larger relative beta2 power in both groups. However, the ADD's also showed a large relative beta2 in site T3 while the controls showed it in F7. In general, relative beta2 values were small and the differences between the groups were minimal.

In terms of total power, the ADD group ranged from 213.2 to 488.7 while the controls ranged from 159.9 to 420.9 uV2. The same trend as was found for the other tasks was also found for this task as the ADD group had more power in all sites when compared to the controls. Differences were much larger for this task as was previously found and a majority of the sites had greater than 100 uV2 difference.

Listening to a Story

Means for the ADD group and the control group are presented in Tables 12 and 13 respectively. Delta1 showed strong relative power for the control group who ranged from 19.5 to 28.2. The ADD group ranged from 15.4 to 28.4 in the delta1 band. Typically controls had more relative delta1 power. Delta2 showed similar values, however there tended to be less relative power in this range

Table 12
Mean Percent Power for Listening to a Story in the ADD Group

Sites	Frequency Bands						
	delta1	delta2	theta	alpha	beta1	beta2	total
F7	25.1	17.8	16.6	11.4	13.1	15.9	328.9
T3	15.4	15.5	17.1	12.2	17.6	22.2	251.6
T5	20.4	18.7	22.7	20.8	11.9	5.5	325.2
FP1	28.2	19.9	20.0	10.8	9.9	11.3	353.4
F3	22.5	21.1	26.0	14.5	10.1	5.8	420.8
C3	19.0	19.7	24.4	24.4	8.7	3.7	490.0
P3	21.0	19.0	24.1	24.5	9.1	2.4	505.7
O1	20.2	19.2	16.8	27.7	11.4	4.7	546.2
FZ	22.7	22.2	29.0	15.3	7.6	3.3	434.5
CZ	20.2	20.0	28.7	22.1	6.9	2.2	578.6
PZ	21.9	18.5	25.6	24.0	7.9	2.0	692.1
FP2	28.4	20.6	19.9	10.8	8.8	11.5	338.9
F4	21.7	21.8	25.6	15.0	9.7	6.2	430.2
C4	20.2	19.0	26.2	22.6	8.6	3.4	496.7
P4	19.4	20.0	24.0	26.1	8.1	2.4	618.1
O2	19.4	22.1	19.4	24.1	10.4	4.5	491.6
F8	25.3	20.9	19.0	12.1	11.0	11.6	291.4
T4	18.2	16.2	17.1	14.8	13.3	20.4	282.7
T6	19.3	18.4	20.3	28.7	8.6	6.7	469.0

Table 13

Mean Percent Power for Listening to a Story in the Control Group

Sites	Frequency Bands						
	delta1	delta2	theta	alpha	beta1	beta2	total
F7	25.1	19.1	16.0	10.0	15.1	14.7	238.5
T3	20.0	17.7	16.0	12.3	18.1	16.0	191.2
T5	24.5	18.7	18.3	17.1	14.3	7.1	230.8
FP1	26.9	20.1	17.8	10.9	13.4	11.0	210.5
F3	22.7	22.1	22.4	12.7	14.0	6.2	305.5
C3	21.2	19.7	19.5	24.4	11.8	3.6	376.6
P3	26.5	19.4	18.4	20.2	12.2	3.3	373.8
O1	24.7	19.3	17.6	19.0	13.7	5.8	344.5
FZ	22.7	23.1	23.7	12.8	13.0	4.7	310.0
CZ	24.1	21.4	23.0	17.7	10.5	3.3	365.3
PZ	28.2	19.4	17.8	20.5	11.5	2.6	460.1
FP2	25.6	18.9	16.9	10.2	14.9	13.6	215.9
F4	23.2	22.1	22.1	12.2	14.1	6.2	310.5
C4	21.8	19.7	20.3	23.4	11.3	3.7	367.5
P4	25.4	18.9	17.8	22.1	12.8	3.1	431.3
O2	24.4	18.9	16.8	20.1	14.3	5.6	365.6
F8	24.1	19.0	17.7	11.0	15.5	12.8	221.5
T4	19.5	15.9	14.7	14.5	19.8	15.6	224.3
T6	22.0	19.3	17.1	20.8	15.0	15.8	297.2

for both groups. Delta1 and 2 accounted for 30-50% of the total power in both groups.

As in all previous tasks ADD's had more power in all sites with the exception of O1. The ADD's ranged from 16.6 to 29% while the controls ranged from 14.7 to 23.7% relative theta. Those sites with the greatest relative theta were FZ, CZ, PZ, C4, F3, F4 for both groups. Those sites with the greatest differences between the groups were C4, CZ, PZ, P3, and P4.

In the alpha band, the ADD group ranged from 10.8 to 28.7% while the controls ranged from 10 to 24.4%. The ADD typically had more relative alpha than controls. Sites O1 and T6 showed the greatest difference between the groups as ADD's tended to have 8% more power than controls. Those sites that showed the greatest relative alpha were T6, O1 and P4 in the ADD's and C3, C4, and P4 in the controls.

In the beta1 band, the controls had more relative power than ADD's in all sites. While the ADD's relative power ranged from 6.9 to 17.6% the controls ranged from 10.5 to 19.8%. Sites where the greatest beta1 occurred were T3, T4 and F7 for the ADD group. For the controls, sites F8 and T6 in addition to the sites in the ADD group had the greatest relative beta1 power. Sites where the greatest differences occurred between the groups were F4, FZ, T4 and T6. In all these sites controls had 5 to 6% more power than ADD's.

The ranges for beta2 power were 2 to 22.2 for the ADD's and 2.6 to 16 for the controls. Despite these ranges controls had more beta2 power than ADD's in a majority of the sites. Sites with the largest beta2 power were T3, T4, F7, FP1, FP2, and F8 for the ADD group. Slightly different sites had the largest beta2 power for the controls as F7, F8, T3, T4, T6 and FP2 were the highest. All of these sites had such a substantial amount of the total power that they most likely contained some muscle artifact. Therefore any interpretation with these sites in the other bands would be considered suspect.

In terms of total power the ADD group had considerably more power than controls in all sites. Differences between groups ranged from 60 to 232 uV2. Sites where the ADD group had more than 200 uV2 than the controls were O1, CZ, and PZ. The ADD group ranged from 251 to 692 uV2 while the controls ranged from 191.2 to 460 uV2. For both groups the greatest total power was found in PZ and P4.

Summary

To summarize the above section several consistent trends were observed throughout all of the tasks. First, in all sites and for all tasks delta1 and delta 2 accounted for the majority of the total power. Typically these two bands accounted for 30 to 50% of the total power. The second consistent finding for all tasks was that the ADD group consistently had larger relative theta power than controls. This result was usually consistent for all sites as well. In a similar way, the control group consistently had more relative beta1 power in all sites and for all tasks. Both groups tended to be fairly equal in their amount of relative alpha and beta2 production with some exceptions. The last consistent trend that was observed was that the ADD group had more total power than controls in almost all sites, for all tasks.

Other notable findings were that temporal locations most often had the greatest beta1 production for all tasks and for both groups. Another result which was fairly consistent was that sites FZ and CZ had the greatest relative theta production for all tasks in both groups. In addition, parietal sites most often had the largest relative theta differences between the groups. In particular, sites PZ and P4 consistently had large discrepancies between the groups in 5 of the 6 task/conditions.

Inter-task Comparisons

While the previous section was intended to display the differences between the two groups, this section is intended to show how the groups behaved when going from the eyes open condition to the different cognitive tasks. This section will be limited to a reporting of changes in absolute magnitude in the theta, alpha, SMR and beta1 bands. These bands were chosen for analysis since they have been focused on to a greater extent in the literature. Also, these frequencies are less prone to contamination from muscle artifact.

In all cases differences in magnitude were calculated by subtracting the magnitude in the eyes open condition by the magnitude in the task condition on a site by site basis. Thus, negative values represent greater magnitude in the on-task conditions.

Eyes Open vs. Reading

Changes in absolute theta are presented in Figure 2. From this figure it can be seen that both groups tended to have higher magnitude theta waves in the reading condition than at rest. This was particularly the case for sites O1 and O2. Both groups behaved similarly in the different brain areas with a slight tendency for the ADD group to shift to higher theta magnitudes in the reading condition than the control group.

