Topographic Mapping of the Brain Activity of Gifted Children

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ABSTRACT

The study compared the brain electrical activity of two groups of gifted children between the ages of 9 and 13 years. The electroencephalogram (EEG) was recorded with eyes closed: "at rest" and during three simple cognitive tasks. Significant differences were found in absolute power in the resting state EEG between the gifted high achievers and non-gifted, age-matched peers. No significant differences were found between the gifted underachievers and age-matched peers. Significant differences were found in absolute and relative power during the word recognition task compared to the resting EEG. No significant differences were found in the comparisons of the topographic maps for the other cognitive tasks and the resting EEG. Results suggest that topographic mapping of brain activity may provide an educational method for discriminating among children of different cognitive abilities. Implications for education are discussed and suggestions for further research are given.

RESUME

Cette étude compare l'activité électrique cérébrale de deux groupes d'enfants surdoués de 9 à 13 ans. Pendant les électroencéphalogrammes (EEG), les sujets était «au repos», les yeux fermés, ou occupés à exécuter trois tâches cognitives simples. Des différences significatives ont été observées en termes de pouvoir absolu dans l'EEG réalisé au repos chez des enfants surdoués très performants et chez leurs pairs non doués du même âge. Aucune différence significative n'a été observée entre les surdoués peu performants et le groupe témoin. Des différences significatives, par rapport à l'EEG au repos, ont été observées en termes de pouvoir absolu et de pouvoir relatif pendant l'exécution de la tâche de reconnaissance de mots. Aucune différence significatives n'a été observée entre les cartes topographiques des autres tâches cognitives et l'EEG au repos. Les résultats semblent indiquer que la cartographie topographique de l'activité cérébrale est une méthode qui permet d'établir des distinctions entre des enfants présentant des aptitudes cognitives différentes. Les conséquences de ces résultats pour l'éducation sont analysées tandis ques des suggestions sont formulées quant à la suite à donner à ces travaux.

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I don't know if you have ever seen a map of a person's mind. Doctors sometimes draw maps of other parts of you, and your own map can become intensely interesting, but catch them trying to draw a map of a child's mind, which is not only confused, but keeps going round all the time.

- J. M. Barrie, ***Peter Pan***

In 1929, Austrian psychiatrist Hans Berger discovered that by placing electrodes on the scalp, it was possible to record electrical brain activity to create an electroencephalogram (EEG). The term electroencephalogram means "electrical brain writing" (Springer & Deutsch, 1985).

Since Berger's discovery, the EEG and various types of brain evoked potentials (EPs) (the brain's transient response to stimulation) have been used as diagnostic and prognostic tools for identifying assumed structural abnormalities (c.f. Nuwer, 1988a, 1988b). However, these tools have only recently been applied to understanding differing states of neuronal organization in learning disorders and dyslexia, and have yet to be applied effectively to understanding what may underlie variances in performance and intellect.

The availability of computer-based, signal analysis algorithms and their use in quantifying electroencephalography may provide the analytic flexibility necessary to approach these tasks. Quantified electrophysiology refers to the computer-based acquisition, display, storage, and analysis of EEG and/or evoked potentials (Zappulla, 1991). Developments in quantified electrophysiology have added reliability and precision to studies which explore relationships between EEG indices and different types of cognitive and behavioral disorders in children (Robinson, 1989).

A number of studies have examined the electrophysiological activity associated with certain aspects of cognitive functioning. Results of studies on attention, (Davidson, Schwartz & Rothman, 1976; Harter & Previc, 1978; Okita, 1989), linguistic processing (Bentin, McCarthy & Wood, 1985; Grabow, Aronson, Greene & Offord, 1979; Kraft, Mitchell, Languis & Wheatley, 1980), and spatial ability (Papanicolaou, Schmidt, Moore & Eisenberg, 1983) have suggested that different cognitive activities yield different brain activity profiles.

Studies of hemispheric EEG asymmetries have shown lateralization of activity in the left hemisphere corresponding to verbal and mental arithmetic tasks, while right hemisphere engagement appeared to be related to spatial tasks (Doyle, Ornstein & Galin, 1974; Galin, Johnstone & Herron, 1978; Galin & Ornstein, 1972; Osaka, 1984). In addition, Osaka (1984) and Galin et al. (1978) found significant shifts in frequency relative to task difficulty, with greater shifts occurring with increasing task difficulty.

With the advent of quantitative electrophysiology and topographic brain mapping, some attention has been given to understanding brain function in children with reading disability. This field is not without controversy. For example, Duffy, Denckla, Bartels, and Sandini (1980), and John et al. (1983) reported that specific dyslexia with positive family history can be discriminated. However, Fein et al. (1986) and Yingling, Galin, Fein, Peltzman, and Davenport (1986) failed to replicate these results. In fact, they were unable to significantly discriminate between pure dyslexics and age-matched controls.

Attention to the distinctions between normal and learning impaired children can be found in studies by Harter, Anllo-Vento, and Wood (1989), John et al. (1989), Lubar et al. (1985), Satterfield, Schell, Nicholas, and Backs (1988), Sutton, Whitton, Topa, and Moldofsky (1986), and Thatcher, McAlaster, Lester, Horst, and Cantor (1983). Only a handful of studies examined the differences between normal, gifted, and gifted learning disabled children. Such comparisons can be found in studies by Chen and Buckley (1988), Kappers (1990), Robinson (1989), and Thatcher et al. (1983).

Some advocates of intelligence testing argue that intelligence tests measure some general all-around innate ability. With the discovery of the EEG there arose the prospect of direct measurement of this characteristic (Gale & Edwards, 1983). Early attempts to correlate psychometric intelligence with EEG yielded inconsistent results. Knott, Friedman, and Bardsley (1942) and Mundy-Castle (1958) found evidence of a relationship between psychometric intelligence and EEG, while others (Gastaut, 1960; Shagass, 1946) found no such relationship. More recently, however, Blinkhorn and Hendrickson (1982), Haier, Robinson, and Braden (1983), and Hendrickson and Hendrickson (1980) obtained significant correlations between EP amplitude and intelligence.

Robinson (1989) has suggested that the study of human intelligence must ultimately involve the study of brain processes. He also argued that inconsistent findings in previous EEG/intelligence studies may have originated partly from an expectation of simple linear relationships where relationships are likely to be curvilinear. However, Gale and Edwards (1983) maintained that the simple correlational studies which yielded such inconsistent results simply did not go far enough. They suggested that research in this field should combine the study of intelligence as a trait with research on information processing.

Any consideration of information processing requires a discussion of memory. Memory is influenced by a variety of cognitive processes, and in turn plays a major role in a number of complex cognitive tasks. Because of its interactions with other processing skills, memory represents a characteristic upon which children with differing cognitive skills and intelligence may be differentiated. There is some evidence that learning disabled children employ inefficient strategies on memory tasks (Bauer, 1979; Torgesen, 1977, 1980) while intellectually gifted children are more effective in their use of certain memory strategies than those of average ability (Robinson & Kingsley, 1979). There is also evidence that the most severe memory problems of learning disabled children are limited to verbal tasks (Liberman, Mann, Shankweiler & Werfelman, 1982; Vellutino, Pruzek, Steger & Meshoulam, 1973). Torgesen, Kistner, and Morgan (1987) suggest that variations in performance which require recall, such as memory-span tasks, may be a result of difficulty in phonological coding of verbal information.

Auditory tasks which examine recognition memory skills and which can be applied to subjects who are essentially motorically passive, lend themselves to inclusion in studies examining the relationship between EEG measures and cognitive functioning. Such passive tasks can be performed during the collection of EEG data where movement tends to disrupt the procedures by introducing non-EEG artifact. The passive nature of the task allows subjects to be compared to themselves at rest in various controlled circumstances.

The evidence supporting the correlation of behavioral, neurobehavioral, and neurophysiological performance with that of EEG and EP parameters, although extensive, is not sufficiently detailed for specific populations and particular problem areas. Few studies, for example, have examined differences between gifted children and non-gifted children. These groups of children, traditionally classified by verbal ability, school performance, and standard tests of achievement, have been assumed to have differently organized central nervous systems.

This study proposes to examine the brain function of two special populations of children while at rest and during three simple cognitive tasks. The specific groups of interest are a sample of non-clinical gifted high achievers and a sample of clinical gifted underachievers. For the purpose of this study, brain function refers to the electro-cortical activity as measured by the computer enhanced, quantified electroencephalogram (QEEG).

The purpose of this study, then, is to compare the spectral characteristics of the EEG of two different groups of gifted children to determine whether QEEG can be used to discriminate between these particular groups of children. In addition, comparisons will be made to ascertain whether differences emerge when performance on cognitive tasks are compared.

2. REVIEW OF THE LITERATURE

Attempting to understand how the mind/brain works is a goal shared by neuroscience and cognitive science (Churchland & Sejnowski, 1988). Coles (1989) suggested that the potential benefits of a marriage between cognitive psychology and psychophysiology are in the possibility of using psychophysiological measures as markers for psychological and physiological events, providing "windows" on the mind and "windows" on the brain.

It is well accepted that the brain is responsible for learning and thinking, yet until recently understanding of covert mental activity has been inferred on the basis of performance on cognitive tasks (Languis & Wittrock, 1986). Due to the development of new experimental techniques in mathematics there is a renewal in brain theory in which the brain is seen as a dynamic system: observation and measurement of behaviorally related information of the brain provides the basis for assessing its dynamic operations. (Freeman & Maurer, 1989).

Electroencephalography

The field of electroencephalography is based on the assumption that the measurement and observation of cortical electrical activity at the surface of the scalp when taken in conjunction with measures of behavior will provide us with information about how the brain works, and how it malfunctions during disordered states of behavior (Freeman & Maurer, 1989).

The Electroencephalogram

The electrical activity of the brain results in various electrical potentials. It has been postulated that these potentials are due to the polarizing effects of the neurons in the brain (Brown, Maxfield, & Moraff, 1973). By placing electrodes in various locations on the scalp, it is possible to record this activity. The EEG records variations of electrical activity in the brain. An EEG is actually a record of the electrical potential differences between pairs of electrodes placed on the scalp over time (Spehlmann, 1981).

The EEG is polyrhythmic and is made up of different frequencies of electrical activity. A number of recognizable brain rhythms have been identified and are characterized by periods where specific waveforms can be observed. The EEG frequency spectrum contains four major frequency bands: delta, theta, alpha, and beta. Delta is characterized by relatively large rhythmic waves of about 0.4 -3.6 Hz. Hertz (Hz) is a measure of the frequency of electrical activity. Theta waves are in the 4 - 7.6 Hz range, while alpha is in the 8 - 13 Hz range. When the peak frequency is above 13 Hz, an individual is producing beta waves.

The International (10-20) System of Electrode Placement

In order to ensure a certain degree of reliability in the recording of the EEG, a standard system of electrode placement has been adopted. The International (10-20) electrode placement system details the location of electrodes over the entire scalp (Jasper, 1958). The system, adopted in Paris in 1949, is called 10-20 because the electrodes are spaced 10% or 20% of the total distance between two standard skull landmarks, the *inion* (the indentation where the nose meets the forehead) and the *nasion* (the small bump at the back of the head just above the neck) (see Appendix A). The standardization of the placement of electrodes provides increased reliability of recordings, both between recording sessions, as well as among different laboratories (Harner & Sannit, 1974).

EEG Activity in Normal Children and Adults

The frequency composition of the EEG changes with age and functional state of the brain. As an individual matures, the dominant frequency becomes more rapid. Brain dysfunction, and brain damage or deterioration may be reflected in a slowing of the frequency in the regions involved (Ahn et al. 1980; John et al. 1980).

The posterior dominant rhythm of the EEG shows the most prominent differences between children and adults. In the normal adult the predominant rhythm in EEG records is 8 - 13 Hz alpha. Alpha seems to reflect a resting brain state. Alpha activity usually decreases following arousal, attention, or involvement in a task. The alpha rhythm is most prominent when a subject's eyes are closed and is attenuated when the subject attends to external or internal stimuli (Lairy, 1976).

In children, the posterior dominant rhythm is slower and of higher amplitude. In children younger than eight, this rhythm may have a frequency of less than 8 Hz, the lower limit of the alpha band. However the gradual increase in the frequency of this occipital rhythm to reach a frequency within the 8 - 9 Hz range (alpha frequency) by age eight or nine leads to its conventional recognition as alpha.

Theta activity in the frontocentral and central regions is quite common in normal children. This activity has been called the characteristic waves of youth (Duffy, Iyer, & Surwillo, 1989). Persistence beyond puberty, especially in the temporal and frontotemporal regions is often associated with behavioral abnormalities.

Conventional Electroencephalography

Conventional techniques for recording and interpreting EEG records pose certain problems due to the complexity of brain function (Stern, Ray, & Davis, 1980). Interpretation of conventional EEG records is performed through visual inspection. This requires that the individual interpreting the record recognize patterns which are associated with normal functioning or pathological conditions (Cooper, Osselton, & Shaw, 1980). There are some disadvantages in using such traditional methods. Many disorders show similar abnormalities in the EEG record, and interpretations may differ for the same record (Monroe, 1969; Struve, Becka, Green, & Howard, 1975; Woody, 1966, 1968). The reliability of interpretations has been demonstrated to be dependant on and influenced by factors such as experience, training, judgement, perceptual ability, state of alertness, fatigue during the interpretive task, clinical frame of reference, as well as a comprehension of the recording principles (Struve et al., 1975).

Cumulative clinical evidence with this method has provided a robust tool for the diagnosis of a number of diseases of the brain. However, the crudeness of the analytic methods has severely limited the utility of EEG for studying variations in function of the structurally normal brain.

Quantified Electrophysiology

Quantified electrophysiology refers to the computer-based acquisition, display, storage, and analysis of EEG and/or evoked potentials. Computer-assisted EEG signal analysis provides a more precise and reproducible examination of EEG features than does visual examination. Quantified electroencephalography (QEEG) is a consistent way of examining the EEG signal, eliminating potential inter- and intra-reader variability. This procedure makes features of the EEG available for statistical analysis, and provides a variety of EEG display techniques (Fisch, 1991). Quantified electrophysiology has increased the reliability and precision of EEG studies of cognitive and behavioral disorders in children and adults (Robinson, 1989).

QEEG (or neurometrics) most frequently employs a frequency (or spectral) analysis to break down the complex patterns of the EEG into its different frequency components. Thus it is possible to determine the amplitude or voltage of the EEG in each of the frequency bands. Amplitude is usually expressed in microvolts (μV) (one millionth of a volt). This method of analysis is known as the fast Fourier transform (FFT) and is based on the Fourier series analysis (Duffy, Iyer, & Surwillo, 1989).

The FFT is a mathematical technique which facilitates the analysis of signals in the frequency domain (Cochran et al. 1967; Yoganathan, Gupta, & Corcoran, 1976). This method, described by Cooley and Tukey (1965), was designed to reduce the number of computations required in Fourier analysis.

The FFT results in a series of amplitudes for the different frequency components of the EEG for the entire EEG recording. When these amplitudes are expressed as mean square values, the resulting plot of the data is called a power spectrum (Cooper, Osselton, & Shaw, 1980). When the amplitude of each component is expressed in terms of its mean square value, it is possible to determine the proportion of the analyzed waveform which is attributable to each particular frequency (Duffy, Iyer, & Surwillo, 1989).

Artifact

One problem inherent in all electrophysiological recording is that of artifact. Artifacts are distortions in the desired signal and depending on their source can be classified into different types: instrumental, environmental, electrical, and physiological. The main types of physiological artifacts are caused by muscle activity in the forehead, eye and head movements, heart rate activity, galvanic skin resistance, and brain wave "spikes" or irregular, slow wave activity (Peffer, 1983). Through the use of band-pass filters, it is possible to eliminate some of the artifactual signals by rejecting certain frequencies (Ciarcia 1988a, 1988b), but many require human pattern recognition skills.

The accuracy of the spectral analysis is affected by the amount of continuous, artifact-free EEG available (Zappulla, 1991). The longer the period of EEG the greater the probability of artifact. A solution to this problem is to break up the record into a series of epochs or short segments (between 2 and 3 seconds). Thus is it possible to reject those segments of EEG which contain artifact from the EEG record prior to analysis. (This process is agrammatically referred to as "artifacting".)

It should be noted that in addition to traditional EEG artifacts from eye movement, muscle tension, etc., the analytic and display algorithms of the computer create a number of new problems related to the selection of recording montages, number of electrodes, and length of the recording (Nuwer, 1988a; Cohn, Staton, & Myers, 1987; Hooshmand, Director, Beckner, & Radfar, 1987).

Topographic Mapping of Brain Electrical Activity

One of the more useful features of quantified electrophysiology is the ability to convert the raw EEG from the time domain to the frequency domain and to represent the distribution of the activity in two-dimensional, color, topographic maps (Zappulla, 1991; Wong, 1991). Topographic mapping provides a method of quantifying aspects of the EEG which might not be observable on visual inspection of the raw EEG (Duffy, Burchfiel, & Lombroso, 1979).

Many clinicians agree that the information provided by topographic brain maps complements the diagnostic information available from conventional EEG (Hooshmand, Beckner, & Radfar, 1989; Duffy, 1989). Jerrett & Corsak, (1988) found that topographic mapping of the EEG was better at detecting low amplitude, slow waves and provided better localization of abnormalities than other neuroimaging techniques (e.g. computerized tomography (CT) or magnetic resonance imaging (MRI)) in 30% of patients with abnormal EEG maps. However, particularly in clinical situations, topographic mapping is unable to show some of the more subtle abnormalities, and thus should not replace the standard EEG (Hooshmand et al., 1989; Coburn & Moreno, 1988).