Differences in alpha magnitudes from the eyes open to reading task are presented in Figure 3. From this figure it is apparent that the two groups behaved differently when going from a resting state to reading. The ADD group tended to shift to higher alpha magnitudes in the reading condition. Although these changes in magnitude were not

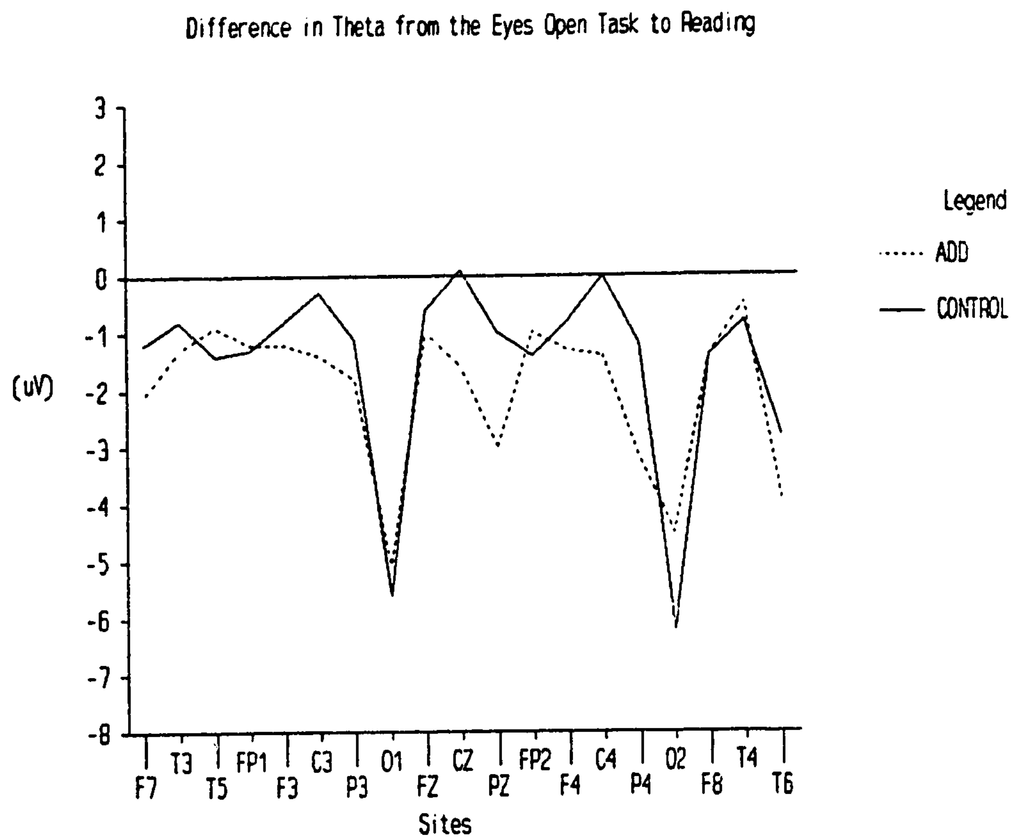


Figure 2 Negative values represent higher theta magnitudes in the reading condition.

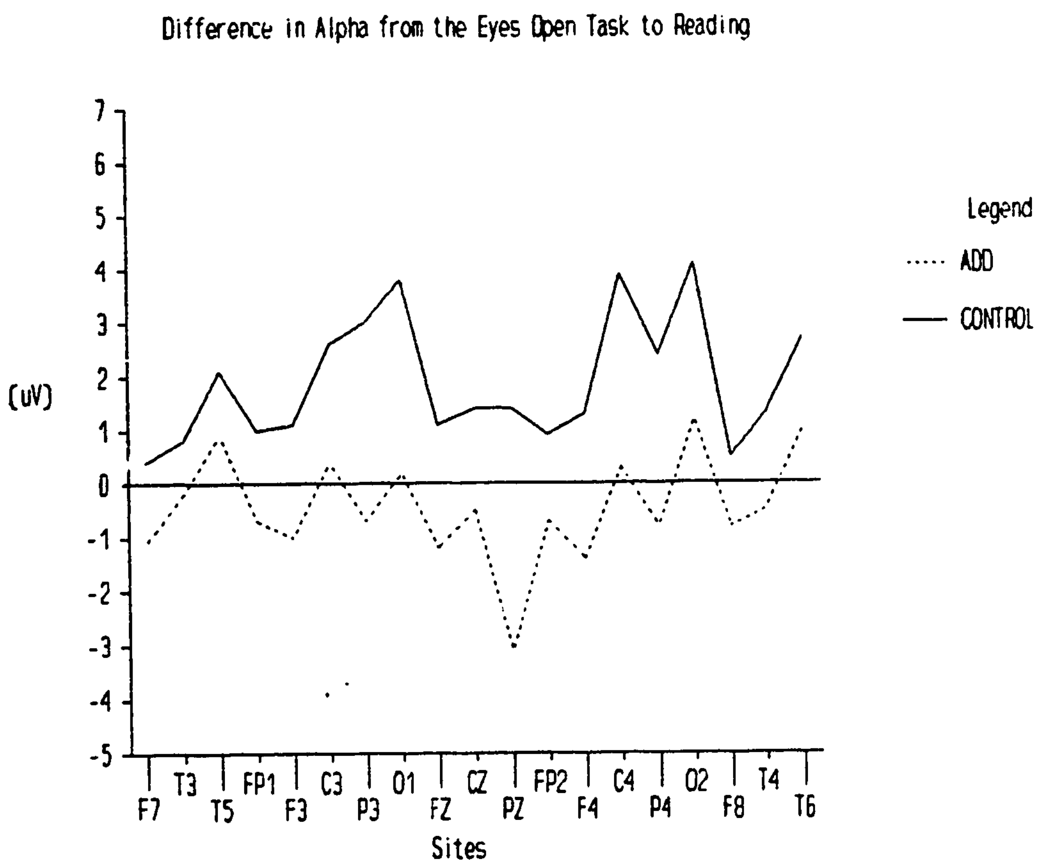


Figure 3 Negative values represent higher alpha magnitudes in the reading condition.

large, site PZ tended to have much higher magnitudes in the reading condition for the ADD group. Conversely, the controls tended to have higher alpha magnitudes in the resting state. This difference between groups was maximal at sites O1, O2, C4 and P4. Stated another way, alpha was suppressed in these sites during the task.

Changes in the SMR band from a resting state to reading are represented in Figure 4. From this figure it can be seen that both groups tended to have higher magnitude SMR waves in the resting state. However, all changes in magnitude were less than 1.5 uV. Sites of interest were T5, where the ADD group had more resting SMR. At site P3 controls produced larger resting magnitudes of SMR. At O2 the two groups diverged as the ADD group tended to produce larger SMR waves for reading while the controls produced larger SMR waves while at rest.

Changes in beta1 from the eyes open task to the reading task are represented in Figure 5. From the figure it can be seen that the control group tended not to change in beta1 magnitude from rest to reading. The only exception was at site T4 where controls had higher beta1 magnitudes at rest. The ADD group had higher beta1 magnitudes in T3, FP1 and FP2, while site T5 had higher resting beta1 magnitudes.

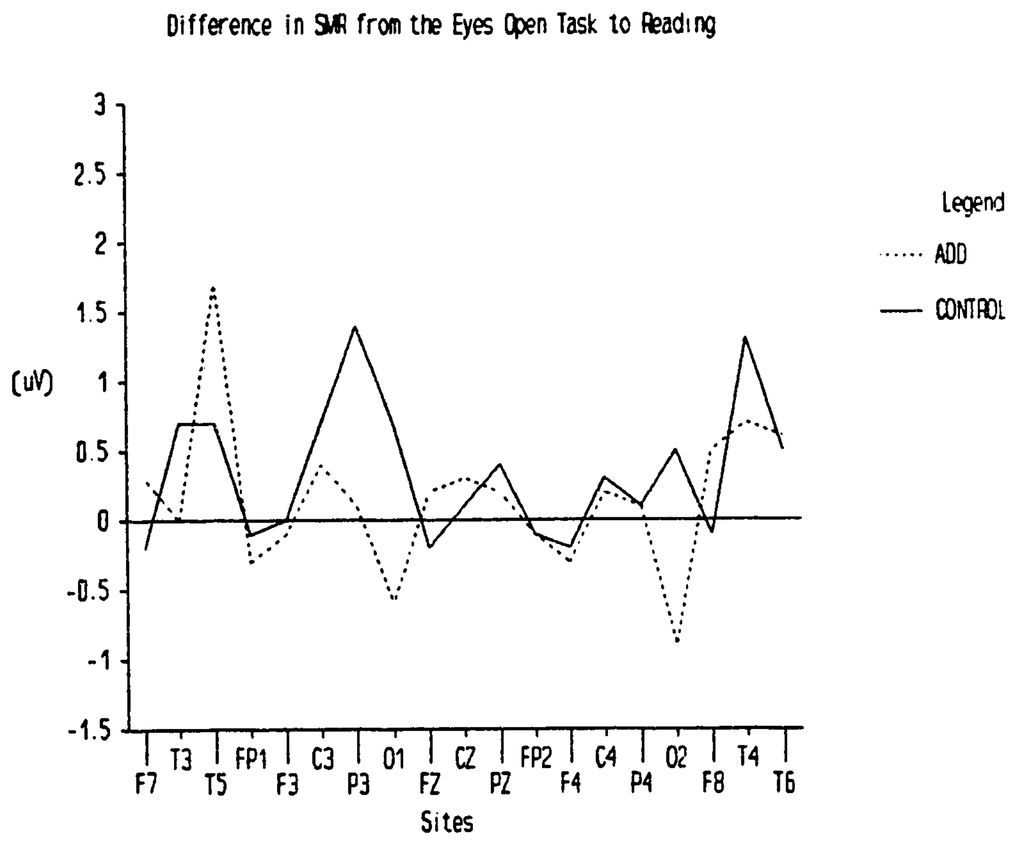


Figure 4 Negative values represent higher SMR values in the reading condition.

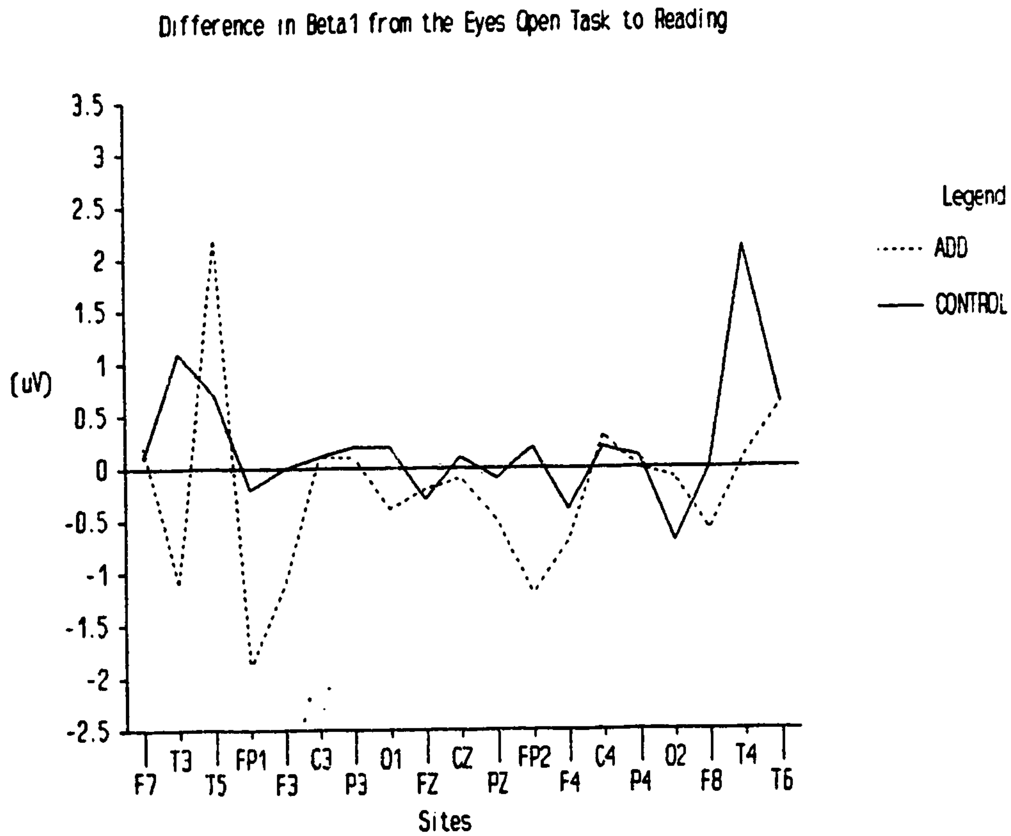


Figure 5 Negative values represent higher beta1 magnitudes in the reading condition.

Eyes Open vs. Drawing

Changes in absolute theta from eyes open to drawing are represented in Figure 6. From this figure one can see that there are several points of divergence between the two groups. At sites O1 and O2, controls shift to higher magnitudes of theta for the drawing task to a greater extent than ADD's. Conversely, ADD's shift to higher theta magnitudes for drawing in the midline sites of FZ, CZ, and PZ to a greater extent than controls. In general both groups had higher theta magnitudes for drawing than for the resting condition.

Changes in absolute alpha from eyes open to drawing are presented in Figure 7. From this figure it can be seen that both groups tend to parallel one another. Both groups tended to produce higher alpha magnitudes when they were at rest than when they were drawing. That is, both groups were able to suppress alpha for the drawing task. Sites where alpha suppression was maximal for both groups were C3, C4, P3, P4, PZ, O1 and O2.

Changes in absolute SMR are presented in Figure 8. Both groups tended to change in similar ways when going from a resting state to a drawing task. Both groups tended to have higher SMR magnitudes at rest in a majority of the sites. The ADD group tended to have magnitudes that stayed within a 1 uV range from task to task. In the control group

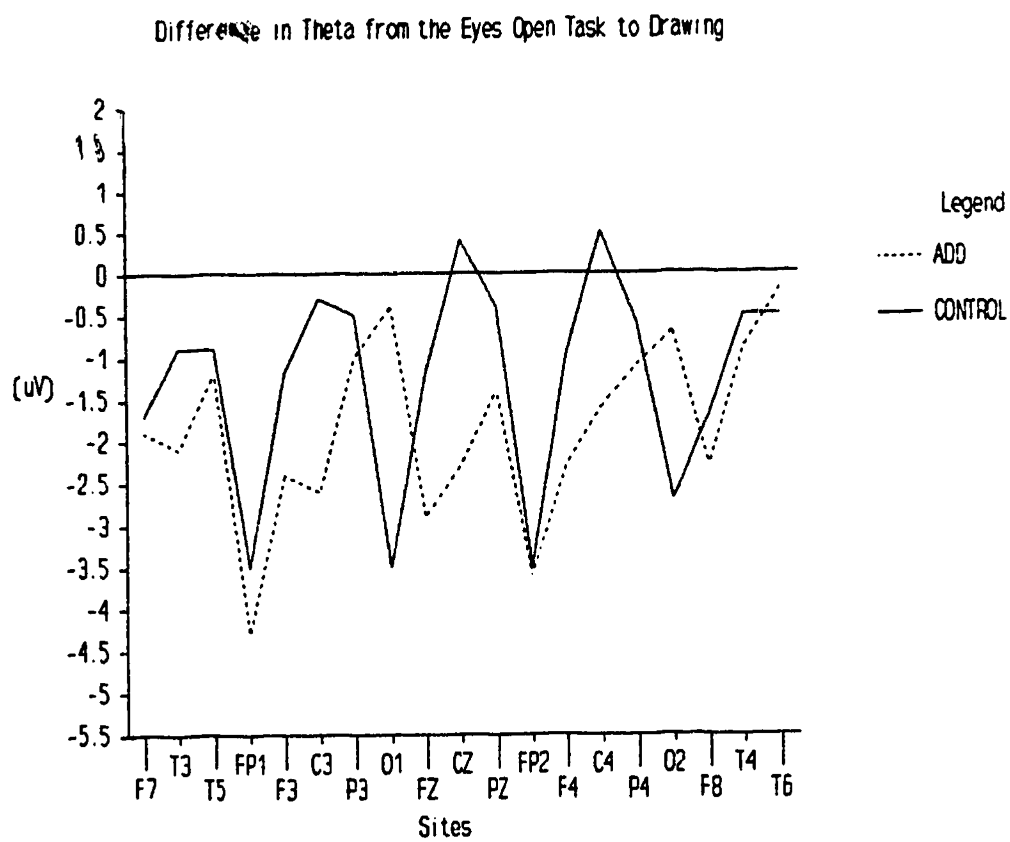


Figure 6 Negative values represent higher alpha magnitudes for the drawing task.

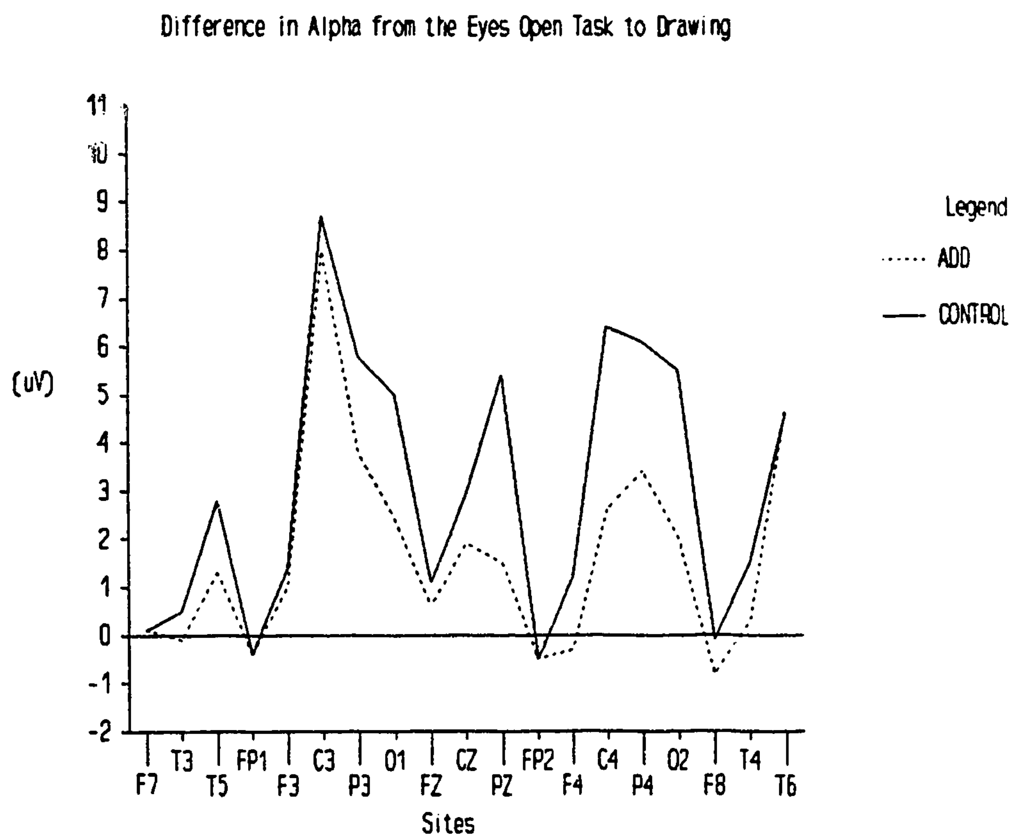


Figure 7 Negative values represent higher alpha magnitudes in the drawing condition.