Electroencephalography and the Study of Cognitive Function

Since the EEG is a continuous measure over time and requires no overt response from a subject, it can be used to study ongoing activity in the brain while subjects perform long and complex tasks. Because the EEG activity is recorded from symmetrical positions on either side of the head, one of the earliest applications to the study of normal cognitive function was to associate the amount of EEG activity occurring in the hemispheres with the type of task in which the subject is involved (Galin & Ornstein, 1972).

EEG and Performance

Although EEG changes during performance of "mental" tasks have been reported over the past five decades, there is still no clear understanding of the relationship between EEG patterns and higher cortical functions (Gevins & Schaffer, 1980).

A study examining the interhemispheric correlation of EEG activity during successful and unsuccessful performance of a cognitive task was conducted by Corsci-Cabrera, Gutierrez, Ramos, and Arce (1988). The EEG activity of eight male volunteers was recorded during an initial baseline and during performance of three cognitive tasks: one verbal, one spatial, and one mixed requiring both verbal and spatial processing. Interhemispheric correlation of the EEG activity was compared between successful and unsuccessful trials as well as among tasks. No differences were found among tasks. However there was increased interhemispheric correlation in beta activity during unsuccessful trials compared with baseline recordings. The results suggest that interhemispheric correlation may reflect success or failure in the cognitive tasks

In a study of the frequency analysis of hemispheric EEG asymmetries during the performance of cognitive tasks (Doyle, Ornstein, & Galin, 1974), it was postulated that language and arithmetic tasks would engage primarily the left hemisphere, while spatial and musical tasks would engage primarily the right hemisphere. The results showed that the ratios of power (right/left) from homologous leads (i.e. each lead compared to its corresponding lead in the opposite hemisphere) were significantly higher primarily in the alpha band for verbal and arithmetic tasks than for spatial tasks. This effect was also found in the beta and theta bands, though not as consistently, and no significant effects were found in the delta band.

Galin, Johnstone, and Herron (1978) found higher alpha power and higher right/left ratios as task difficulty increased. Subjects were required to complete a series of block designs of increasing complexity as well as reading and writing tasks. Significant differences were found among subjects. Some subjects showed increases in alpha power only in the left hemisphere while in others increases were only on the right. The right/left ratios of alpha activity were significantly lower for the block design task than for the writing task, regardless of difficulty.

Osaka (1984) also found a hemispheric effect when subjects were engaged in arithmetic and visuo-spatial tasks. Although the peak alpha frequency of the power spectrum increased during both arithmetic and visuo-spatial tasks, the increase was found in the left hemisphere during arithmetic tasks and in the right hemisphere during the visuo-spatial tasks. The shift was found to be greater as task difficulty increased.

Rugg and Dickens (1982) recorded EEGs while subjects were at rest and while performing a verbal and a visuo-spatial task. They found significantly lower alpha power during performance of both tasks compared to the rest condition. No differences were found between tasks or between hemispheres. They also found significantly higher theta power in the right hemisphere during task performance. Theta power was higher during the visuo-spatial task than the verbal task.

In an investigation children's hemispheric processing during the performance of Piagetian conservation and reading tasks (Kraft, Mitchell, Languis, & Wheatley, 1980), greater right-hemispheric processing was found during encoding of information, while greater left-hemispheric processing was found during retrieval and verbal/logical expression of the information.

Loring, and Sheer (1984) investigated lateralization of the 40 Hz EEG rhythm during the performance of verbal analogy and geometric figure rotation tasks. Significant lateralization of 40 Hz EEG activity in the left hemisphere was found during baseline recordings and the verbal task.

EEG and Memory

Studies examining the relationship of brain functioning and short-term memory, memory scanning, and recognition memory have primarily been conducted using an EP paradigm. Pratt, Michalewski, Barrett, and Starr (1989a) studied evoked potential responses during a memory scanning task in a group of normal young subjects using verbal (digits) and non-verbal (musical notes) stimuli. Subjects were required to memorize sets of items and identify whether a presented probe stimulus belonged to or did not belong to a memorized set. Pratt et al. found that the amplitudes and latencies of the EPs varied with the number of items in the memorized set and that amplitudes were correlated with reaction time.

In an extension of this study with older subjects, Pratt, Michalewski, Patterson, and Starr (1989b) found that reaction times for the younger subjects were faster than the older subjects for each of the stimulus types and for different item set sizes, whereas latency measures accompanying the evoked potentials were similar for both age groups. As a result, they suggested that the effects of aging on short-term memory are primarily on response selection and not on memory-scanning processes.

Studies examining EPs and recognition memory have shown that potentials evoked during the initial presentation of words which are averaged on the successful retrieval of the words in a test of memory differ from those which are not (Johnson, Pfefferbaum, & Kopell, 1985; Karis, Fabiani, & Donchin, 1984; Paller, Kutas, & Mayes, 1987). It has also been shown that EPs elicited by the successful recognition of 'old' words are significantly different from EPs elicited by the successful rejection of 'new' words (Johnson et al., 1985; Karis et al., 1984; Neville, Kutas, Chesney, & Schmidt, 1986).

These findings were supported by Rugg and Nagy (1989) who examined the evoked potentials of subjects as they performed recognition memory tasks. Using word lists, subjects were required to make an "old/new" discrimination for each word. Significant effects were found when comparing the potentials to 'old' words with those to 'new' words. However, they also found that accuracy of responses to the probes influenced the number of significant effects which decreased when controlled for guessing.

Wijers, Otten, Feenstra, Mulder, and Mulder (1989) measured EPs in a task that combined the classic selective attention ('odd-ball') paradigm with memory search and mental rotation paradigms. Subjects were instructed to attend to stimulus letters in one color and to ignore those in a different color while attempting to detect target letters from a memorized set and indicating whether were presented normally or in mirror-image. The results demonstrated that there was no significant effect of the presentation of the target letters, nor were there any differences associated with the color of the letters. However, significant differences were found between target and non-target stimuli.

Rugg and Nagy (1989) suggested that EPs represent only a subset of the processes underlying retrieval from memory. Little attention has been given to the underlying EEG activity during the performance of memory tasks, specifically those dealing with recognition and/or verbal memory. Neuropsychological and electrophysiological evidence suggests that there is some degree of cerebral localization related to specific types of processing (Sattler, 1988).

Stigsby, Risberg, and Ingvar (1977) recorded the EEG in normal subjects under four conditions: an auditory memory test, 'auditory rest' (white noise), a visual reasoning task, and 'visual rest' (watching black dot on white screen). A comparison of auditory rest to auditory memory showed increased amplitude in the alpha, theta, and delta bands in the frontal region. Decreases in alpha activity were found during the auditory test in the frontal, temporal, and occipital regions, but only in the occipital region during the visual task.

Early studies have shown localized, transient attenuation of the rhythmic alpha and/or beta activity following sensory perception or motor behavior in conscious human subjects (Jasper & Andrews, 1938; Jasper & Penfield, 1949).

EEG and Special Populations

Another area in which research efforts have concentrated is in the application of quantified electrophysiology to the identification of individuals who suffer from certain disorders such as Alzheimer's disease (Coben, Chi, Snyder, & Storandt, 1990; Mody, McIntyre, Miller, Altman, & Read,1988) and some psychiatric disorders (Garber, Weilburg, Duffy, & Manschreck, 1989; Williamson & Kaye, 1989).

Other researchers turned their attention to special populations. Cantor, Thatcher, Hrybyk, and Kaye (1986) found that autistic children had significantly more slow wave activity, less alpha activity, and less inter- and intrahemispheric asymmetry than normal or mentally handicapped children. Gasser, Mocks, Lenard, Bacher, and Verleger (1983) found that the spectral parameters of the EEG differentiated a group of mildly retarded children and an age matched control group in the bands and leads of developmental relevance.

In addition to studies of dyslexia (Duffy et al., 1980; Fein et al., 1986; Lycklama a Nijeholt, van Drongelen, & Hilhorst, 1989), some attention has been focused on the ability of quantified electrophysiology to identify learning disabled children (Kaye, John, Ahn, & Prichep, 1981; John et al., 1985 ; John et al., 1989). Fein et al. (1983) suggested that the reliability of both absolute and relative power support the use of the EEG power spectra as an index of brain function for studies of normal and learning disabled children.

Significant EEG power percent differences for certain frequencies were found between a group of learning disabled children without hyperactivity and an age-matched control group during baseline and while performing reading, arithmetical, and spatial tasks (Lubar et al., 1985).

Fuller (1977, 1978) found that learning disabled boys showed less alpha attenuation than the normal control boys in EEG power spectra during resting intervals, while listening to instructions on tape, and during active performance of mental arithmetic and immediate recall.

A study of disabled and normal readers (Schucard, Cummins, & McGee, 1984) revealed significantly lower amplitude right hemisphere auditory EPs during tasks that involved visual-phonemic transfer of information. There were significantly higher amplitude left hemisphere responses during the visual-phonemic task compared with normal readers.

Sutton et al. (1986) found statistically significant inter-group differences between learning disabled and non-learning disabled children demonstrating greater inter-regional, stimulus dependent EP synchrony in the learning disabled group. They argued that these findings provided support for the notion that in some cases learning disabilities may reflect altered connections among selected brain regions.

Satterfied and Braley (1977) demonstrated that certain independent EP components showed abnormal changes with maturation in hyperactive children, and suggested that these changes may reflect abnormal development.

The Gifted

In all cultures and historical periods, some individuals have been identified as gifted because they exhibited talents that were not evident in the majority of people (Horowitz & O'Brien, 1985). According to Lyon (1981), the gifted are a minority distinguished by their exceptional ability. Despite this, psychologists and educators have yet to reach agreement on a universal definition of giftedness. This creates problems when attempting to identify those children who should be in special programs provided for the gifted. In fact, it is one's definition of giftedness which determines the nature of the research questions asked, the research methodology employed, and the specific characteristics of the sample (Horowitz & O'Brien, 1985; Passow, 1981; Renzulli, 1978).

Gifted individuals can be found at all ages and grade levels and while the definition of giftedness depends on the specific situation, in general, giftedness is characterized by above average intellectual ability or potential which may be accompanied by superior academic achievement and creative capability (Lewis & Doorlag, 1991; Renzulli, 1978).

It is Terman who perhaps more than any other researcher is responsible for shaping the perceptions of the gifted in this century (Yarborough & Johnson, 1983). In his landmark study, Terman (1925) demonstrated that not only were gifted children superior in intellect, but they were better adjusted and healthier than their non-gifted peers. His sample of 1,500 children is still the most studied group of gifted individuals in the world (Lewis & Doorlag, 1991). Terman's conception of giftedness was based on his assumption of a direct relationship between giftedness and intellectual activity and his belief that standardized intelligence testing was the ideal method for identifying this giftedness (Yarborough & Johnson, 1983).

In considering the question of whether or not high IQ alone, as a measured by standard tests of intelligence, should be used to identify individuals as gifted, there arises the issue of what intelligence tests actually measure. The first tests of intelligence were constructed to identify those children who lacked the abilities to benefit from classroom teaching (Howe, 1990). Current tests of intelligence have developed from these original tests, however there is still some question as to how effective they are at measuring intelligence (Sternberg, 1984).

A significant component of intelligence involves the ability of individuals to acquire and assimilate novel concepts and conceptual systems and apply their current knowledge to these systems (Sternberg 1982, 1985). IQ as measured by tests of intelligence is not a robust measure of an individual's everyday functioning (Sattler, 1988; Howe, 1990). Due to personality and motivational factors, there are variations in social competence and expression of talent even among individuals with the same IQ (Zigler & Faber, 1985). IQ scores have been found to provide a good measure of how well a child will do in school (Howe, 1990), and therefore, may provide a measure of learning ability and academic potential.

There is some dissatisfaction with the use of IQ scores for identifying gifted children (Horowitz & O'Brien, 1986; Birch, 1984; Kirschenbaum, 1983). Some researchers maintain that the definition of intellectual giftedness should not be based on specific IQ score but rather on an individual's ability to retrieve information rapidly, and to effectively organize and synthesize knowledge (Sternberg, 1985; Rabinowitz & Glaser, 1985). While it is argued that the identification of the gifted should be an ongoing process, based on multiple criteria (Renzulli, 1978; Shore, Cornell, Robinson, & Ward, 1991), intellectual ability as reflected by standard IQ scores continues to be a major consideration in the identification of gifted individuals (Alvino, McDonnel, & Richert, 1981; Lewis & Doorlag, 1991).

Studies have indicated that the gifted have better social skills, are more mature, and are more self-confident and self-controlled (Hogan & Weiss, 1974; Hogan, Viernstein, McGinn, Daurio, & Bohannon, 1977). Gifted children are quick and logical thinkers, are developmentally advanced in language and thought (Davis & Rimm, 1985), and have high motivation or persistence (Passow, 1981; Franks & Dolan, 1982).

In memory scanning, high IQ children were found to be faster than average children (Keating & Bobbit, 1978), and were not as greatly affected by set size. It has been suggested that such efficiency in processing information may directly contribute to superior intelligence (Spiegel & Bryant, 1978). Lajoie and

Shore (1986) found that while gifted children were not always the fastest in mental processing, they were found to spend more time in planning solutions.

Foster (1986) argued that giftedness may be the result of precocious development as opposed to superior ability. Basically, the argument is that high IQ children develop at an earlier age the same intellectual strategies and knowledge as older children (Kanevsky, 1990). Indeed, Scruggs and Cohn (1983) found that the performance of gifted children was similar to that of university undergraduates in a paired-associate learning task. However, Kanevsky (1990), in study of problem solving, demonstrated that differences in performance were the result of factors related to learning and problem solving strategies associated with intellectual ability and could not be solely attributed to precocious development. This difference in strategy was also noted by Maniatis (1983) who found variations in the editing strategies used during Logo programming between gifted and non-gifted groups of children.

Underachieving Gifted

It is possible to be intellectually gifted and still face learning problems (Lewis & Doorlag, 1991). There is a subgroup of gifted children who have great difficulty in school performance despite their high level of intelligence. The causes of underachievement are many and include such factors as motivation, developmental delays, and environmental influences (e.g. socio-economic status, isolated rural settings, cultural minorities) which may not encourage the development of intellectual potential (Whitmore, 1980). Dowdall and Colangelo (1982) point out that the underlying theme of most definitions of underachieving gifted is the existence of a discrepancy between these individuals' potential and their performance.

Because of their high intellectual ability, this group is often overlooked and the special problems that they pose have not been adequately addressed. Part of the difficulty appears to lie in the identification of these individuals (Sattler, 1988).

Learning Disabled Gifted

Although it may be argued that the learning disabled gifted and underachieving gifted are two different populations, Berk (1983) maintains that because of ambiguities in the definition of giftedness and the emergence of the discrepancy between ability and performance as a primary consideration in their identification learning disabilities has become a category of underachievement. This view is in fact supported by research evidence (Kirk & Elkins, 1975; Ysseldyke, Algozzine, Shinn, & McGue, 1982). Whitmore (1980) also suggested that specific learning disabilities as well as general or specific deficits in academic skills are factors which contribute to underachievement in gifted children.

Learning disabled gifted individuals demonstrate good communication skills and are much like their gifted peers in their abstract thinking and creative abilities (Baum, 1984; Suter & Wolf, 1987). There is evidence that the learning disabled often show weaknesses in memory skills which may result in poor performance in the areas of reading, writing, or mathematics (Baum, 1984; Ganschow, 1985).

EEG and Intelligence

As previously stated, early studies which attempted to correlate psychometric intelligence with EEG measures yielded inconsistent results. More recently, however, the focus has shifted to examining specific spectral characteristics of the EEG and their correlation with IQ as well as the relationship between the concept of neural efficiency and IQ.

Corning, Steffy, and Chaprin (1982) found that children who exhibited excess slow frequency activity had low verbal and normal performance subtest scores, while those with the least slow frequency activity were above normal on verbal and performance scores. Gasser, Von Lucadou-Muller, Verleger, and Bacher (1983) correlated the spectral parameters of the EEG with IQ and found higher alpha frequency was related to high IQ scores,and that there were no significant differences in correlations between the left and right hemispheres with IQ.

Schafer (1982) argued that although neuroscience has yet to identify a validated biological determinant of behavioral intelligence, that differences in certain aspects of neural function should relate to individual differences in intelligence. The results of his study indicated that a high level of neural adaptability as indexed by the temporal expectancy effect on auditory EPs positively correlated with high IQ, suggesting that this might provide a biological determinant of intelligence. In fact, AEP shift and IQ were found to indicate a kind of adaptive flexibility of intellectual functioning (Shucard & Horn, 1973).

EEG Studies of the Gifted

There are few EEG studies which examine differences between gifted children and non-gifted children. Thatcher, McAlaster, Lester, Horst, and Cantor (1983) explored the relationship between certain EEG measures and cognitive functioning in children. Their specific focus was the extent to which measures of asymmetry and coherence were related to cognitive ability as measured by standard psychometric tests. The subjects, aged 5-16 years, were classified into five academic groups on the basis of their WISC-R and WRAT test scores. These groups were identified as gifted, normal, borderline normal, low achievers, and very low achievers.

Thatcher, et al. (1983) found significant inverse relationships between coherence and full scale IQ scores (i.e. coherence decreased as full scale IQ increased). Additionally, they found that more right hemisphere coherence variables were related to full scale IQ than left hemisphere variables, and that fewer intrahemispheric and more interhemispheric relationships were found. Results of the analyses on amplitude asymmetry demonstrated significant positive relationships. They also found that regardless of which hemisphere displayed the greatest amplitude, the greater the asymmetry between the two hemispheres, the higher the full scale IQ.