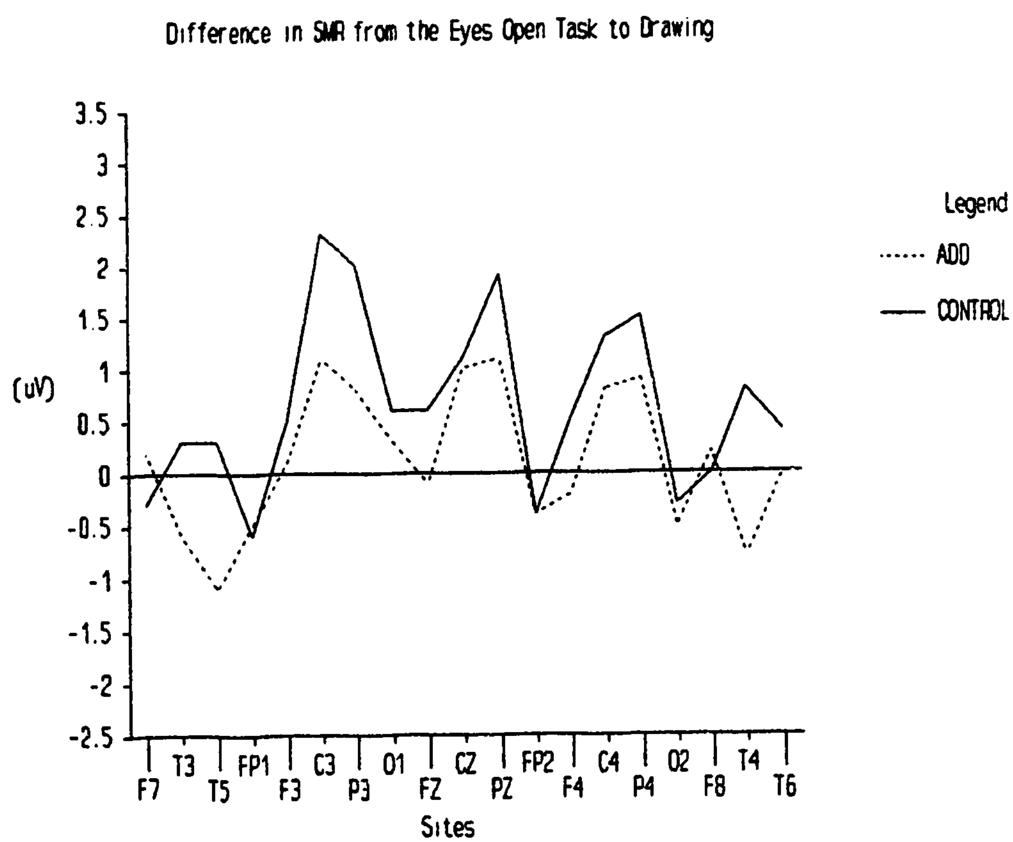


Figure 8 Negative values represent higher SMR magnitudes for the drawing task.

sites C3 and PZ had as much as 2 uV more SMR in the resting state than in the drawing task.

Changes in beta1 magnitudes from eyes open to drawing are presented in Figure 9. From this figure you can see that both groups tended to have higher magnitudes of beta1 while drawing. Also, changes in magnitude tended to be parallel in the two groups. Some points of divergence between the groups were at sites O1, O2 and T4. At O1 and O2, controls tended to shift towards higher beta1 in the drawing condition than ADD's. Conversely, ADD's shifted towards higher beta1 in site T4 than controls.

Eyes Open vs. Math

Changes in theta magnitudes from the eyes open state to the mathematics task are presented in Figure 10. From this figure it can be seen that both groups tend to shift towards higher theta magnitudes in the math task. However, the ADD group tended to shift towards even higher theta magnitudes than the controls.

Changes in the alpha band are presented in Figure 11. From this figure you can see that both groups tended to produce less alpha in the math condition than in the eyes open condition. This tendency to produce less alpha was especially strong in central and parietal sites for both groups. In general, controls were much better at suppressing alpha for the math task than ADD's.

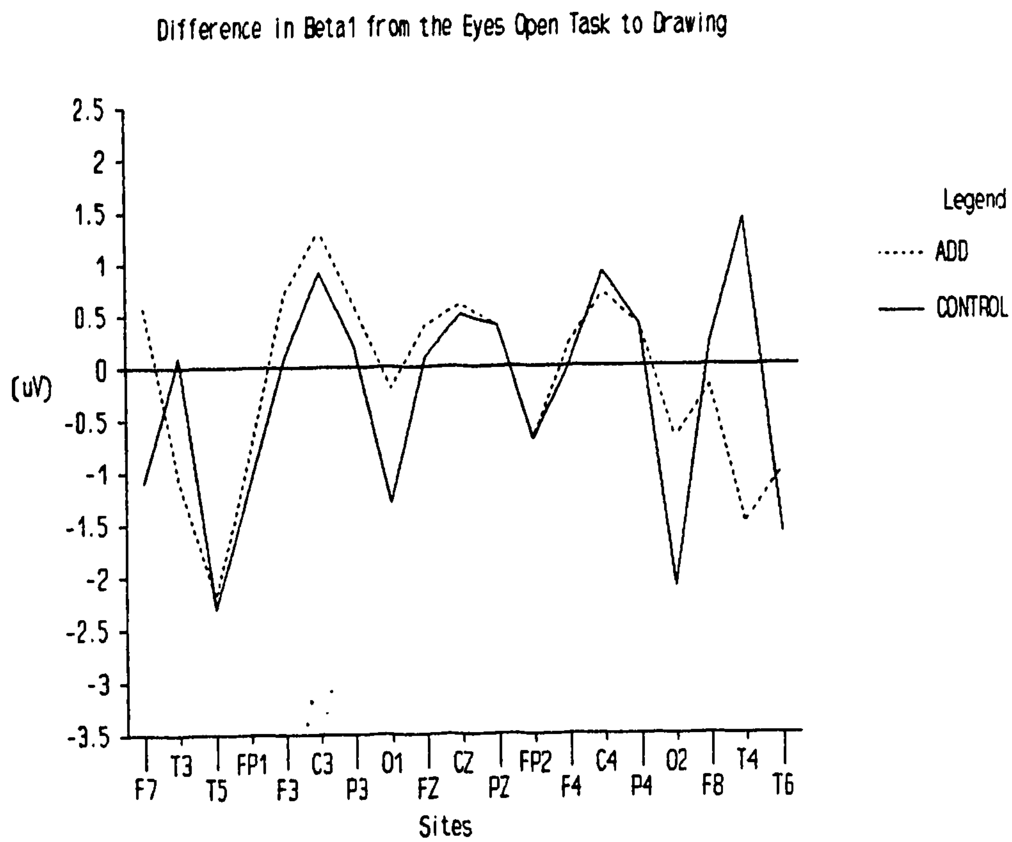


Figure 9 Negative values represent higher beta1 magnitudes in the drawing condition.

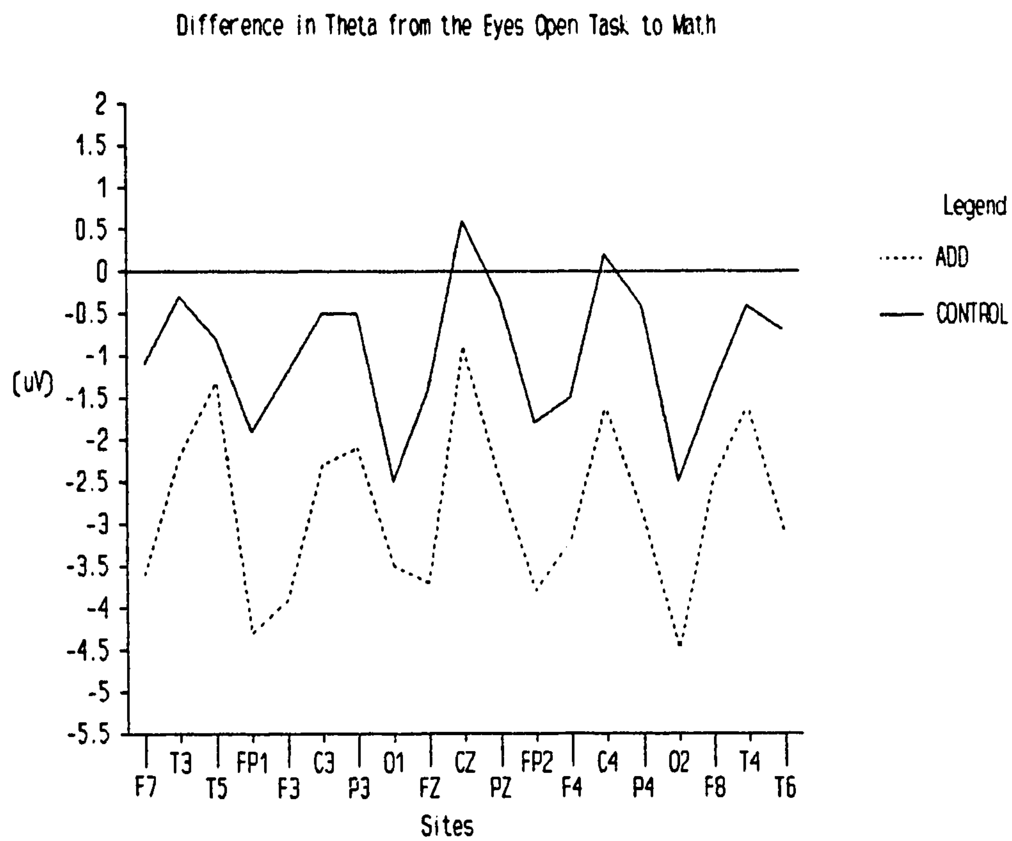


Figure 10 Negative values represent higher theta magnitudes for the math task.