Their results also clearly showed significant differences in coherence and amplitude asymmetry among the different academic groups. Coherence was found to increase from the gifted group to the very low achievers group, and asymmetry tended to be higher in the gifted group than other academic groups.

Kappers (1990) explored the use of neuropsychological treatment for a high gifted, eight-year-old, dyslexic boy. Prior to beginning the treatment program the subject was tested and shown to be below normal level in reading words, text reading, and spelling. In addition, the Brain Electrical Activity Mapping (BEAM) results of the cognitive evoked potential (P300) demonstrated asymmetries between the two hemisphere with greater activity in the left hemisphere than the right and a delayed latency. The cognitive evoked potential is a technique which records the evoked potential (EP) to irrelevant sensory stimuli during the performance of various cognitive tasks. The assumption is that the probe-evoked responses will reflect the allocation of processing resources to the primary task (Halgren, 1990). Following a year of treatment designed to stimulate right hemisphere processing and improve reading performance, test results indicated that word reading was higher than normal for the subject's age group and text reading had improved to near normal level. The BEAM results indicated an increase in right hemisphere processing with the resulting maps showing a normal symmetrical distribution over both hemispheres, and a normal latency (Kappers, 1990).

In a theoretical paper, Chen and Buckley (1988) reviewed some of the research correlating intelligence and EEG measures as well as other related studies. They suggested that the behaviors of electrical brain activity and their related hierarchy of higher cortical functions can be incorporated into the function of a non-linear complex system using the properties of chaos modelling. They postulated that by applying the study of dynamic determinism to the investigation of neural activities of the human brain, the "strange attractors" in the cerebral correlates or cognitive processing in the gifted will be discovered.

Summary of the Chapter

This chapter presented a summary of the relevant literature in the areas of electrophysiology, quantified electrophysiology and their application to the study of cognitive function. Research examining the relationship between electrophysiological measures and performance on cognitive tasks and psychometric intelligence was also discussed. The application of this technique for the identification of special populations of individuals was explored, with particular reference to the gifted.

3. RESEARCH METHODOLOGY

Statement of the Problem

This study is concerned with the following questions: What are the differences in the spectral characteristics of the EEG of special populations of children? Can QEEG be used to discriminate between these particular groups of children? What differences emerge between tasks and between subjects when performance on different tasks are compared?

The purpose of this study is to compare the brain function of two special populations of children, specifically a non-clinical population of gifted high achievers and a clinical population of gifted underachievers. Comparisons will be made of brain activity both at rest and while involved in simple cognitive tasks. For the purpose of this study, brain function refers to the electro-cortical activity as measured by QEEG.

EEG and the Study of the Gifted

Freeman and Maurer (1989) have suggested that the measurement and observation of the EEG when taken in conjunction with measures of behavior will provide us with information about how the brain works. Although some studies have found significant correlations between psychometric tests of intelligence and

EEG activity (Corning, Steffy, & Chaprin, 1982; Haier, Robinson, & Braden, 1983) there is still some question as to whether these tests actually measure some general innate ability (Gale & Edwards, 1983).

This argument is not confined to the field of psychophysiology. There is some controversy as to whether high IQ alone should be used to identify individuals as gifted (Birch, 1984; Renzulli, 1978).

Studies have indicated that gifted children are quick and logical thinkers, are developmentally advanced in language and thought (Davis & Rimm, 1985), have high motivation or persistence (Franks & Dolan, 1982; Passow, 1981), and faster than average children in memory scanning (Keating & Bobbit, 1978).

Much like their gifted peers, gifted learning disabled individuals demonstrate good communication skills, as well as abstract thinking and creative abilities (Baum, 1984; Suter & Wolf, 1987). However, there is evidence that the gifted learning disabled often show weaknesses in memory skills (Baum, 1984; Ganschow, 1985).

Although these groups of individuals are identified on the basis of psychometric test scores, they are assumed to have differently organized central nervous systems. The few studies which explored electrophysiology and giftedness provide evidence to suggest that there are differences between non-gifted, gifted, and gifted learning disabled individuals (Kappers, 1990; Thatcher et al., :983). Based on this evidence it is proposed that the following hypotheses be tested.

Hypothesis 1:

> Gifted non-clinical subjects will manifest differences in the spectral characteristics of their resting EEG compared with age-matched, medically healthy, non-gifted peers.

Hypothesis 2:

> Gifted clinical subjects will manifest differences in the spectral characteristics of their resting EEG compared with age-matched, medically healthy, non-gifted peers.

Hypothesis 3:

> The differences found between the spectral characteristics of gifted non-clinical subjects and gifted clinical subjects compared to age-matched non-gifted peers will be similar.

Cerebral Localization

The concept of cerebral localization was first proposed by Franz Gall who suggested that the brain was not a "uniform mass" and that certain mental functions could be localized to specific regions (Springer & Deutsch, i989). In most individuals, the left hemisphere is involved in processing language (Krashen, 1977). Traditionally, the left hemisphere is primarily responsible for verbal functions such as verbal sequencing and verbal learning and memory, speech, spelling, reading, writing, and certain kinds of tasks that require linear or sequential organization of information (Krashen, 1977; Sattler, 1988). Left hemisphere processing has been characterized as analytic, sequential, serial, and differential (Bogen, 1977).

The right hemisphere, often referred to as the minor hemisphere (Nebes, 1977), is involved in non-verbal, perceptual, and spatial functions. The functions include spatial visualization, visual learning and memory, complex visual motor organization, and non-verbal sequencing (Nebes, 1977; Sattler, 1988). Right hemisphere processing is considered holistic, gestalt-like, parallel, and integrative (Gazzaniga, 1977; Nebes, 1977).

Each of the hemispheres is subdivided into four regions each associated with different functions. Frontal lobe function is typically associated with planning, initiation, regulation of behavior, and expressive verbal fluency. The temporal lobes are involved in auditory perception, auditory comprehension, and learning and memory. The parietal lobes are associated with somatosensory functions and visual-spatial ability, while the occipital lobes are involved in visual perception and the semantic associations assigned to visual objects (Kolb & Wishaw, 1990; Sattler, 1988; Walsh, 1978).

Evidence arising from EEG and/or EP studies exploring performance on tasks involving linguistic processing (Bentin, McCarthy & Wood, 1985; Kraft et al., 1980), memory (Rugg & Nagy, 1989; Stigsby, Risberg & Ingvar, 1977) and spatial ability (Papanicolaou et al., 1983) suggest that different tasks engage different regions of the brain.

The tasks used in this study are all verbal suggesting greater engagement of the left hemisphere, which is typically associated with language processing. In addition, given that these tasks involve verbal memory and are presented in an auditory mode, it is anticipated that specific differences which emerge will involve the temporal lobes, the region associated with learning and memory and auditory perception. Thus the following hypothesis will be tested.

Hypothesis 4:

> There will be significant differences in the topographic maps of the EEG during the cognitive tasks compared with the maps of the resting state EEG particularly in the left temporal region.

Method

Subjects

The study involved a sample of twelve children, seven non-clinical gifted, and five gifted underachievers from a clinical setting, between the ages of 9 and 13 years. Six of the subjects were male and six female. The specific groups of subjects were defined by performance on standard psychometric tests and academic achievement. Specifically, children were identified as gifted if they were at or above grade level in all subject areas as measured by the Wide Range Achievement Test - Revised (WRAT-R), with a full scale IQ score of 130 or higher on the Wechsler Intelligence Scale for Children - Revised (WISC-R). The non-clinical subjects were recruited from the University of Toronto School through the gifted education program of the University of Toronto's Department of Education.

The clinical subjects were recruited through the Child and Family Studies' Neuropsychology Clinic of the Clarke Institute of Psychiatry in Toronto. The children had already been assessed by a team of clinical psychologists and were identified as gifted underachievers. The children had been identified as gifted underachievers if they obtained a full scale IQ score of 120 or higher on the WISC-R, or had at least two or more subscale scores in the gifted range, and were below grade level in at least one subject area on the WRAT-R with low scores in the area(s) attributed to a learning or emotional disability (Gelcer, 1991; Gelcer & Dick, 1986). In addition, they were participating in a program for gifted underachievers. All of the gifted clinical subjects who participated in the study had been classified according to the DSM III-R (American Psychiatric Association, 1987) characteristics. A summary of the means for the WISC-R and WRAT-R scores for each group are provided in Tables 1 and 2.

Table 1

Means of WISC-R Verbal, Performance, and Full Scale IQ scores.

	Gifted Clinical	Gifted Non-Clinical
Verbal IQ	125	138
Performance IQ	115	134
Full Scale IQ	122	138

Table 2

Means of WRAT-R Standard Scores and Percentiles for Reading, Spelling, and Arithmetic

	Gifted Clinical		Gifted Non-Clinical	
	SS	%	SS	%
Reading	137	83	120	97
Spelling	128	56	103	96
Arithmetic	134	33	96	94

All the subjects were right-handed. None had a history of severe pre- or perinatal problems, head injury, or neurological diseases, and none were taking medication. Participation in the study was voluntary for all subjects. Informed consent was obtained from the parent or guardian (see Appendix B for a copy of the consent form).

Description of the Measuring Instruments

The following psychometric tests were administered to all subjects in the study. These instruments were used primarily for classifying individuals into the two groups and will not be considered in the analyses.

Halstead-Reitan Neuropsychological Test Battery

The Halstead-Reitan Neuropsychological Test Battery consists of eleven basic tests used for evaluating children suspected of having brain damage. The test was designed for children between 9 and 14 years of age. The battery is made up of tests designed to measure ability in such areas as verbal skills, motor steadiness, learning and concept formation, auditory and visual perception, and attention. Only the data from the WISC-R, which forms part of the battery, were used in this study.

Wechsler Intelligence Scale for Children - Revised (WISC-R)

The WISC-R is made up of 12 subtests, and covers an age range from 6 years to 16 years, 11 months. The subtests are divided into two groups, making up two different scales: the Verbal Scale and the Performance Scale. The Verbal Scale is composed of the Information, Similarities, Arithmetic, Vocabulary, Comprehension, and Digit Span subtests. The Picture Completion, Picture Arrangement, Block Design, Object Assembly, Coding, and Mazes subtests form the Performance Scale.

The WISC-R provides three IQ scores: a Verbal IQ, a Performance IQ, and a Full Scale IQ. These represent deviation IQ scores as they are obtained by comparing an individual's score to a table of scores from a representative sample of age-matched peers. Raw scores are obtained for each of the subtests which are subsequently converted to standardized scores for the individual's age group using the tables provided.

The IQ tables for the WISC-R are based only on the scores of 10 of the 12 subtests. The Digit Span and Mazes subtests are not included in the calculation of the IQ, even when they have been administered.

Wide Range Achievement Test - Revised (WRAT-R)

The WRAT-R is an individually administered achievement test consisting of three subtests: Spelling, Reading, and Arithmetic. Each of the subtests is designed to measure ability in these broad areas. The Reading subtest is designed to measure children's ability to recognize letters and name them, and to pronounce words. The Spelling subtest involves writing one's name, copying letter-like marks, and writing words from dictation. The Arithmetic subtest is designed to measure skills involving counting, solving word problems, and written computation problems.

The WRAT-R is a timed test taking approximately 20-30 minutes to administer and is concerned primarily with mastery of the mechanics of the three subject areas.

The Electrophysiological Monitoring System

Two different computer-based electrophysiological monitoring systems were used to record and analyze the EEG data. The following is a description of the systems and a description of the database used for statistical comparison.

QSI 9000 and 9500

The QSI models 9000 and 9500 are two computer-based electrophysiological monitoring systems. The QSI 9000 allows for the acquisition and storage of 20 channels of EEG data. These data can be displayed on its high resolution graphics monitor, simulating the output of the polygraph printout of conventional EEG devices.

Individual 2.5 second epochs (i.e. segments) of EEG can be selected for FFT analysis. The resulting calculations can be displayed as a table of means and standard deviations for each of the power bands, as a histogram in a vertical bar graph, or as an averaged spectral distribution indicating the individual frequency components.

In addition, these data can be converted into two-dimensional colored topographic maps of the EEG activity in all regions of the brain for each frequency band.

The QSI 9500 is similar to the 9000. However, it provides greater flexibility in the analysis of the EEG data. It also has a more extensive database for statistical comparison. It is for this reason that the analysis of the data collected on the QSI 9000 was performed using the QSI 9500. It was necessary to use the QSI 9000 for the EEG recording as there was no other system available for data collection.

The QSI 9500 Database

One of the most useful elements of quantified electroencephalography (QEEG) is the process of statistical probability mapping (SPM). This process allows for the comparison of topographic maps to a normative database of medically-healthy, age-matched individuals.

The QSI 9500 has an extensive database ranging in age from 6 to 79 years. Since EEG data are dependent upon age, especially during the early years of development (Duffy, Iyer, Surwillo, 1989; Spehlmann, 1981), subjects are grouped accordingly. Above the age of 20, subjects are grouped by decade, while the pediatric groups are defined by developmental ages. There are no separate groupings by gender as electrophysiological differences between males and females are minimal. The comparison group from the database used in this study was a norm group of 142 medically healthy, 9 to 13-year-olds.

Procedure

All subjects were administered the Halstead-Reitan Neuropsychological Test Battery either by the psychometrist in the Child and Family Studies Centre at the Clarke Institute of Psychiatry or by the interns from the Metropolitan Toronto Separate School Board under the supervision of the board's neuropsychologist. The battery consisted of a number of subtests reflecting different abilities (e.g. memory, motor skills, etc.), including the Wechsler Intelligence Scale for Children (WISC-R) and the Wide Range Achievement Test (WRAT-R). All of the neuropsychological testing took place in the Child and Family Studies Centre.

As part of the study all subjects were given a standard EEG. EEG testing was carried out in the EEG laboratory of the Addiction Research Foundation of the University of Toronto.

EEG Recording

EEG recording was made on the QSI model 9000 and monitored on its screen using a referential montage with a linked ear reference. The QSI 9000 default recording parameters were employed with filters set for a bandpass of 0.5 - 30 Hz and a sampling time of 9.77 milliseconds. The electrical signal output by the brain is relatively small (in the microvolt range), thus it is necessary to use a series of amplifiers to augment the signal for recording purposes. The number of times the signal is amplified or increased is referred to as amplifier gain. The recording amplifiers were conventionally set using a constant gain of 80K (representing an amplification of 80,000 times, or a maximum gain of $\pm$ 64 μV). The 21 silver electrodes were placed according to the International 10/20 configuration. Preparation time including the measurement of the head and the placement of the electrodes took approximately forty-five minutes.

An initial resting recording of five minutes was made with eyes closed, and another five minutes with eyes open, awake but relaxed. The eyes open recording was done as a standard procedure to determine the reactivity of the alpha activity in the EEG, and was not included for analysis in this study. The "reactive alpha" is the posterior rhythm which is evident in the EEG when the eyes are closed, and which disappears when the eyes are opened. This rhythm generally occurs at approximately 10 Hz for adults and sometimes below 8 Hz in young children, and is often referred to as the "alpha peak". Following the at rest recordings, the specific tasks were presented in an "eyes closed" condition. The EEG was continually recorded during the cognitive tasks.

Cognitive Tasks

Three verbal tasks were used in the study: listening to a list of words, memorizing a list of words, and recognizing words from a list. During the first task, subjects were presented aurally with a list of 25 words. Subjects were instructed to relax and listen to the words. Words were presented at a rate of one word every four seconds.

In the second task, subjects were presented with another list of 26 words. For this task they were instructed to listen to the list of words and try to remember them.

For the final task, subjects were presented with a list of 26 words made up of an equal number of new words and old words in random order. Old words were drawn from the second list of words which subjects had previously been asked to memorize. Subjects were instructed to listen to the list of words and raise both index fingers if they heard a word which they recognized from the previous list. The lists of words used for the three tasks can be found in Appendix C.

EEG Frequency Spectrum

The EEG frequency spectrum conventionally is broken down into four major frequency bands: delta (0.4 - 3.6 Hz), theta (4 - 7.6 Hz), alpha (8 - 12.6 Hz), and beta (13+ Hz). While technically the beta band includes the activity occurring above 13 Hz, the beta rhythm typically is between 13 and 35 Hz (Fisch, 1991). For practical purposes beta often is divided arbitrarily into slower and faster components. The QSI 9500 separates the beta band into three components: beta 1 (13 - 15.6 Hz), beta 2 (16 - 19.6 Hz), and beta 3 (20 - 30

Hz). For the purposes of this study only two components of beta activity were examined, beta 1 and beta 2, representing frequencies of developmental interest.

Recording Montages

In multichannel recordings (e.g. more than one electrode or lead), an important consideration is the electrode combination or montage. As previously stated, the EEG records variations of electrical activity in the brain and is actually a recording of the electrical potential differences between pairs of electrodes (Spehlmann, 1981).

Montages can be classified as bipolar or referential. In bipolar montages, the electrodes pairs are linked in chains of contiguous electrodes either going from front to back (longitudinal bipolar) or across the head left to right (transverse bipolar) (Fisch, 1991; Jasper, 1958; Sharbough, 1990). In a referential montage each scalp or "active" electrode is compared either to a common reference, usually a neutral, extra-cerebral electrode (Fisch, 1991; Sharbough, 1990). Electrode locations used as neutral references include the contralateral ear, the nose, the chin, or linked ears (joined electrically). It is not possible to find a completely neutral reference since electrodes placed on the ear, nose, or neck may potentially pick up signals from a non-cerebral source such as muscle activity or a component of the electrocardiogram (ECG) (Kiloh, McComas, Osselton, & Upton, 1981; Sharbough, 1990). Typically, linked ears is one of the most frequently used references. The default recording montage for the QSI 9000 is the referential montage using linked ears as the common reference.