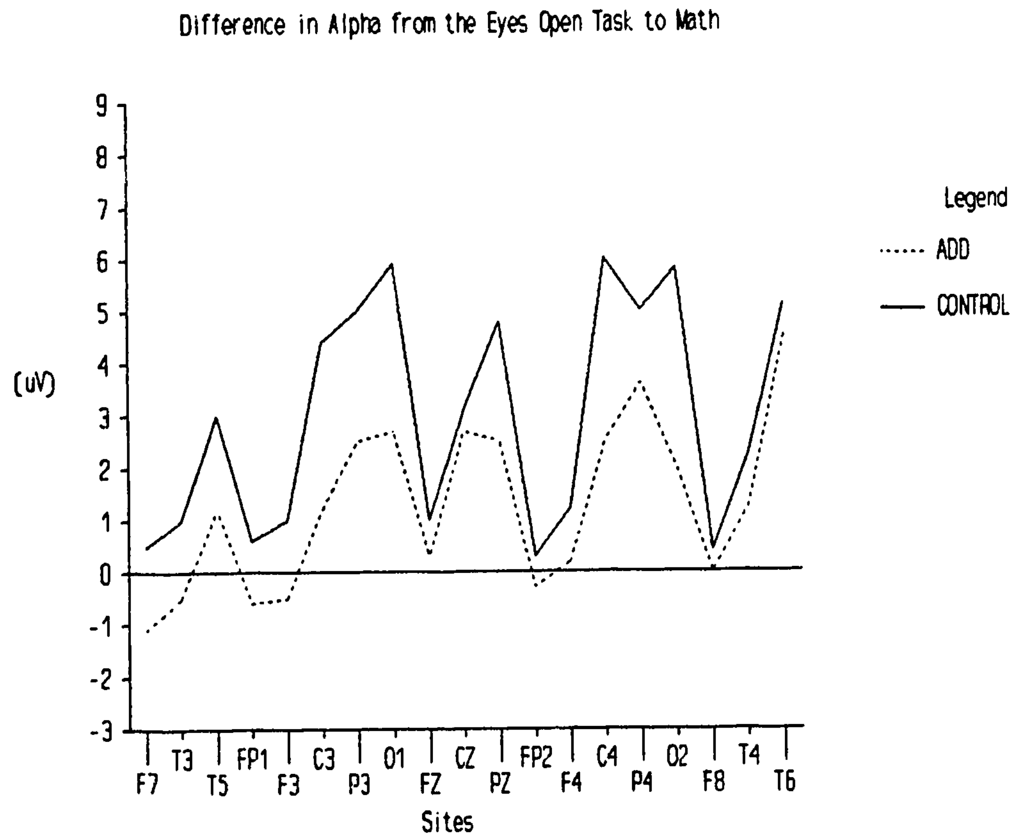


Figure 11 Negative values represent higher alpha magnitudes for the math task.

Figure 12. Interestingly, the pattern for SMR matched the pattern for theta and alpha. That is, the controls produced more SMR in the resting state than the ADD's but both groups had similar changes in magnitude.

Changes in magnitude in the beta1 band are presented in Figure 13. This figure shows that there was very little change from a resting state to the math task in the beta1 band. Also, both groups changed in almost identical ways. Only at T3 and T4 did the controls have higher resting beta1 magnitudes than ADD's.

<u>Eyes Open vs. Listening to a Story</u>

Changes in theta magnitudes from eyes open to listening are present in Figure 14. This figure shows a very similar pattern to that shown in figure 1. That is, the midline sites tended to show a greater shift to theta in the ADD group than the controls. Conversely, the controls shifted to larger magnitudes of theta in O1 and O2 than the ADD group. Both groups had higher magnitudes of theta in the listening to a story condition for all sites.

Changes in the alpha magnitudes are presented in Figure 15. From this figure it can be seen that both groups tended to suppress alpha in all sites. Thus, the magnitudes were larger for the eyes open state than for listening to a story in all sites. Controls appear to be better able to suppress

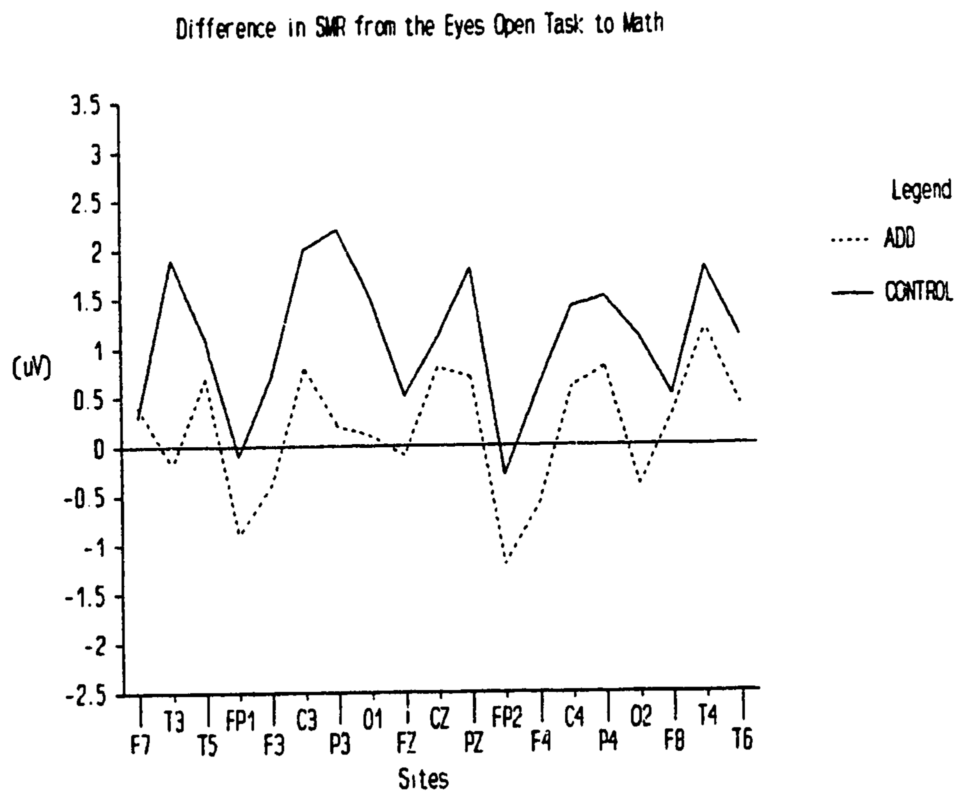


Figure 12 Negative values represent higher SMR magnitudes in the math condition.

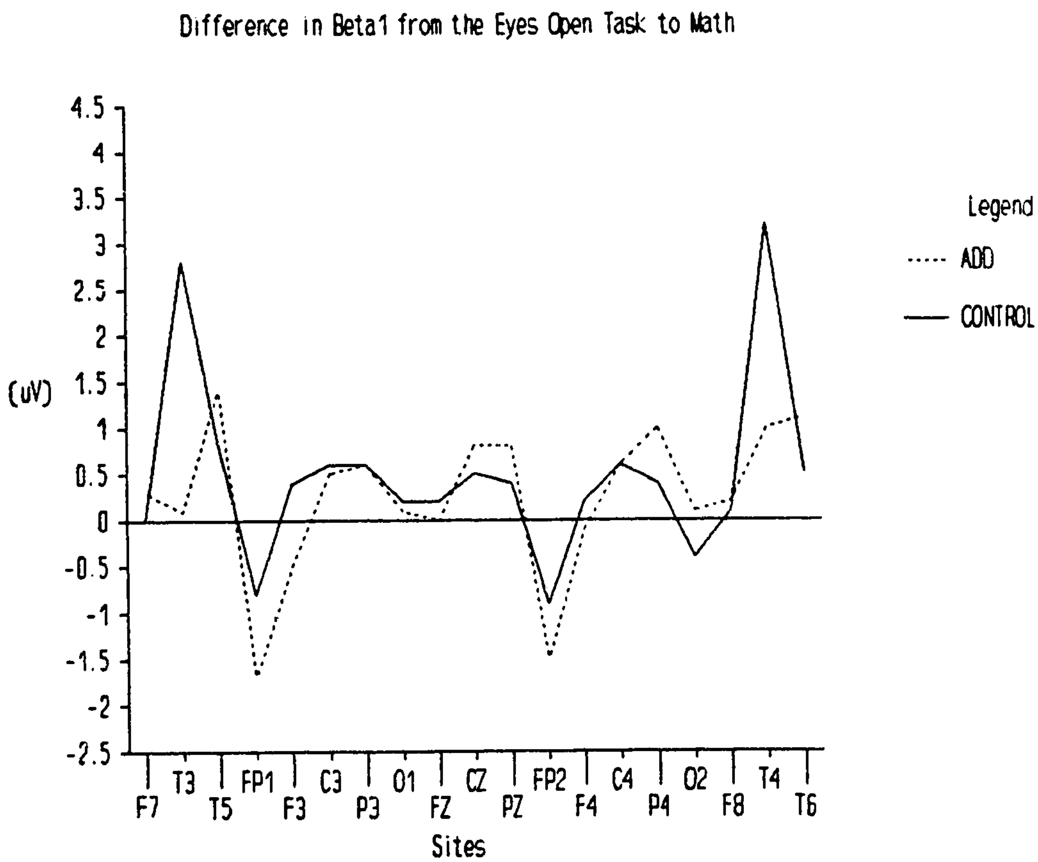


Figure 13 Negative values represent higher beta1 magnitudes for the math task.