Artifact Rejection

Artifact rejection was affirmed manually prior to analysis on the QSI model 9500. The term "artifact" is used to denote a distortion in the desired EEG signal. There are different types of artifact arising from different influencing factors. As mentioned in Chapter 2, these can be classified as instrumental, environmental, electrical, and physiological. The process of "artifacting" involves the rejection by visual inspection of those segments of EEG which contain artifact from the EEG record prior to spectral analysis.

Description of the Electrophysiological Measures

The data, once edited for artifact, were subjected to a Fourier transform in order to perform a spectral analysis on each of the 20 data channels. The following characteristics of the EEG were examined:

Power

Power provides a measure of the intensity of electrical signal recorded from different regions of the brain. The application of the FFT results in the amplitude spectrum which represents the voltage, displayed in microvolts, for each frequency. The power spectrum is derived by squaring the amplitude spectrum and is consistent with engineering applications (Zappulla, 1991). The power spectrum can be group by traditional frequency bands (e.g delta, theta, alpha, and beta), and across all frequency bands (total power). Power is expressed as voltage squared and provides an average of the amplitude of the electrical activity in the EEG. For the purposes of this study, two measures of power were examined: absolute power, and relative power.

Absolute Power. Absolute power refers to the average intensity of the electrical signal in each of the frequency bands, based on constant gain for all recording amplifiers. Absolute power is derived directly from the power spectrum, grouped by frequency band. The term intensity is used here as an expression of magnitude or quantity (the greater the power, the higher the intensity).

Relative Power. Relative power is the proportion of power in each frequency band relative to total power for each region of the brain. Relative power is derived by dividing the power within a frequency band by the total power across all frequency bands.

Asymmetry

Asymmetry refers to the power relationships between the two hemispheres. Amplitude asymmetry is derived by calculating the difference in power between two leads. This can computed for total power as well as for absolute power in each frequency band. For the purpose of this study, power relationships were computed for homologous leads (i.e. when each lead is compared to its corresponding lead in the opposite hemisphere) for each frequency band, providing a measure of lateralized differences.

Summary of the Chapter

This chapter presented the research methodology employed in this study. The underlying questions being examined were outlined and hypotheses formulated. Descriptions of the subjects, the measuring instruments, the electrophysiological monitoring system, and the comparison database were provided. In addition, the procedure and the electrophysiological measures employed in the study were discussed.

4. RESULTS

This chapter presents the results of the data analyses. In addition to the topographic maps of brain activity, the statistical probability maps used in the analyses are provided. A description of the color scales used in the maps is given. Since the group of gifted underachievers were drawn from a clinical population and the gifted high achievers from a non-clinical school setting, the two groups will be referred to as the "gifted clinical group" and the "gifted non-clinical group", respectively.

Analysis of the Data

EEG Data Analysis

EEG recordings were visually inspected. All segments which contained artifact were rejected during the processing of the data. All artifact-free segments were then included in the analyses. Data were analyzed using the analytic module of the the QSI 9500 system. A Fourier-based analysis was performed for each EEG recording at each electrode.

Subjects were grouped through the "grouping" utilities of the QSI 9500 and comparisons made using the $\underline{z}$ test, and the grouped and individual $\underline{t}$-test analyses provided by the system. Statistical probability maps were generated from these results with the level of significance set at .05 ($p < .05$). Conventionally, any differences within ± 2 standard deviations from the mean of the comparison group are considered to be within normal limits and thus not significant.

The results provide information on how different brain regions vary from the database of matched healthy age-related peers. The database is resident in the QSI 9500 and represents an independent sample of over 800 subjects for eyes closed EEG. From these data, comparison information on absolute and relative power, and power symmetry differences for five standard frequency bands for each of 20 brain regions were extracted. These measures represent standard quantitative electrophysiological protocols utilized for evaluating brain function (Thatcher, 1983).

Color Scales for Topographic Maps

Two types of full color topographic maps were generated in the analyses, each having a different color scale. The maps generated from the individual EEG data, the grouped EEG data, and the database use a "hot metal" scale, where the minimum value is represented in black ("black-cold") with values increasing through shades of blue, green, yellow, orange, and red to the maximum value represented in white ("white-hot").

The statistical probability maps generated using the z-test and the t-test use a bipolar scale since differences between maps can be positive or negative. The bipolar scale is symmetrical, with zero deviation between the two sources being represented in black. Increasing negative deviations between the source maps are represented by progressively lighter shades of blue to a maximum negative deviation represented in white. Increasing positive deviations between the source maps are represented by shades of red progressing through shades of orange and yellow to the maximum positive deviation represented in white. Figure 1 shows these two color scales.

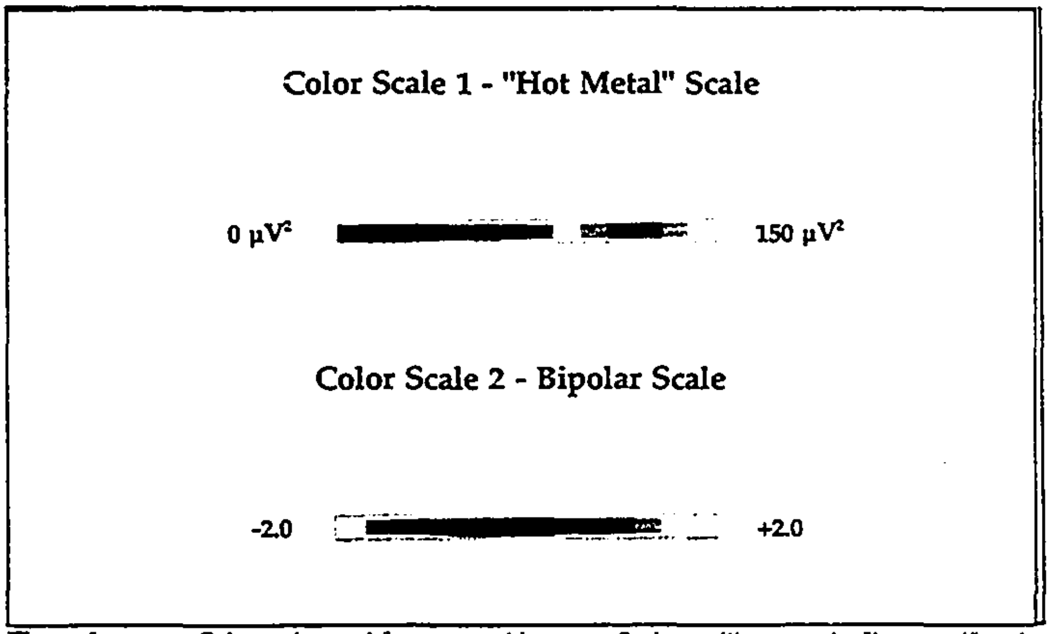

Figure 1 Color scales used for topographic maps. Scale one illustrates the "hot metal" scale, and scale two illustrates the bipolar scale.

Analysis of the Resting EEG

The spectral characteristics of the initial five minute resting samples were computed including absolute power, relative power, and hemispheric asymmetry for five standard frequency bands. The topographic maps for each of these measures in the initial resting state EEG were compared to an extensive database for medically healthy, age-matched, normal functioning peers. Statistical probability maps were generated for all univariate comparisons which indicated the specific regions of the brain in which statistically significant differences were found. The following sections present the results of these analyses.

Comparisons of Gifted Non-Clinical Group to Age-Matched Peers

Absolute Power

Figure 2 shows the topographic maps of absolute power for the gifted non-clinical group in comparison to a database of medically-healthy, age-related, 9 to 13 year old peers. Column one represents the distribution of power over all regions in each frequency band for the gifted non-clinical subjects, and column three represents a similar set of topographic maps for the database comparison group. Each row from top to bottom represents a different frequency band. These are delta, theta, alpha, beta 1, and beta 2 respectively. Column two represents the statistical probability maps (z-scores) indicating the differences, in standard deviation units, between the maps for the gifted non-clinical group in column one and the maps for the database comparison group in column three.

Significant differences were found in the delta band in the mid-occipital, mid-parietal, and left anterior temporal regions, the white colored areas, indicating that the absolute power of the gifted non-clinical group was significantly lower than the comparison group of 9 to 13 year olds. Absolute power appeared to be lower in most regions in all frequency bands, represented as blue areas, although the differences were within normal limits (i.e., within ±2 standard deviations of the mean of the comparison group). This pattern of low power was evident in all the individual topographic maps and did not appear to be a statistical phenomenon caused by the averaging of the data.

Relative Power

Although differences were found between the gifted non-clinical group and the database of age-matched peers in absolute power, no differences were found in relative power as indicated in the statistical probability maps in column two of Figure 3. Column one displays the topographic maps of relative power of gifted non-clinical Group representing the proportion of power in each frequency band

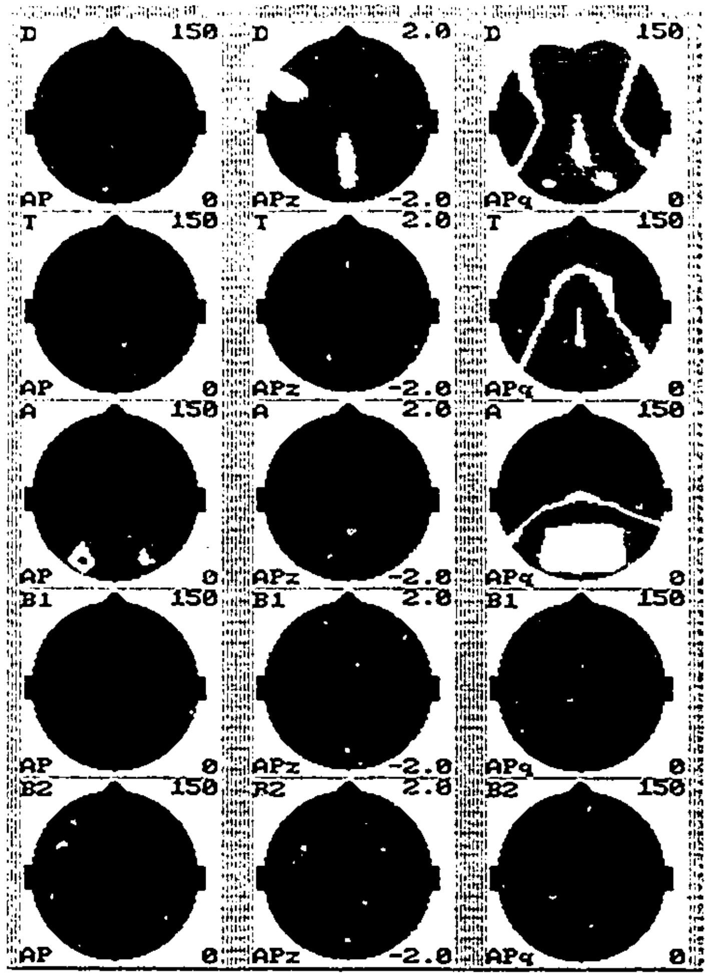

Figure 2 Topographic maps of absolute power for the initial resting state EEG for the gifted non-clinical group compared to the database of medically-healthy, age-matched peers (aged 9 to 13 years).

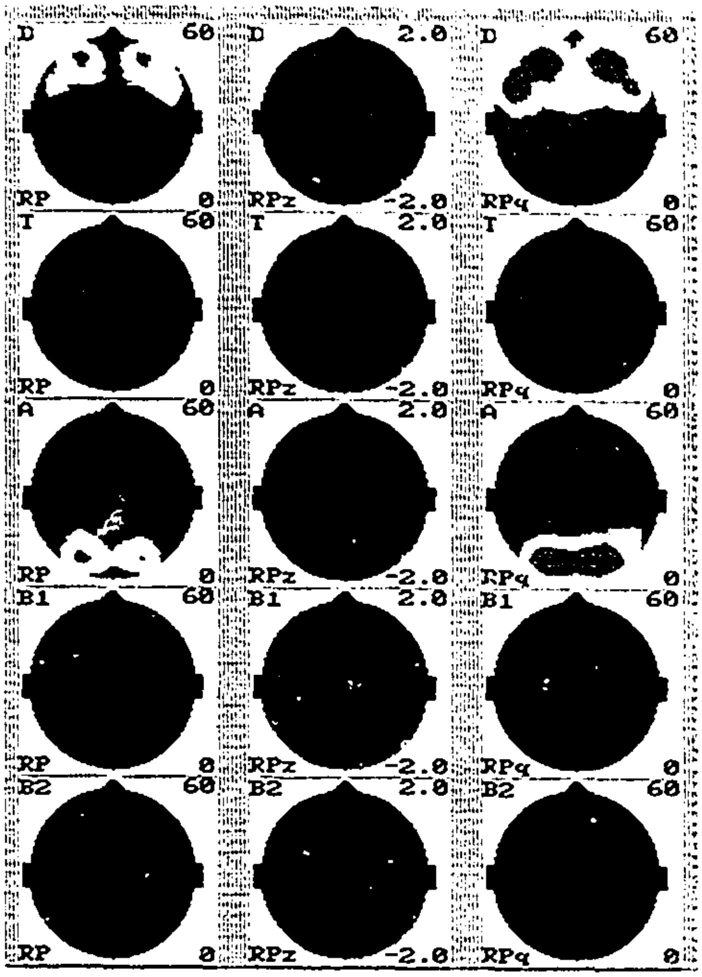

Figure 3 Topographic maps of relative power for the initial resting state EEG for the gifted non-clinical group compared to the database of medically-healthy, age-matched peers (aged 9 to 13 years).

over all regions relative to total power. The topographic maps for the database of medically-healthy peers aged 9 to 13 years are shown in column three.

Asymmetry

The topographic maps for amplitude asymmetry are displayed in Figure 4. They illustrate the differences in the amount of activity in each region of one hemisphere compared to homologous regions in the opposite hemisphere. Since these differences may be higher (positive) or lower (negative) the maps are generated using the bipolar color scale.

Column one represents the topographic maps of asymmetry for the gifted non-clinical group. They suggest that there is a difference in the amount of activity between the two hemispheres, with the left hemisphere having less power than the right, particularly in the temporal regions in all frequency bands. The maps in column three illustrate the pattern of asymmetry for the database comparison group. Note that similar differences are also apparent, but they are found in the posterior region.

The statistical probability maps in column two did not show any significant differences between the asymmetry of the gifted non-clinical group and the database of age-matched peers. The apparent difference in the anterior temporal region in the delta band fell within normal limits.

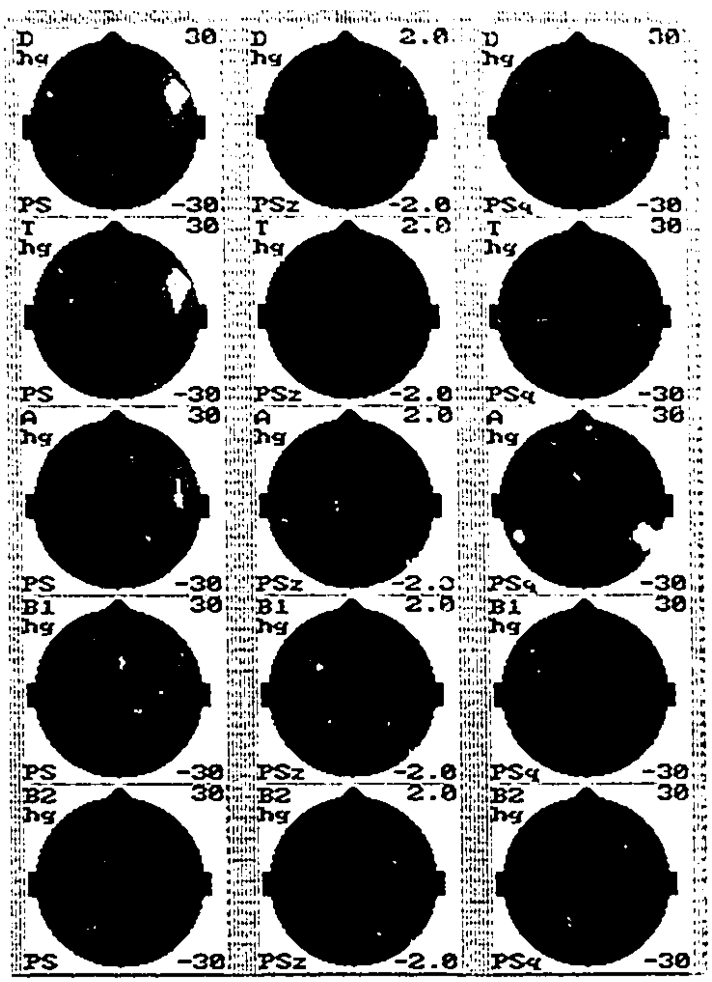

Figure 4 Topographic maps of asymmetry for the initial resting state EEG for the gifted non-clinical group compared to the database of medically-healthy, age-matched peers (aged 9 to 13 years).

Comparisons of Gifted Clinical Group to Age-Matched Peers

Absolute Power

Figure 5 illustrates the comparison of the topographic maps of absolute power for the gifted clinical group shown in column one to the database of age-matched peers shown in column three. Going from top to bottom in the columns, topographic maps indicate the distribution of absolute power over all regions for the delta, theta, alpha, beta 1, and beta 2 frequency bands respectively.

The statistical probability map shown in column two indicated no significant deviations between the clinical group and the database for 9 to 13-year-old peers. The slight differences observed in these maps, as indicated by the pink areas in alpha, beta 1, and beta 2, fell within the normal limits (i.e., within ± 2 standard deviations of the mean of the comparison group).