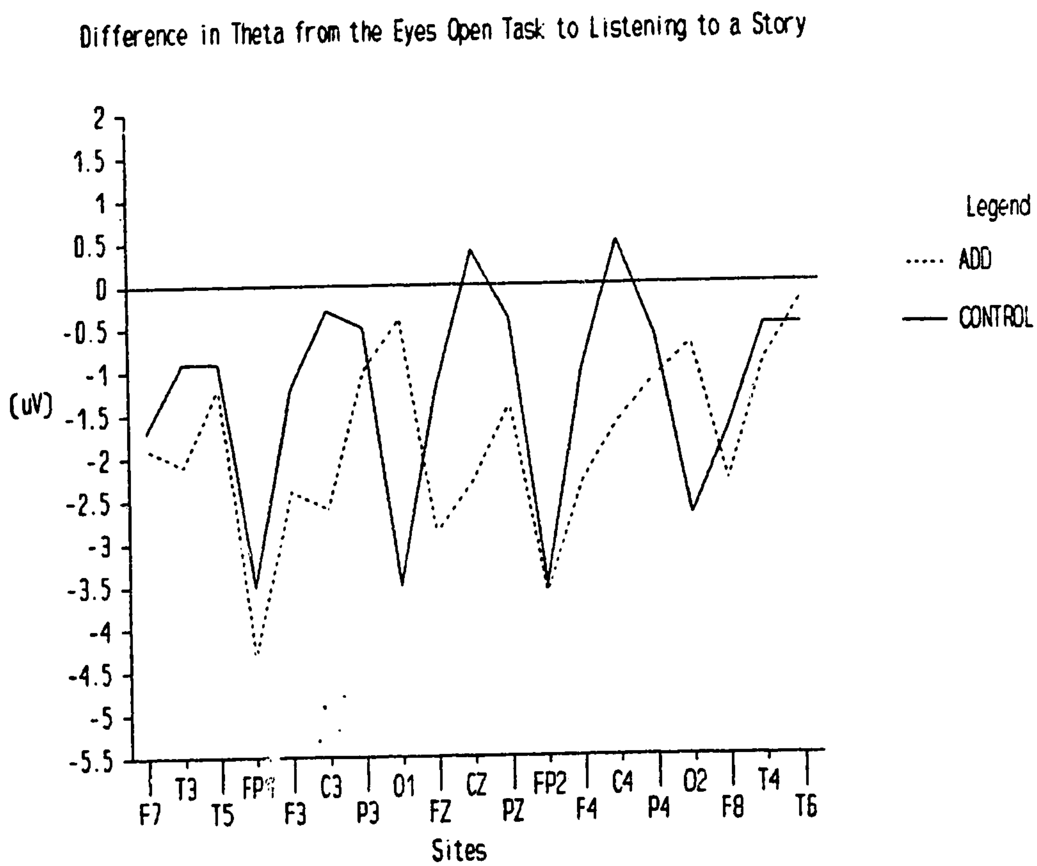


Figure 14 **Negative values represent higher theta magnitudes for the listening task.**

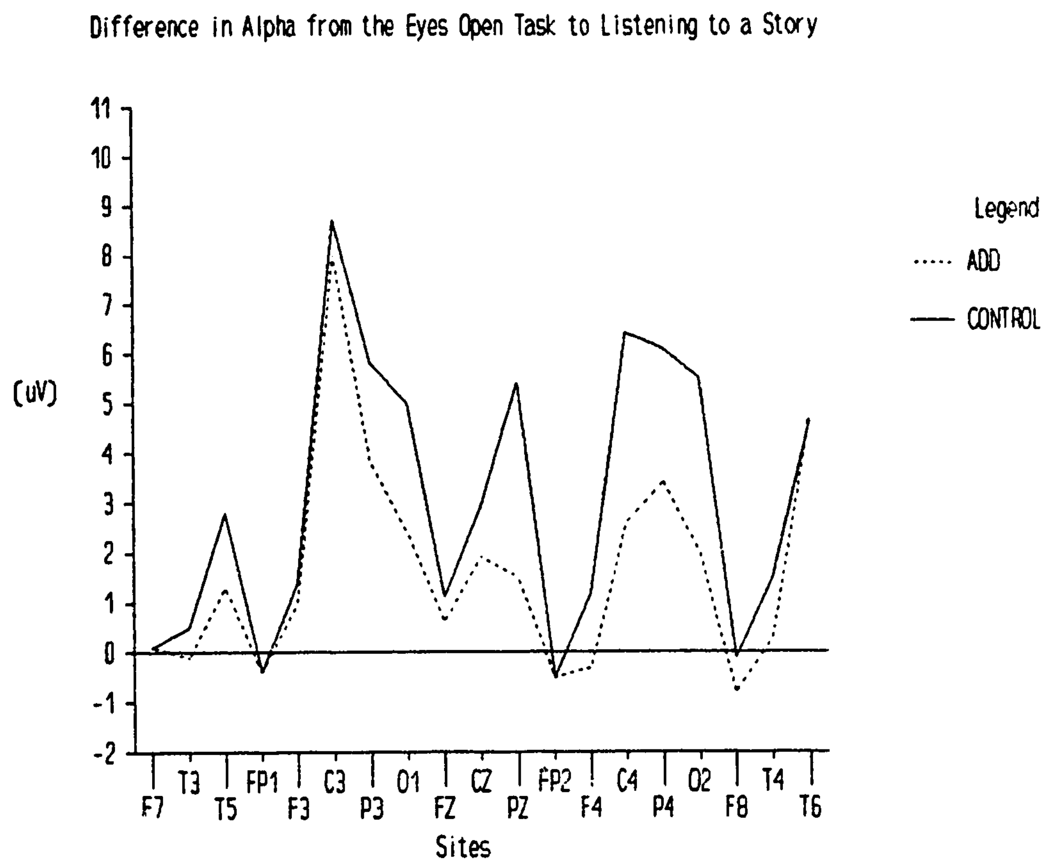


Figure 15 **Negative values represent higher alpha magnitudes for the listening task.**

alpha, especially at sites C4, P3, P4, O1 and O2.

Changes in SMR magnitudes from eyes open to listening are presented in Figure 16. This figure shows that both groups tended to have higher SMR magnitudes at rest than when listening to a story. Also controls tended to have even higher resting magnitudes than ADD's.

Changes in beta1 magnitudes are presented in Figure 17. From this figure you can see that both groups tended to shift in magnitude in the same way. However, controls tended to have slightly higher beta1 magnitudes while listening to a story in sites O1 and O2 than the ADD group. In general, both groups tended to have higher beta1 magnitudes while listening to a story.

Summary

In summary, there were several trends that were consistent when examining inter-task changes in magnitude. First, both groups tended to shift towards higher magnitudes of theta on-task than at rest. For the ADD group this shift was maximal in the midline sites. For the controls the shift to theta on-task was greatest at sites O1 and O2. Second, controls tended to have smaller magnitudes of alpha when performing tasks than when at rest. Further, controls suppressed alpha to a greater extent than ADD's in a majority of the sites. Third, changes in SMR magnitudes from rest to on-task were similar for both groups across the

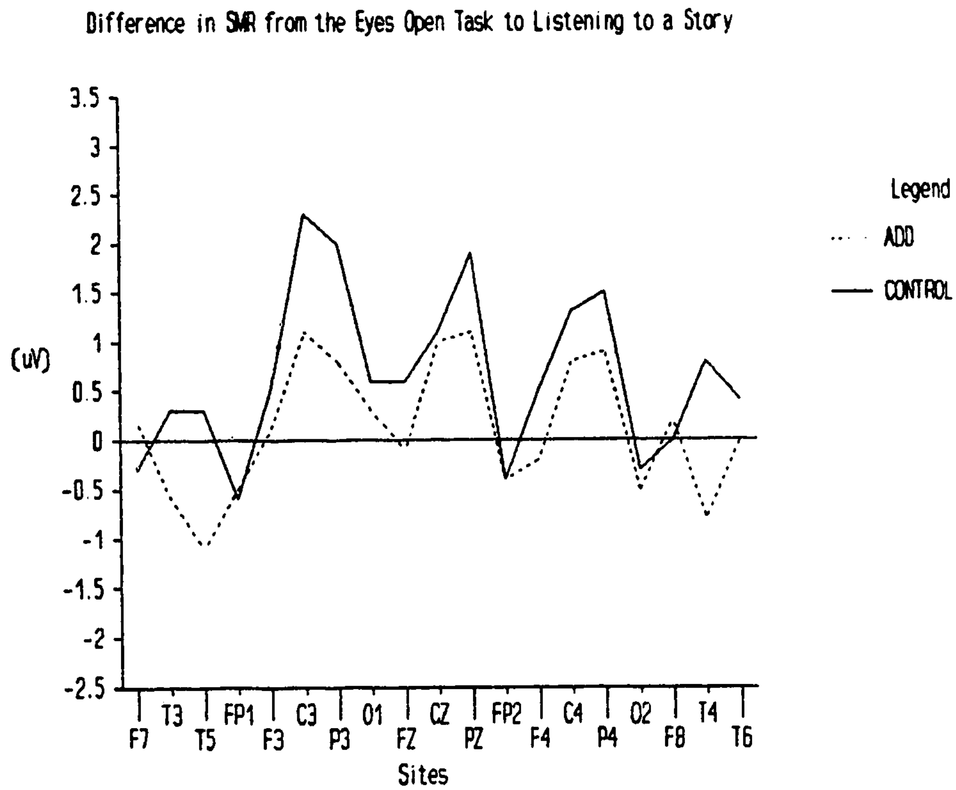


Figure 16 Negative values represent higher SMR magnitudes in the listening to a story condition.