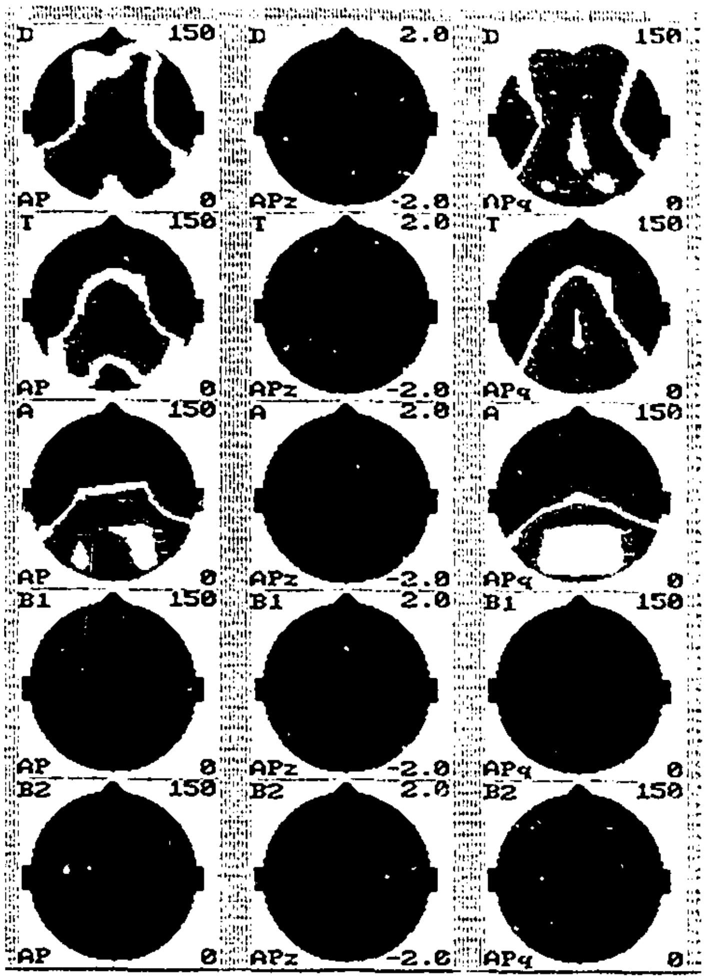

Figure 5 Topographic maps of absolute power for the initial resting state EEG for the gifted clinical group compared to the database of medically-healthy, age-matched peers (aged 9 to 13 years).

Relative Power

The statistical probability maps in column two for the comparison of relative power shown in Figure 6 indicated no significant differences between the gifted clinical group in column one and the database of peers aged 9 to 13 years in column three.

Asymmetry

The topographic maps of asymmetry for the gifted clinical group in column one indicated some slight differences in power between the left and right hemispheres (see Figure 7). These differences did not appear to be consistent for all frequency bands, with power being slightly higher on the right than on the left in the posterior temporal region in the alpha band, and slightly higher on the left than on the right in the temporal region in beta 1 and beta 2. The pattern of asymmetry for the database group of 9 to 13 year old peers is displayed in column three. There were no significant differences between patterns of asymmetry of the gifted clinical group compared to the database comparison group.

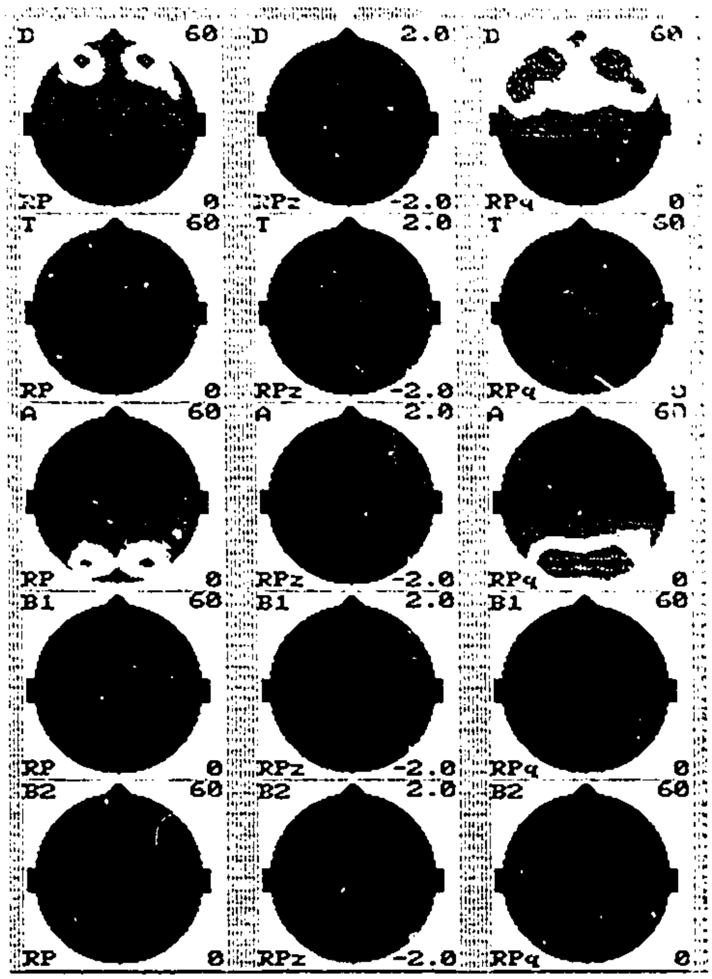

Figure 6 Topographic maps of relative power for the initial resting state EEG for the gifted clinical group compared to the database of medically-healthy, age-matched peers (aged 9 to 13 years).

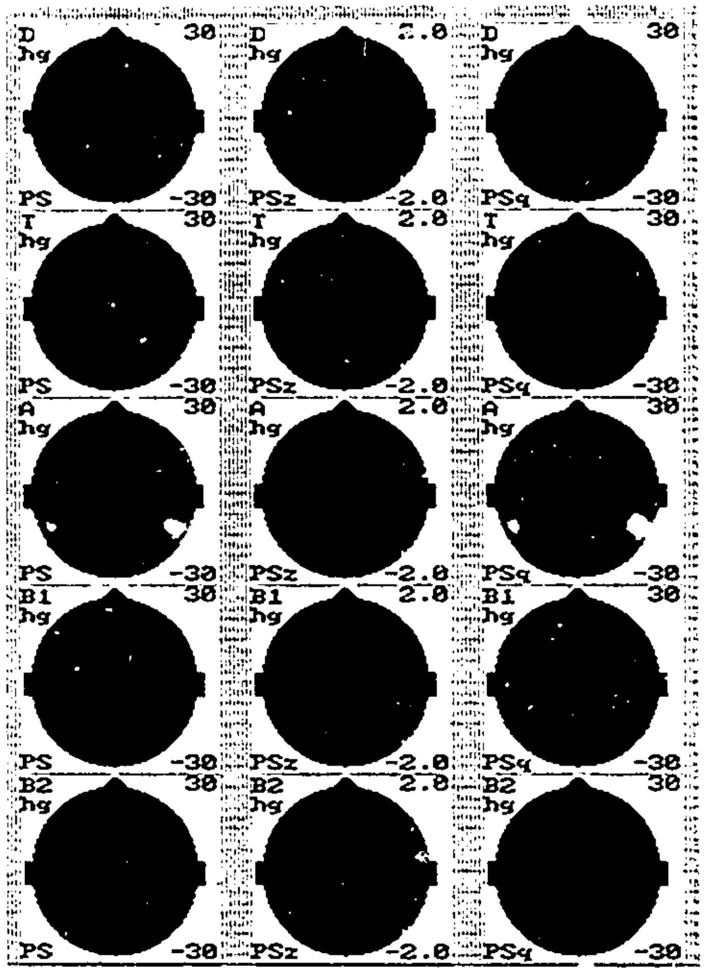

Figure 7 Topographic maps of asymmetry for the initial resting state EEG for the gifted clinical group compared to the database of medically-healthy, age-matched peers (aged 9 to 13 years).

The Gifted Non-Clinical Group Compared to the Gifted Clinical Group

Absolute Power

Figure 8 illustrates the comparison of absolute power for the initial resting state EEG between the non-clinical group shown in column one, and the clinical group shown in column three. The statistical probability map in column two indicated that the absolute power of the non-clinical group was lower than the clinical group in all regions in all frequency bands. Differences were significant in most regions except the right temporal in both delta and theta, in the central, frontal, and left temporal regions in alpha, in the left frontal, left anterior temporal, central, left posterior temporal, left and right occipital, and right frontal regions in beta 1, and in the left frontal, left anterior temporal, left temporal, left posterior temporal, central, mid-parietal, and right posterior temporal regions in beta 2.

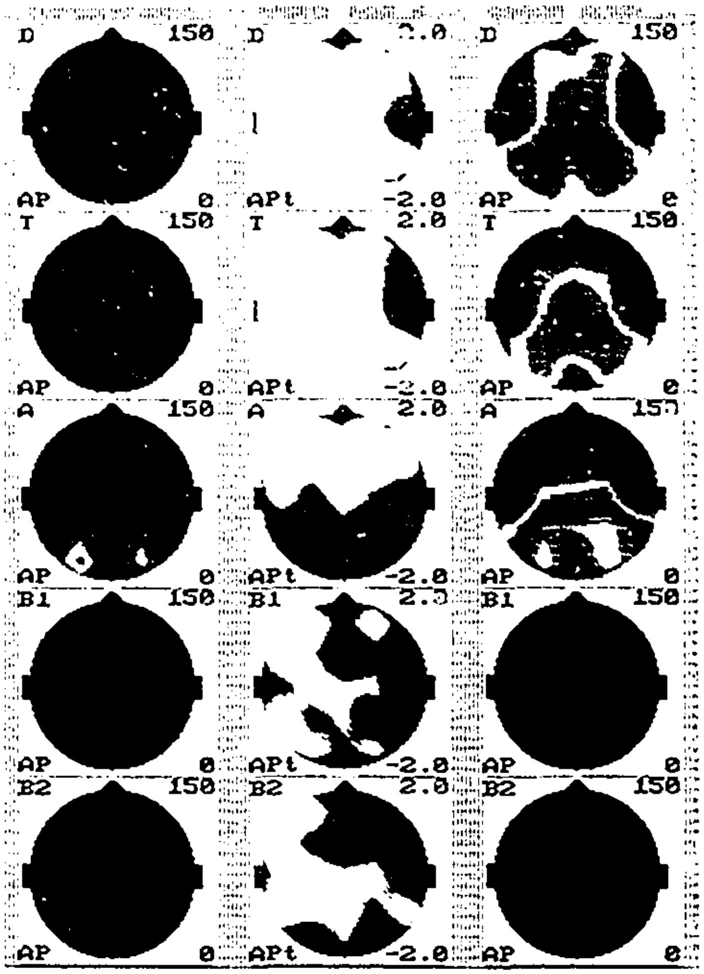

Figure 8 Topographic maps of absolute power for the initial resting state EEG of the gifted non-clinical group compared to the gifted clinical group.

Relative Power

The comparison of the topographic maps of relative power for the initial resting state EEG between the non-clinical and the clinical groups are displayed in Figure 9. The maps in column one represent the proportion of power in all regions in each frequency band relative to the total power for the gifted non-clinical group with the same set of maps for the gifted clinical groups shown in column three.

The statistical probability map in column two indicated no significant differences between the two groups. Although there appeared to be some differences, particularly in the posterior regions in beta 2, these were within normal limits.

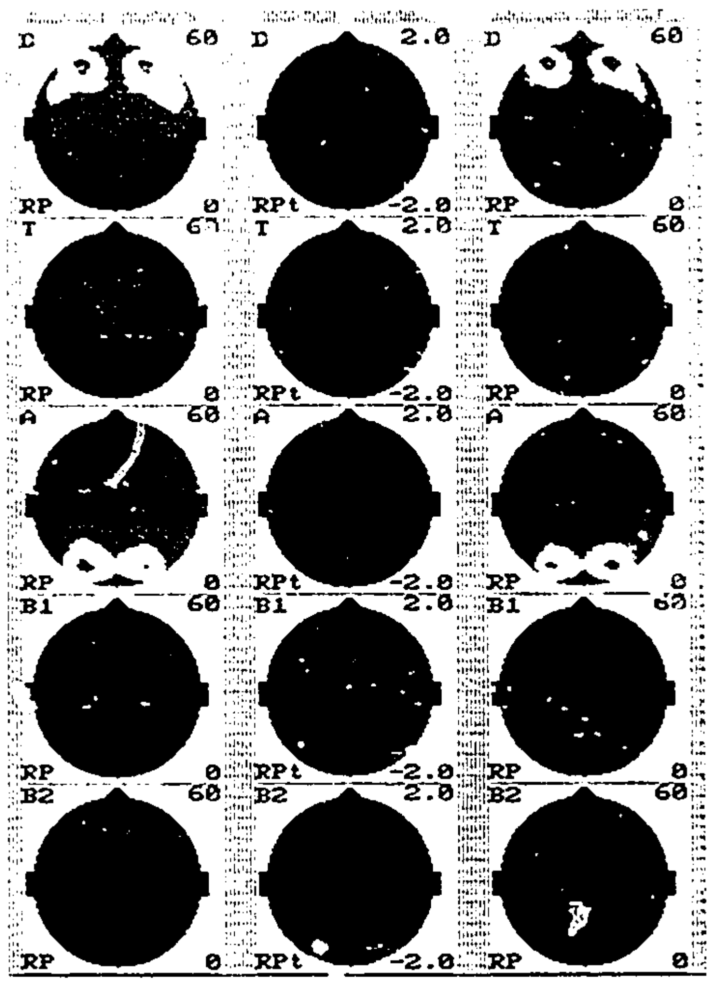

Figure 9 Topographic maps of relative power for the initial resting state EEG of the gifted non-clinical group compared to the gifted clinical group.

Asymmetry

The comparison maps of amplitude asymmetry between the gifted non-clinical group in column one, and the gifted clinical group in column three for the initial resting state EEG are displayed in Figure 10. As previously discussed, there is lower activity for the non-clinical group in the left hemisphere compared to the right hemisphere particularly in the anterior temporal and temporal regions in delta, theta, alpha, and beta 1. The maps in column three indicate that for the gifted clinical group there is lower activity in the left posterior temporal region compared to the right in alpha, but higher activity in the left temporal region than the right in beta 1.

The statistical probability maps in column two suggested that there was significantly lower activity in the left anterior temporal and temporal regions, and significantly higher activity in the right anterior temporal and temporal regions in delta for the non-clinical group compared to the clinical group. Differences in these regions were also apparent in other frequency bands, however these differences all fell within normal limits.

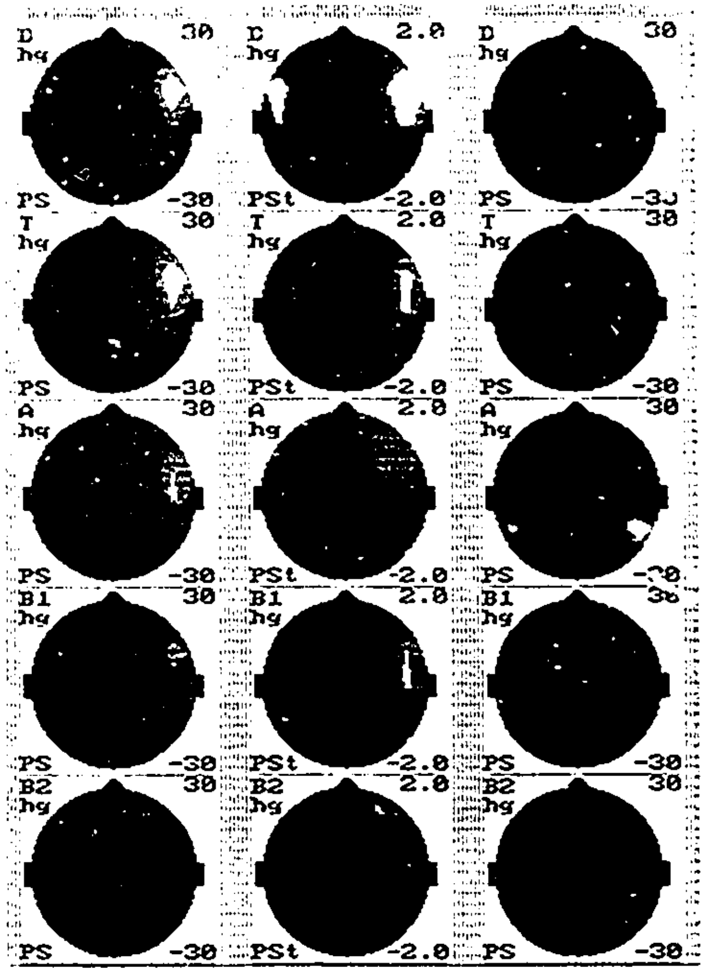

Figure 10 Topographic maps of asymmetry for the initial resting state EEG of the gifted non-clinical group compared to the gifted clinical group.

Analyses of Cognitive Tasks

For the analyses of the cognitive tasks, the initial resting state EEG record was used as a baseline reading for each of the subjects, and each task was compared to this baseline. The three tasks were, in the order in which they were administered, listening to a list of words, memorizing a list of words, and recognizing words from a list.

Listening Task - Gifted Non-Clinical Group

Figure 11 presents the comparison of the topographic maps for absolute power between the listening task and the baseline for the gifted non-clinical group. The baseline recording is shown in column one and the maps for the listening task are shown in column three. The statistical probability maps in the second column showed no significant differences between the two recording conditions.

While no significant differences were found when combined in a group, when looked at individually there were some differences. However, there did not appear to be any trends either in the regions which were activated, nor in increases or decreases in power (see Figure 12).