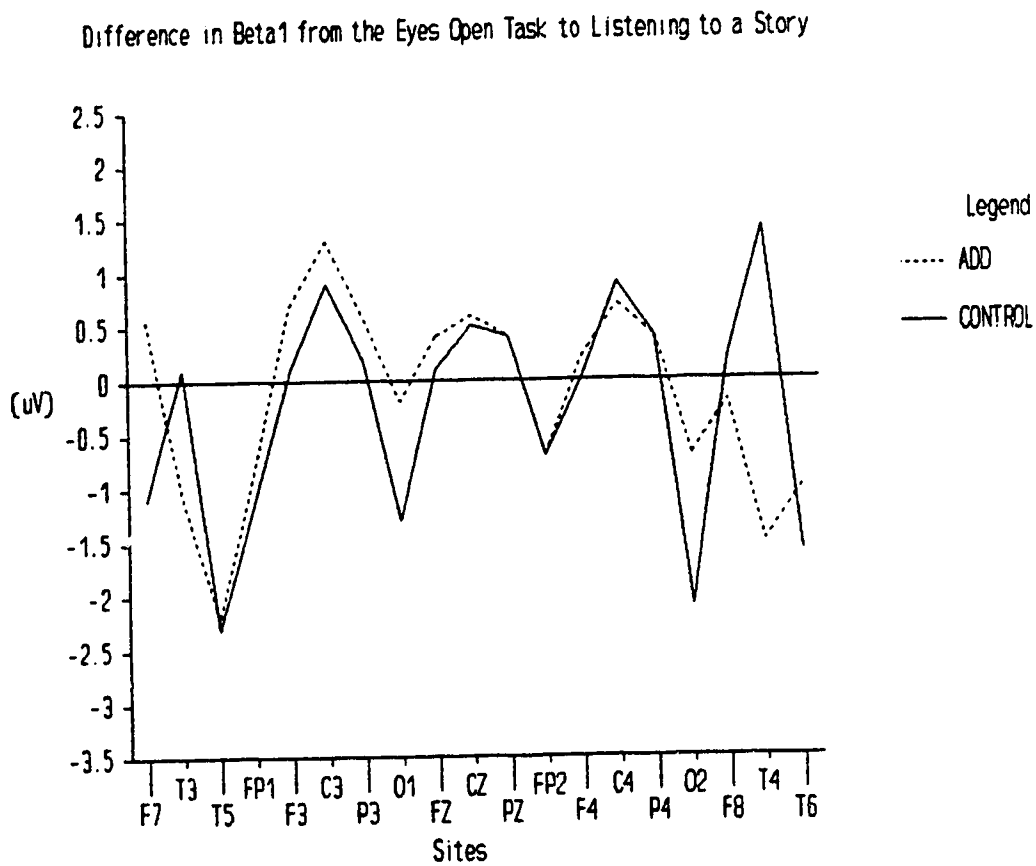


Figure 17 Negative values represent higher beta1 magnitudes for the listening task.

sites. For every task, both groups tended to have higher SMR magnitudes at rest than on-task. Lastly, changes in magnitude in the beta1 band were small for both groups. However, there was a trend to shift towards higher beta1 magnitudes for the drawing and listening to a story tasks in both groups.

CHAPTER 5

Discussion

Results of this study demonstrated that behaviorally different groups tend to have different EEG results on relative measures. While statistical tests of significance were not run the trends in the data were strong.

No known studies have reported relative power figures for on-task EEG's, therefore it is difficult to compare the present results. However, when comparing these results to those of Mann et. al. (in press) several consistencies were found. First, Mann et. al. found the most significant differences between the normals and ADHD children in the theta and beta1 bands, with the ADHD children having more relative power in the theta band and less in the beta1 band. Secondly, Mann et. al. found the most highly significant differences between the groups for the theta and beta1 bands were in the drawing task. These trends were also observed in the present study as the groups tended to have the largest differences in theta and beta1 for the drawing task. There were no other similarities between the present study and Mann et. al.'s study. This may have been due to the fact that Mann et. al. examined ADHD children while the present ADD sample did not display symptoms of hyperactivity. Also, Mann et. al. did not examine sites along the midline and the highest differences in the theta band were observed in the midline sites of FZ, CZ, and PZ in the present study.

From previous normative studies it has been reported that with increasing age, children tend to shift towards greater relative and absolute power in the faster bands (Gasser et. al. 1988). Also, the amplitudes of all the frequency bands tend to decrease with age, with the delta and theta bands decreasing at a faster rate than the beta bands (Matousek and Petersen, 1973). Satterfield (1973) suggested that children with minimal brain dysfunction may have a delayed central nervous system maturation. In the present study the ADD group tended to have greater power in the delta and theta bands with relatively lower power in the beta1 and beta2 bands. Also, the ADD group had higher overall amplitudes, with dominant, high amplitude delta and theta waves. This result suggests that the ADD group may have a developmentally younger EEG when compared to the controls of this study. Thus, the maturational lag theory may be supported by these results.

The ADD group tended to have the greatest shift to theta in the central sites. Also, the largest delta amplitudes and differences with the controls occurred at these central sites. Central locations have also been shown to be areas of decreased cerebral blood flow in ADD adults (Lou, Henriksen and Bruhn, 1984; Lou, Henriksen, Bruhn, Berner and Nielsen, 1989). Thus, it is possible that these diffuse amounts of delta and theta represent some striatal dysfunction in the ADD group.

The results from the present study have certain implications for the role of the various frequency bands while performing cognitive tasks. In the theta band, it was observed that the ADD group consistently had higher theta values than controls for all task/conditions. It was also observed that both groups tended to shift to larger amplitude theta waves when performing tasks. These two findings suggest that theta has an active role on-task, yet the precise nature of that role is unclear. Ray (1990) has pointed out that theta plays a role in visualization and imagery. Interestingly, the control group had the greatest shift to higher amplitude theta in the occipital bands for the reading and drawing tasks, which both involve visualization.

It has been suggested that the alpha band is related to attentional processes (Fuller, 1977; Ray, 1990; Ray and Cole, 1985). This suggestion has arisen from a number of studies where it was observed that alpha tended to be blocked when a subject was required to pay attention (Mulholland, 1974). In the present study, both groups appeared to attenuate alpha for a majority of the tasks. Further, it was observed that the control group was better able to attenuate alpha than the ADD group for all tasks. This is consistent with the findings of Fuller (1977, 1978).

The finding that SMR decreases in magnitude when going from a resting state to performing a cognitive task seems to be contrary to what most believe is its role. Most researchers would expect that the frequency ranges of 12 to 20 Hz reflect cortical activation (Ray, 1990). Thus, it seemed logical to assume that those sites which were actively involved in a task, should have produced more SMR and beta1 activity. However, the present study showed a shift to smaller magnitude waves in the frequency range of 12 to 16 Hz for all tasks and for a majority of the sites, and there was little change in magnitude in the beta1 band. One explanation for this may be in the nature of the EEG itself. That is, by nature the faster waves tend to be smaller in magnitude than the slower waves. Therefore, what might have occurred is that when faced with a cognitive task, subjects may have produced waves that were faster in frequency within the bandwidth of 12 to 20 Hz. This result would make SMR and beta magnitudes appear smaller on-task. Further analysis to determine if this is the case is warranted.

Conclusions

The primary objective of the present study was to carefully describe the nature of the EEG while performing various cognitive tasks in successful and attention disordered children. These results were intended to serve as an initial baseline estimate of the "on-task" EEG. While the sample sizes were small, it is believed that these results may be indicative of the EEG of 10 to 12 year old boys. Replication studies of a larger scale would be required to establish these results as normative.

The second primary objective of this study was to describe the two groups of children and to compare and contrast their on-task EEG's. The present study did show that the two groups had definite differences that were consistent throughout sites and tasks. Although no statistical tests of significance were performed, due to small sample sizes, the trends were strong and very visible.

Several conclusions can be drawn from the results of the present study. First, there are changes from the resting state to on-task conditions as reflected by the EEG. Further, these changes vary from task to task and tend to follow distinct patterns in the various frequency bands. The fact that the largest differences between the groups occurred on-task demonstrates the importance of examining differences between groups on-task.

A second conclusion is that the theta band appears to be the band that shows the most clear differences between ADD and successful children. Consistently and throughout all the tasks and sites, the ADD group had larger magnitude theta waves and larger relative theta power than controls. However, as statistical tests of significance were not run this conclusion must be regarded as tentative.

Implications

The implications of this study for EEG biofeedback training criteria are quite profound. Current clinicians who are training ADD and ADHD children are employing paradigms that involve decreasing theta and increasing beta or SMR production (Lubar, 1991). This study tends to confirm this paradigm as the two groups tended to differ in both the theta and beta bands in all sites and for all tasks. Individual variability and small sample sizes makes it impossible to definitively state any absolute criteria for training based on the present results.

Limitations

There are several limitations to the present study. First, with the small sample size of the present study no definitive normative statements can be made about either ADD children or successful achieving children. Secondly, not all task variables were controlled in the present study. That is, factors including task difficulty, fatigue, interest level of the subject, and recording non-task behaviors were not controlled for in the present study. All of these factors may be sources of variability within the

EEG record that need to be examined for their effects on the EEG. Lastly, no inferential statistics were performed on the neurometric data in this study. Therefore, the probability that the group differences found in this study are true can not be definitively stated.