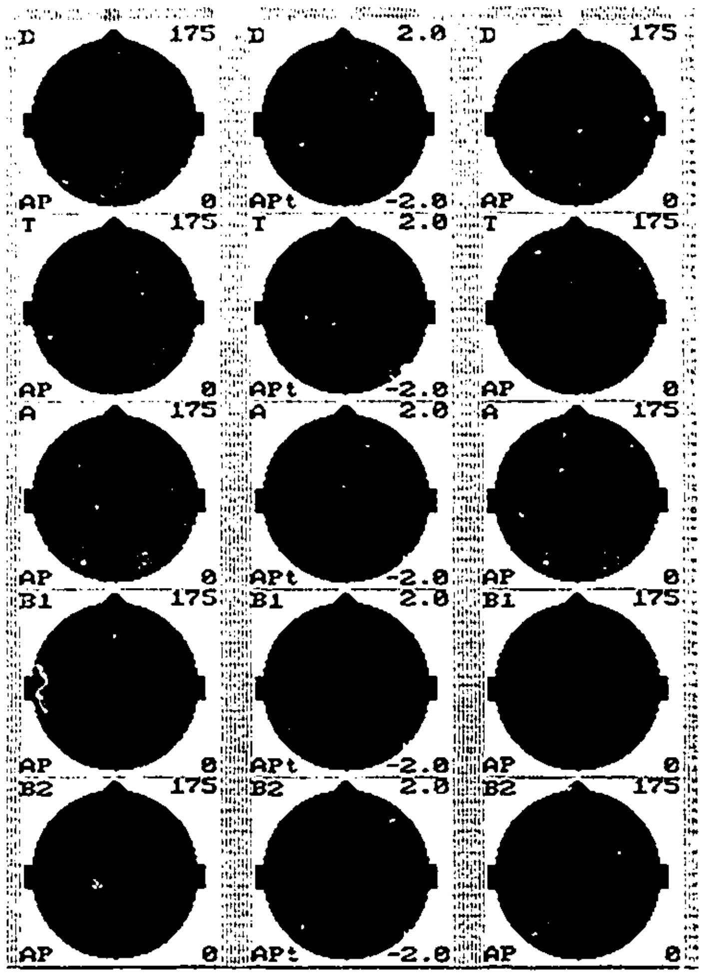

Figure 11 Comparison of topographic maps of absolute power between the initial resting state EEG and the listening task for the gifted non-clinical group.

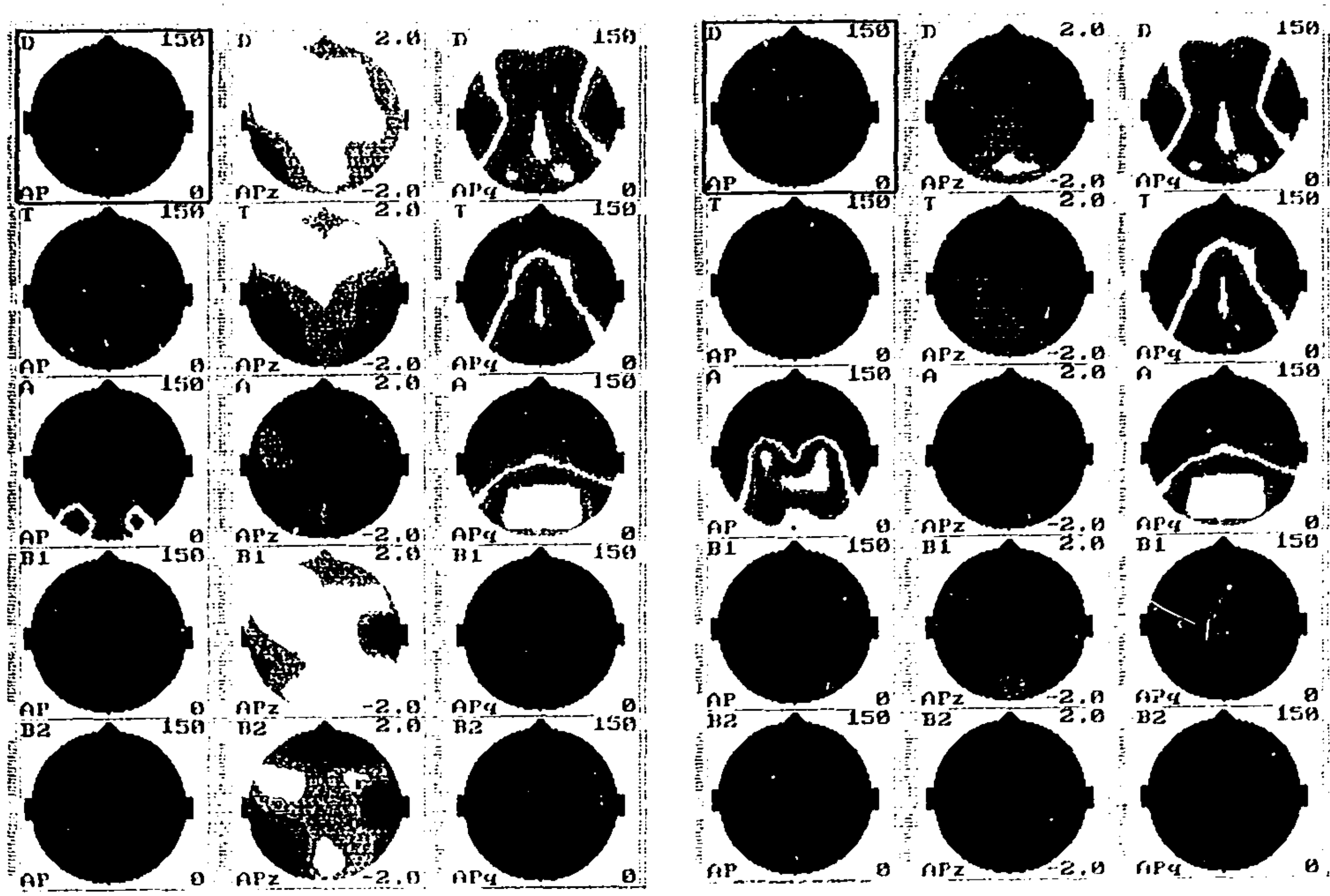

Figure 12 Sample of individual comparison maps of absolute power between the resting state EEG and the listening task for the gifted non-clinical group.

The topographic maps of relative power for the comparison of the listening task to the baseline are displayed in Figure 13. The maps for the baseline are again in column one and for the task in column three.

Although the statistical probability maps in column two suggest that the proportion of power in the theta band was greater in the resting state EEG than for the listening task, particularly in the right temporal region, these differences fell within normal limits, and were therefore not significant.

The topographic maps for amplitude asymmetry between the baseline in column one and the listening task in column three are displayed in Figure 14. Once again, the apparent differences observed in the beta 2 band on the statistical probability maps in column two were not significant.

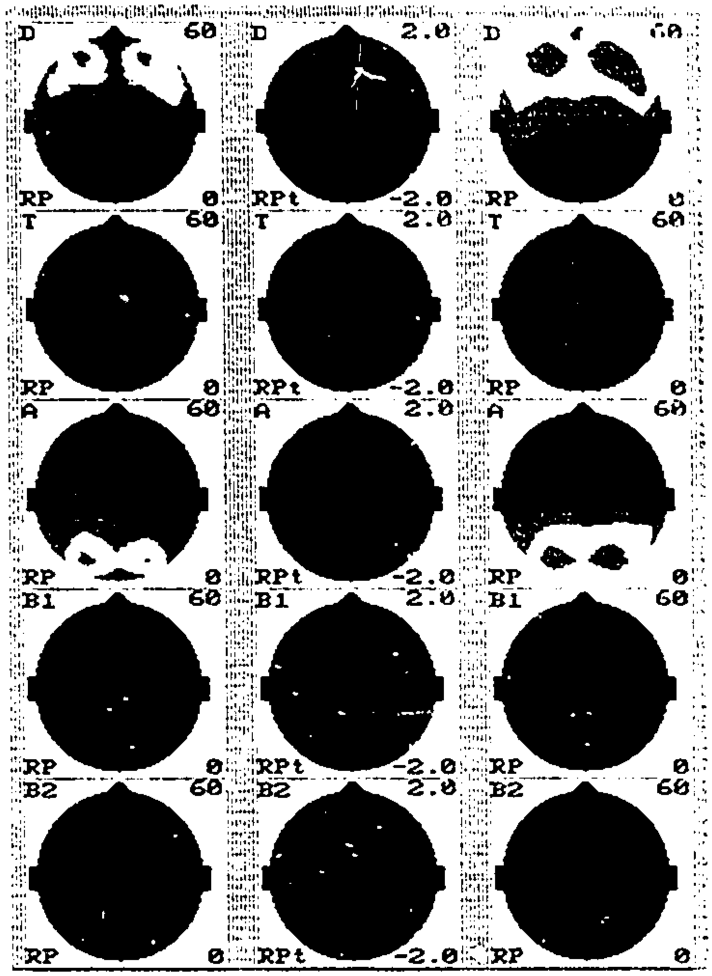

Figure 13 Comparison of topographic maps of relative power between the initial resting state EEG and the listening task for the gifted non-clinical group.

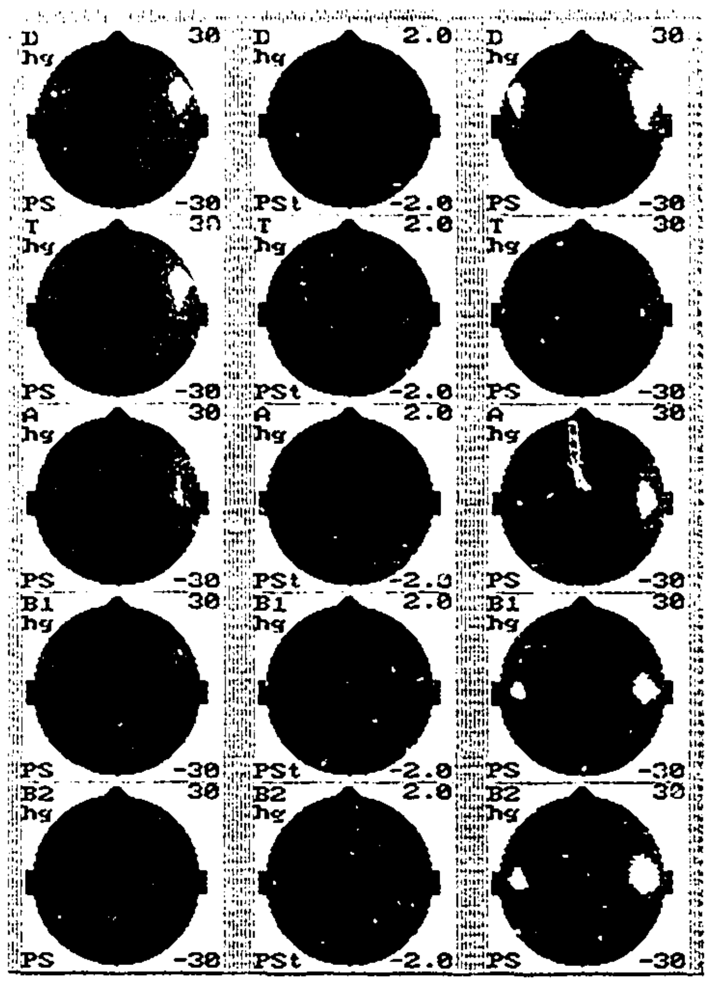

Figure 14 Comparison of topographic maps of asymmetry between the initial resting state EEG and the listening task for the gifted non-clinical group.

Listening Task - Gifted Clinical Group

The comparison of the topographic maps for absolute power between the listening task and the baseline for the gifted clinical group are shown in Figure 15. The baseline recording is shown in column one and the maps for the listening task are shown in column three. The statistical probability maps in the second column show some differences in delta and alpha, indicating lower power in the baseline than in the listening task, however, these were not significant.

As with the non-clinical group, no significant differences were found when combined in a group, although when looked at individually there were some differences. Again, there did not appear to be any trends either in the regions which were activated, nor in increases or decreases in power (see Figure 16).

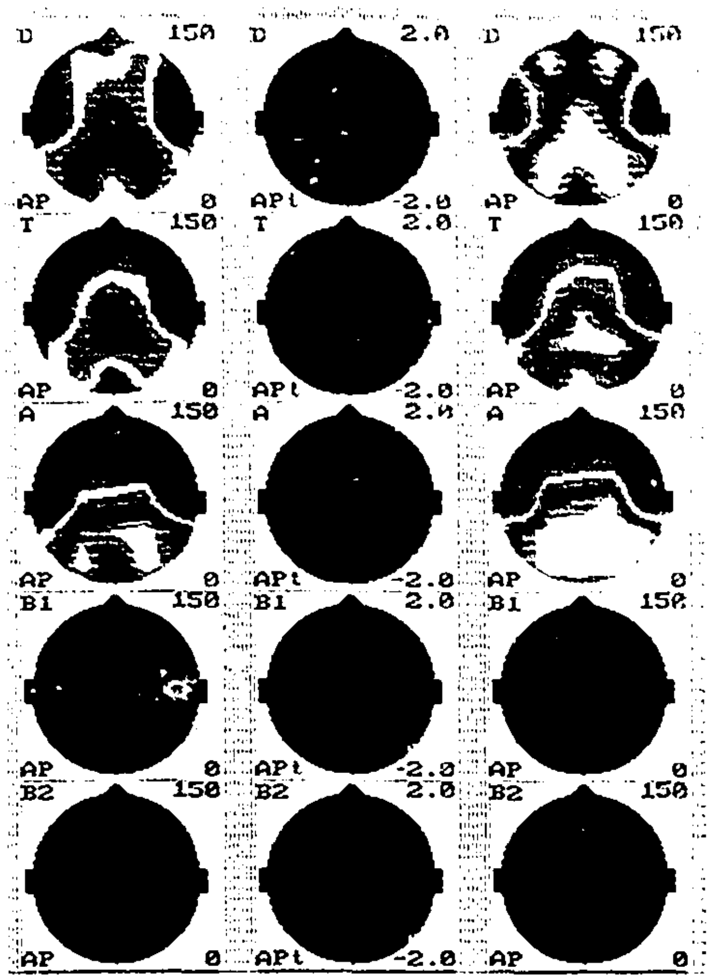

Figure 15 Comparison of topographic maps of absolute power between the initial resting state EEG and the listening task for the gifted clinical group.

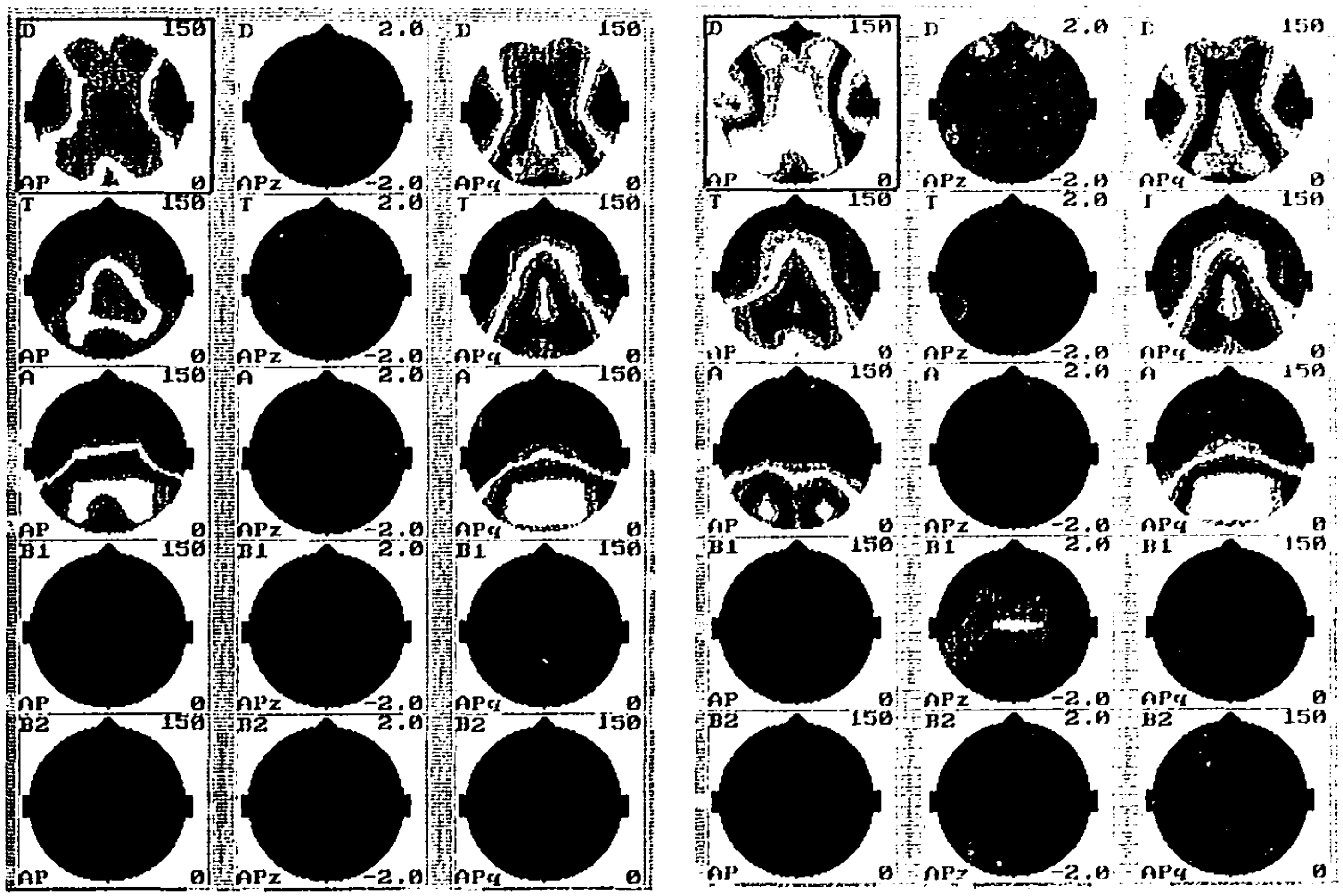

Figure 16 Sample of individual comparison maps of absolute power between the resting state EEG and the listening task for the gifted clinical group.

The topographic maps of relative power of the baseline compared to the listening task are presented in Figure 17. The statistical probability maps in column two indicate that there was lower power in theta particularly in the mid-frontal, left frontal, and left central regions in the listening task shown in column three than in the baseline in column one. However, these differences were within normal limits. Although there appeared to be a significant increase in the proportion of power in the delta band in the frontal regions in the listening task, this may have been due to eye movement.

Figure 18 represents the comparison of the topographic maps of asymmetry between the baseline in column one and the listening task in column three. While there appeared to be differences in the statistical probability maps in column two, these were within normal limits.

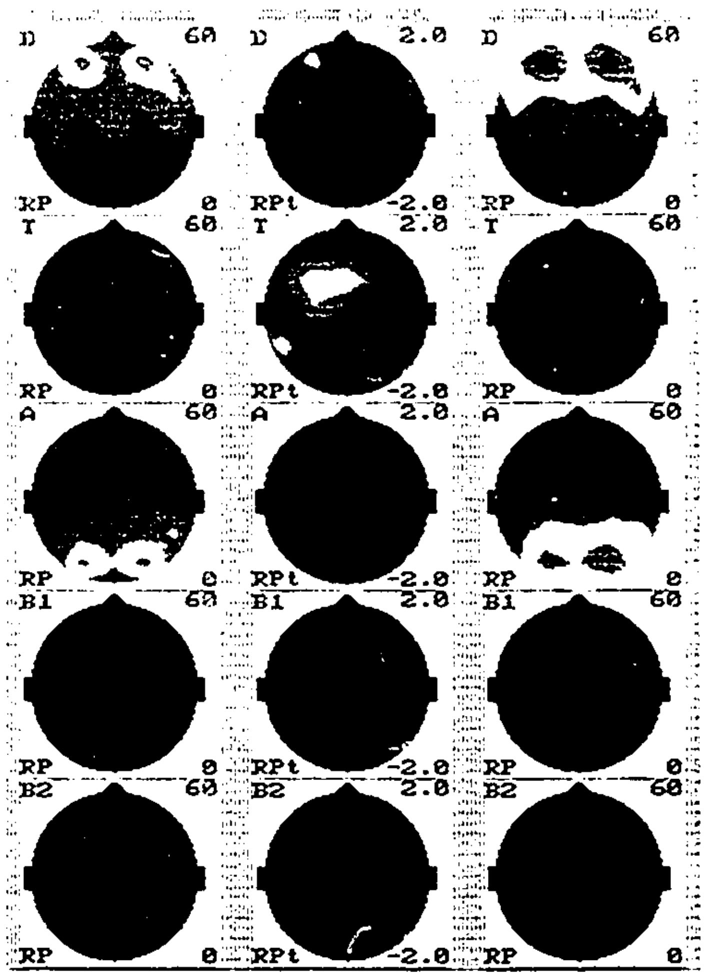

Figure 17 Comparison of topographic maps of relative power between the initial resting state EEG and the listening task for the gifted clinical group.

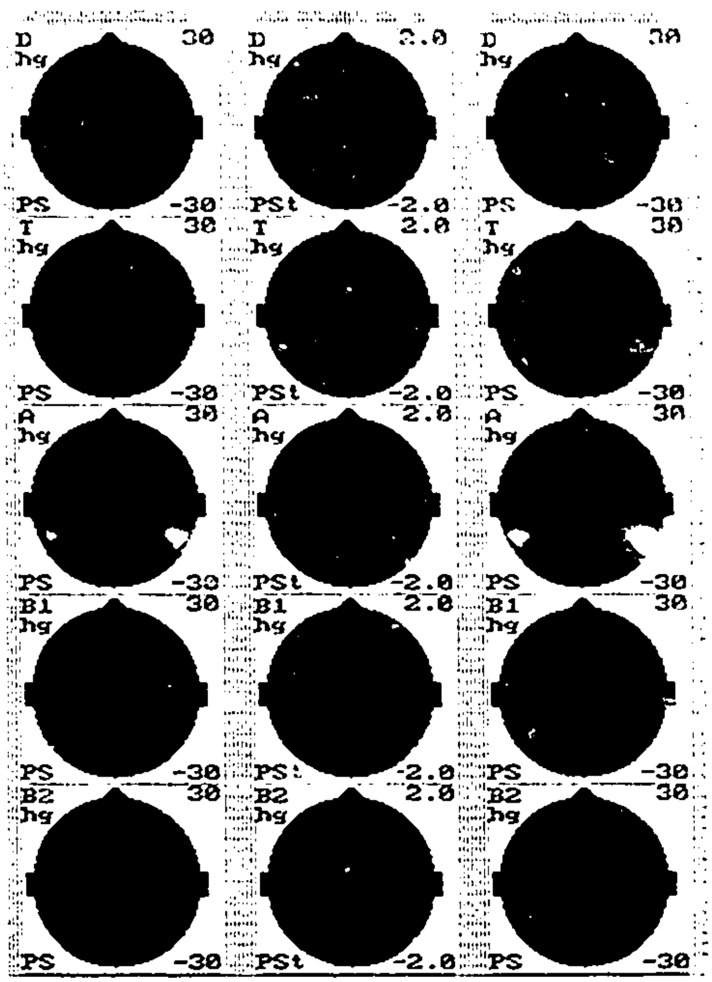

Figure 18 Comparison of topographic maps of asymmetry between the initial resting state EEG and the listening task for the gifted clinical group.

Memorizing Task - Gifted Non-Clinical Group

The comparison of the topographic maps of absolute power between the baseline and the memorizing task for the gifted non-clinical group are shown in Figure 19. The statistical probability maps in column two indicated that there were no significant differences between the initial resting state EEG in column one and the EEG for the memorizing task in column three.

Similarly, in the comparison of relative power presented in Figure 20, the statistical probability maps in column two showed no significant differences between the baseline in column one and the memorizing task in column three.

An examination of the maps of power relationships in Figure 21 suggests increased asymmetry in beta 2 for the memorizing task in column three than the baseline in column one, particularly in the left and right parietal and posterior temporal regions. However, as indicated in the statistical probability maps in column two these differences were not significant.

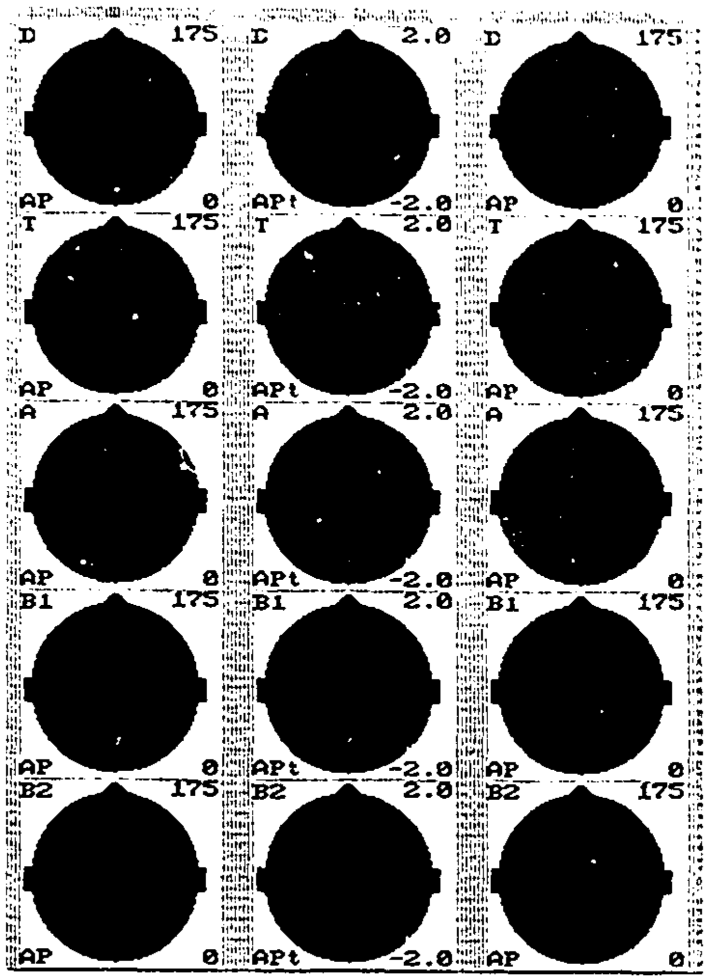

Figure 19 Comparison of topographic maps of absolute power between the initial resting state EEG and the memorizing task for the gifted non-clinical group.

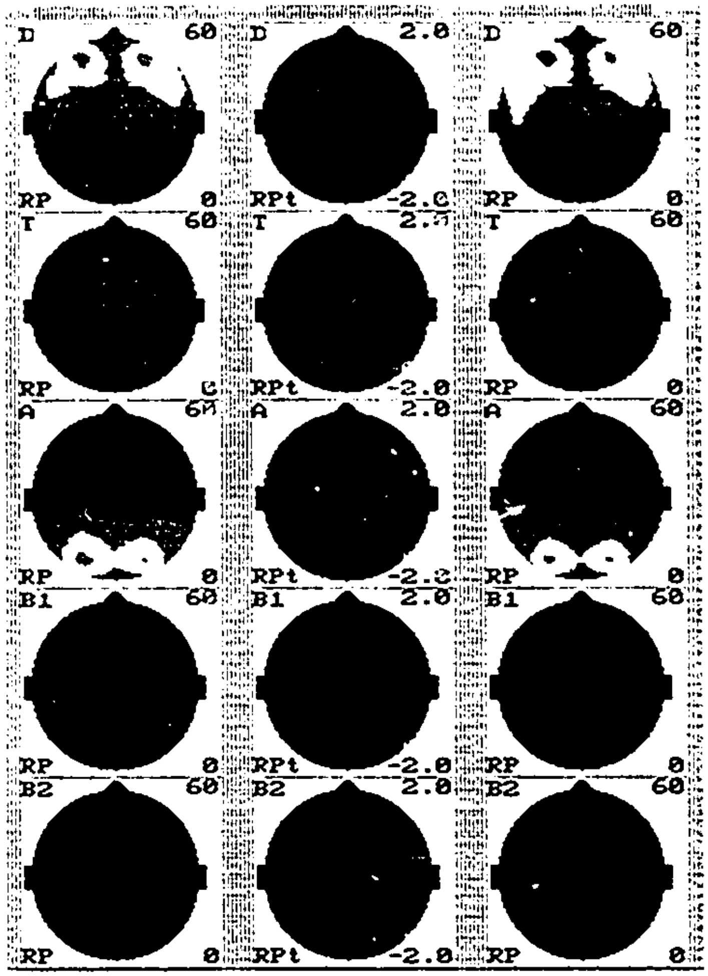

Figure 20 Comparison of topographic maps of relative power between the initial resting state EEG and the memorizing task for the gifted non-clinical group.

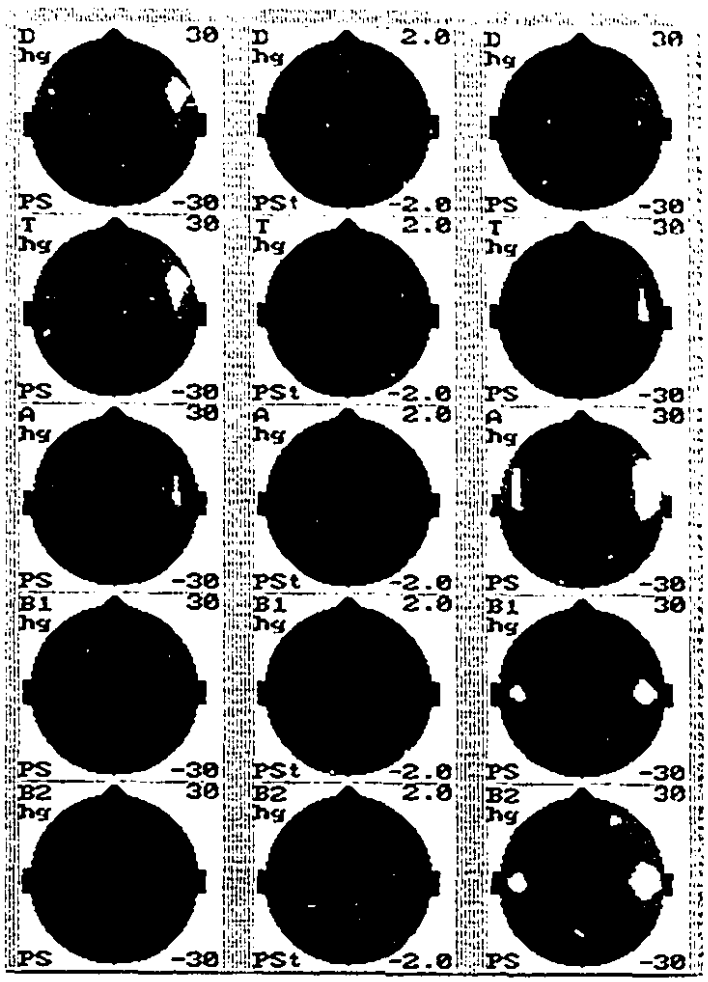

Figure 21 Comparison of topographic maps of asymmetry between the initial resting state EEG and the memorizing task for the gifted non-clinical group.

Memorizing Task - Gifted Clinical Group

The comparison of absolute power between the initial resting state EEG and the memorizing task for the gifted clinical group is presented in Figure 22. The statistical probability maps presented in column two revealed no significant differences between the baseline in column one and the memorizing task in column three.

In the comparison maps of relative power (see Figure 23), there would appear to be a greater proportion of power in the theta band in the left posterior temporal, left occipital, and right occipital regions, and in beta 2 in the left posterior temporal region for the memorizing task shown in column three compared to the baseline in column one as observed in the statistical probability maps in column two. However, these differences were within normal limits.

No significant differences were found in the topographic maps of asymmetry, displayed in Figure 24, between the resting state EEG in column one, and the memorizing task in column three.

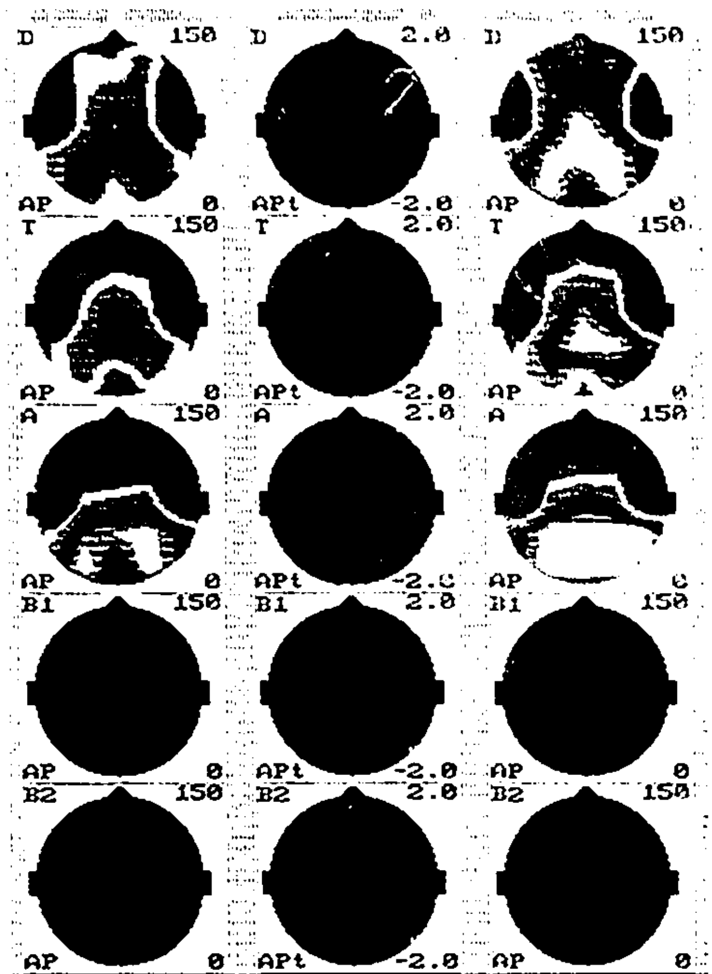

Figure 22 Comparison of topographic maps of absolute power between the initial resting state EEG and the memorizing task for the gifted clinical group.