Future Directions

The present study has several implications for future research in the area of EEG research. The whole area of dynamic EEG assessment has really just begun. This study is viewed as a first step towards understanding the nature of the EEG. The next logical step in the research is to conduct a larger scale normative study using on-task measures. Also, it should be possible to establish multi-site centers that could pool normative on-task EEG data.

Other avenues of EEG research that need to be explored include an intense investigation of the variables involved in measuring the EEG on-task. It is recognized that recording task behavior, averaged over time, may include a number of different neurological processes that get 'blurred' in the analysis. A carefully designed study might be able to control the different task variables to see if there are significant changes in the EEG during a single on-task recording.

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APPENDIX A

GENERAL INFORMATION AND HISTORY FORM

I. GENERAL INFORMATION

Child's Name: ______________________________
last first

Birthdate: ____________________ Sex: ____
year month day

Name of Parent(s) with whom the child resides:

Father: ______________________________
last first

Mother: ______________________________
last first

Address: ______________________________
Street or Box # City or Town Postal Code

Phone (home):__________ Phone (business):__________

PLEASE ANSWER AS BEST YOU CAN EACH OF THE FOLLOWING QUESTIONS ABOUT THIS CHILD'S BIRTH AND INFANCY.

I. BIRTH HISTORY

#1 Country of Birth: __________________
#2 City or Town of Birth:__________________
#3 Hospital of Birth:__________________
#4 Were the natural parents of this child related by blood in any way?
Don't know _____ Yes _____ No _____
#5 Natural mother's obstetrical history (mark X in all appropriate boxes).
A _____ have no knowledge of natural mother's history
B _____ had difficulty becoming pregnant with this child
C _____ have experienced miscarriage Number _____
D _____ have experienced still birth Number _____
#6 Natural mother's health during pregnancy with this child (Mark X in all appropriate boxes).
A _____ have no knowledge of natural mother's pregnancy
B _____ german measles during the first 3 months
C _____ high fever during the first 3 months

D _____ excessive vomiting during the first 3 months
E _____ uterine bleeding or "spotting" during first 3 months
F _____ high blood pressure
G _____ treatment for kidney problems
H _____ heart disease
I _____ chronic anemia
J _____ diabetes or suspected diabetes
K _____ surgery under general anaesthesia
L _____ thyroid disease
M _____ drugs and medication during pregnancy
N _____ toxemia
O _____ uterine bleeding or "spotting" during final 3 months
P _____ weight gain during pregnancy under 10 pounds
Q _____ weight gain during pregnancy over 30 pounds
R _____ induced labour
S _____ Other; Please Specify _______________

#7 Age of mother at the delivery of this child.
A _____ Don't know
B _____ under 16 years
C _____ 16 - 40 years
D _____ over 40 years

#8 Length of pregnancy with this child.
A _____ Don't know
B _____ 28 weeks or less
C _____ 29 - 32 weeks
D _____ 32 - 36 weeks
E _____ over 36 weeks (child was overdue)

#9 Length of labor with this child.
A _____ Don't know
B _____ less than 8 hours
C _____ 8 - 19 hours
D _____ longer than 19 hours

#10 Child's birth weight.
A _____ Don't know
B _____ less than 5.5 pounds
C _____ 5.5 - 8 pounds
D _____ more than 8 pounds

#11 Presentation at Birth.
A _____ Don't know
B _____ Normal
C _____ Breech
D _____ Other; Please Specify _______________

#12 Was the child born by caesarian section?
Don't know _____
Yes _____ Anticipated _____ Emergency _____
No _____

#13 Did birth cause any injury to this child?
A _____ Don't know
B _____ yes
C _____ no

#14 Is this child a twin?
A _____ Don't know
B _____ yes, 1st born
C _____ yes, 2nd born
D _____ no

#15 Family history of illness (please mark X for all these which have been experienced by any of this child's blood relatives).
A _____ Don't know
B _____ early blindness
C _____ squint
D _____ early deafness
E _____ diabetes before age 40
F _____ mental retardation
G _____ mental illness
H _____ heart attacks before age 40
I _____ Others; Please Specify ______________________

#16 Child's first week of life.
A _____ Don't know circumstances of birth
B _____ baby placed in special nursery in hospital
C _____ baby stayed in hospital after mother went home
D _____ baby had breathing problems
E _____ baby given oxygen
F _____ baby jaundiced
G _____ baby given blood transfusion
H _____ baby had difficulty sucking
I _____ baby born with congenital abnormality or handicap
J _____ baby suffered convulsions while in hospital
K _____ baby had no serious problems
L _____ Others; Please Specify ______________________

#17 Was this child breast-fed?
A _____ Don't know
B _____ Yes How long? _____ Weeks
C _____ No

#18 Weaning
A _____ Don't know
B _____ no problem finding a suitable formula
C _____ tried several formulas D _____ weaned to a cup

#19 Appearance of child during first few weeks after birth.
A _____ Don't know
B _____ normal appearance; healthy
C _____ pale, delicate looking
D _____ Others; Please Specify ______________________

#20 In infancy, did this child reach out to prepare himself to be picked up when mother approached him?

A _____ Don't know
B _____ Yes
C _____ No

#21 At what age did this child first sit unsupported (sitting at least 1 minute without using his arms to support him)?

A _____ Don't know
B _____ before 5 months
C _____ 5 - 8 months
D _____ after 8 months

#22 At what age did the child first walk unsupported (at least 10 steps)?

A _____ Don't know
B _____ before 11 months
C _____ 11 - 15 months
D _____ after 15 months

#23 At what age did the child begin to use words in a meaningful way?

A _____ Don't know
B _____ was using word by 1 years
C _____ by 1 1/2 years
D _____ by 2 years
E _____ by 2 1/2 years
F _____ after 2 1/2 years

#24 At what age did the child begin putting 2 words together?

A _____ don't know
B _____ by 1 1/2 years
C _____ by 2 years
D _____ by 2 1/2 years
E _____ by 3 years
F _____ after 3 years

#25 At what age did the child begin using short sentences?

A _____ Don't know
B _____ by 1 1/2 years
C _____ by 2 years
D _____ by 2 1/2 years
E _____ by 3 years
F _____ after 3 years

II. HISTORY OF ILLNESS

#26 Please check all of these which the child has experienced.

A _____ mumps
B _____ german measles
C _____ red measles
D _____ chicken pox
E _____ scarlet fever
F _____ whooping cough

G _____ chest problems
H _____ heart trouble
I _____ allergies; unusual reactions to vaccinations
J _____ disorders requiring surgery
K _____ meningitis or encephalitis
L _____ poliomyelitis
M _____ serious head injury with loss of consciousness
N _____ convulsions/seizures
O _____ fainting
P _____ accidental poisoning
Q _____ failure to thrive
R _____ sleep disturbances
S _____ hospital admissions. How many _____.
T _____ Others; Please Specify ____________________

#27 Has this child received regular immunization shots and vaccinations?
A _____ Don't know
B _____ Yes
C _____ No

#28 Does this child have any serious or chronic health problems at present?
No _____
Yes _____
If yes, please describe. (please print)____________________

#29 Is this child taking any medication on a regular basis at present?
No _____
Yes _____
If yes, please describe. (please print)____________________

#30 Has this child been hospitalized, or undergone surgery where general anaesthesia was given?
No _____
Yes _____ Number of hospitalizations _____
If Yes, please describe. (please print)____________________

III. DEVELOPMENTAL DISORDERS

#31 Has this child had any difficulty with the following (mark X on any that apply)?

A _____ speech/articulation problems
B _____ language difficulties
C _____ memory problems
D _____ motor clumsiness
E _____ enuresis
F _____ psychological trauma
G _____ Others; Please Specify ________________________

#32 Would you say your child has difficulty sustaining attention?

No _____
Yes _____

#33 Does this child display hyperactive behaviors?

A _____ most of the time
B _____ some of the time
C _____ rarely

IV. Emotional Functioning

#34 Please check items which best describe this child's emotional functioning at this time.

A _____ seems generally happy and has fun
B _____ cries easily
C _____ oversensitive to criticism
D _____ worries excessively
E _____ has extreme fears/frightens easily
F _____ seems frequently sad/unhappy
G _____ appears tense/nervous
H _____ handles ups and downs easily
I _____ seems to be inhibited or bottles things up
J _____ expresses anger
K _____ Others; If you wish to elaborate or add to any of the above please do so in the space provided ____
____
____
____

#35 Please check items which best describe this child's personal relationships.

A _____ gets along well with other children in a group
B _____ relates well to children one on one
C _____ has difficulty relating with other children
D _____ is often aggressive or teases others
E _____ has few friends

F _____ has many friends
G _____ can share things easily
H _____ is frequently getting into fights
I _____ bosses other children around
J _____ gets picked on by other children
K _____ seems to enjoy helping others
L _____ relates well to adults
M _____ has difficulty relating to adults
Other please describe. ____

Please write down any additional concerns/comments you may have regarding this child. ____

THANK YOU FOR TAKING THE TIME TO FILL OUT THIS QUESTIONNAIRE. PLEASE BE ASSURED THAT ALL OF THE INFORMATION CONTAINED WITHIN THIS FORM WILL BE HELD IN THE STRICTEST CONFIDENCE.