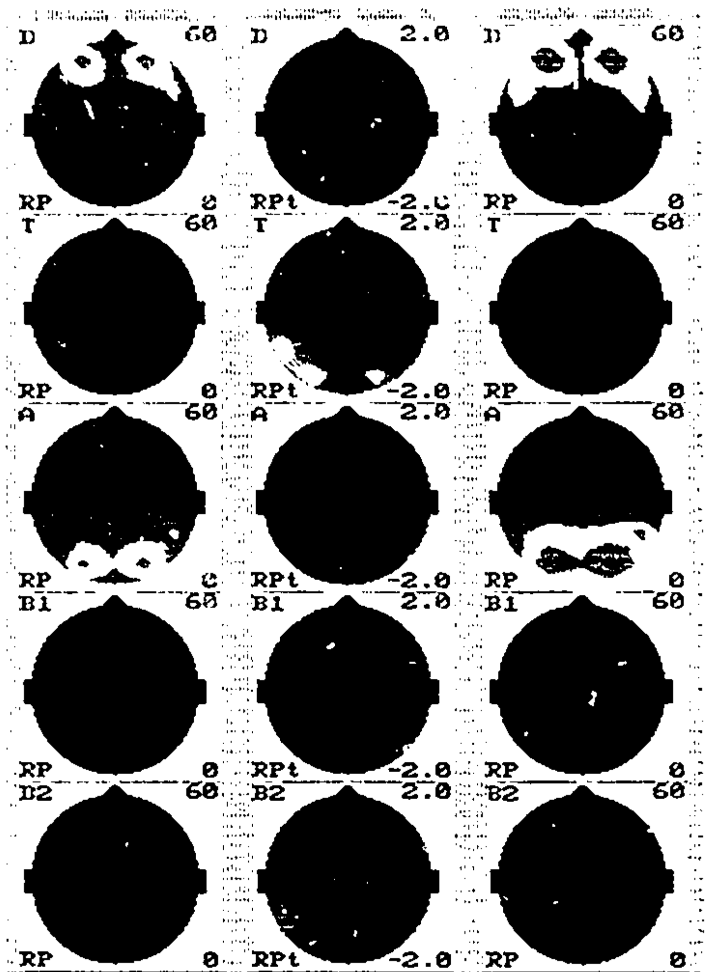

Figure 23 Comparison of topographic maps of relative power between the initial resting state EEG and the memorizing task for the gifted clinical group.

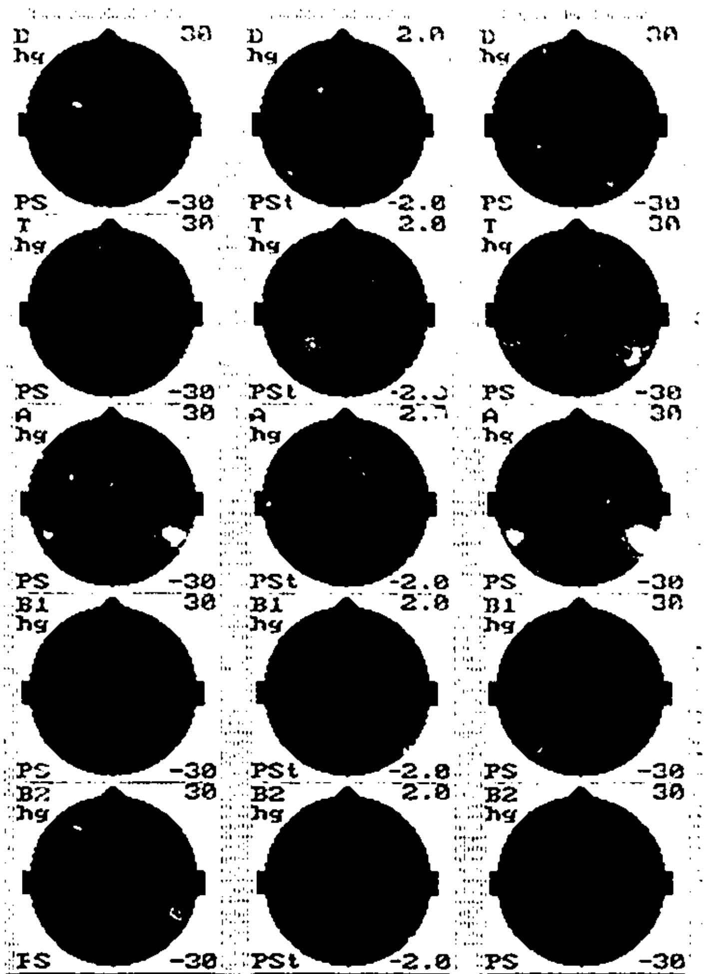

Figure 24 Comparison of topographic maps of asymmetry between the initial resting state EEG and the memorizing task for the gifted clinical group.

Recognition Task - Gifted Non-Clinical Group

The maps of absolute power for the resting EEG in column one and the recognition task in column three are presented in Figure 25. The statistical probability maps indicated an increase in power in the delta band in the left and right anterior temporal regions, and significant differences in the left and right frontal regions during the recognition task. Note that the differences in frontal activity may have been due to increased eye movement.

Figure 26 displays the maps of relative power for the baseline in column one compared to the recognition task in column three. Significant decreases in the left and right frontal regions were found in the theta, alpha, and beta 2 bands, while an increase was shown in these two regions in the delta band for the recognition task. However, given the results on absolute power, these also may have been due to increased eye movement.

In the maps of amplitude asymmetry presented in Figure 27, there would appear to be greater asymmetry in the delta band in the recognition task in column three than in the baseline in column one. However, as indicated in the statistical probability maps in column two there were no significant differences.

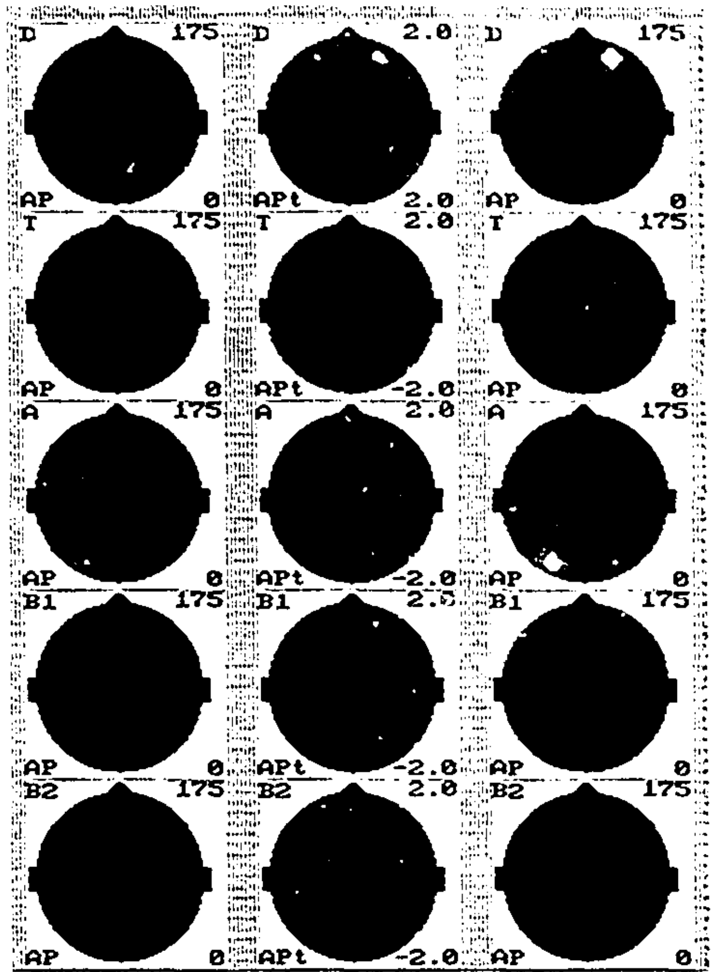

Figure 25 Comparison of topographic maps of absolute power between the initial resting state EEG and the recognition task for the gifted non-clinical group.

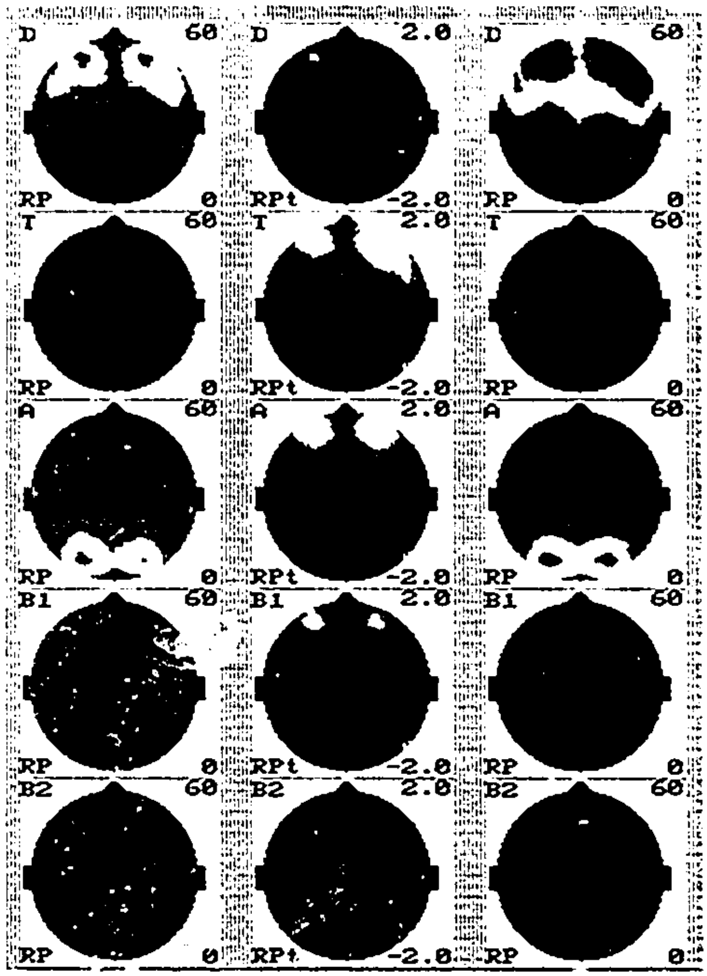

Figure 26 Comparison of topographic maps of relative power between the initial resting state EEG and the recognition task for the gifted non-clinical group.

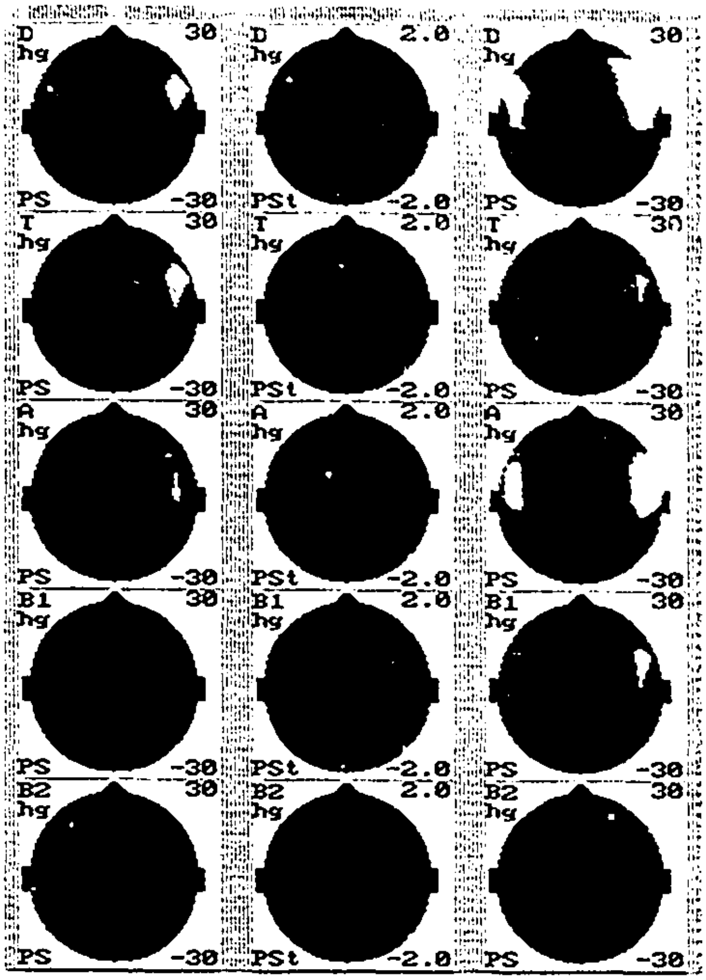

Figure 27 Comparison of topographic maps of asymmetry between the initial resting state EEG and the recognition task for the gifted non-clinical group.

Recognition Task - Gifted Clinical Group

Figure 28 illustrates the comparison of the topographic maps for absolute power between the resting EEG in column one and the recognition task in column three. The statistical probability maps in column two indicated an apparent increase in power during the recognition task in the right anterior and posterior temporal regions, in theta in the right parietal region and in alpha in the right occipital, right frontal, left frontal and left posterior temporal regions, however, these differences fell within normal limits.

In the maps of relative power displayed in Figure 29, the statistical probability maps indicated that the proportion of power in the theta band was significantly higher in the left posterior temporal and right occipital regions for the baseline recording in column one, compared to the recognition task in column three. Although there appeared to be a higher proportion of power in theta in the left occipital region, and in beta 2 in the left and right posterior temporal regions for the baseline recording the differences remained within normal limits.

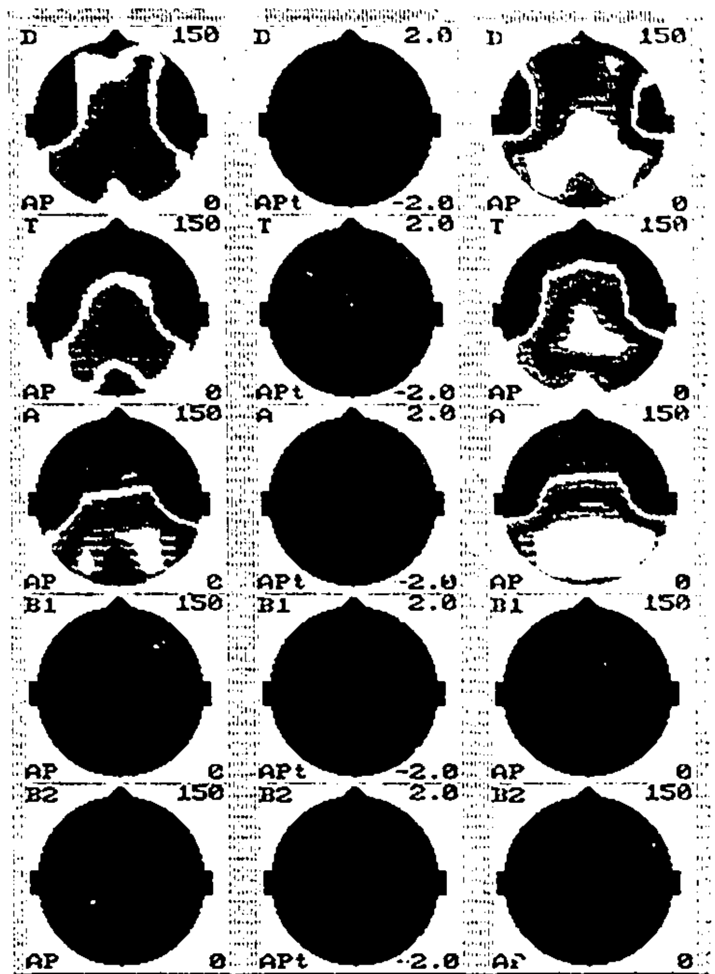

Figure 28 Comparison of topographic maps of absolute power between the initial resting state EEG and the recognition task for the gifted clinical group.

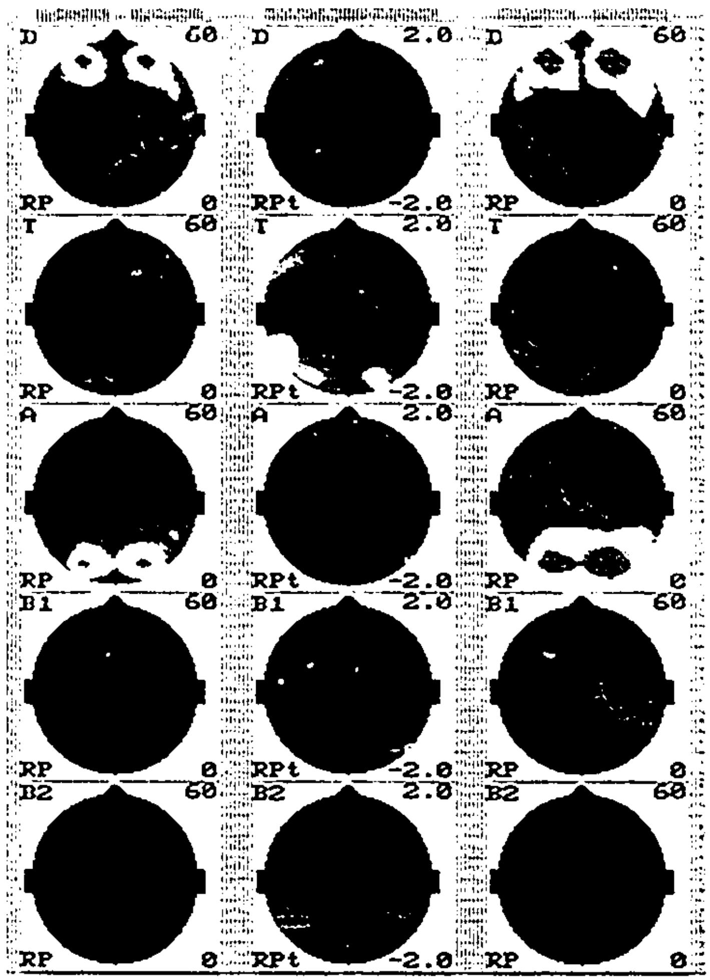

Figure 29 Comparison of topographic maps of relative power between the initial resting state EEG and the recognition task for the gifted clinical group.

The maps of amplitude asymmetry are presented in Figure 30. The maps in column one represent the resting EEG and the maps in column three represent the recognition task. As illustrated in the statistical probability maps in column two there was a significant difference in the degree of asymmetry in the delta band in the left and right frontal regions between the baseline and the recognition task. However, the observed differences in beta 2 between the left and right temporal regions fell within normal limits. While there appeared to be differences in power between the left and right hemisphere (higher on the right lower on the left) during the recognition task, except for the significant differences noted previously, these differences remained within normal limits.

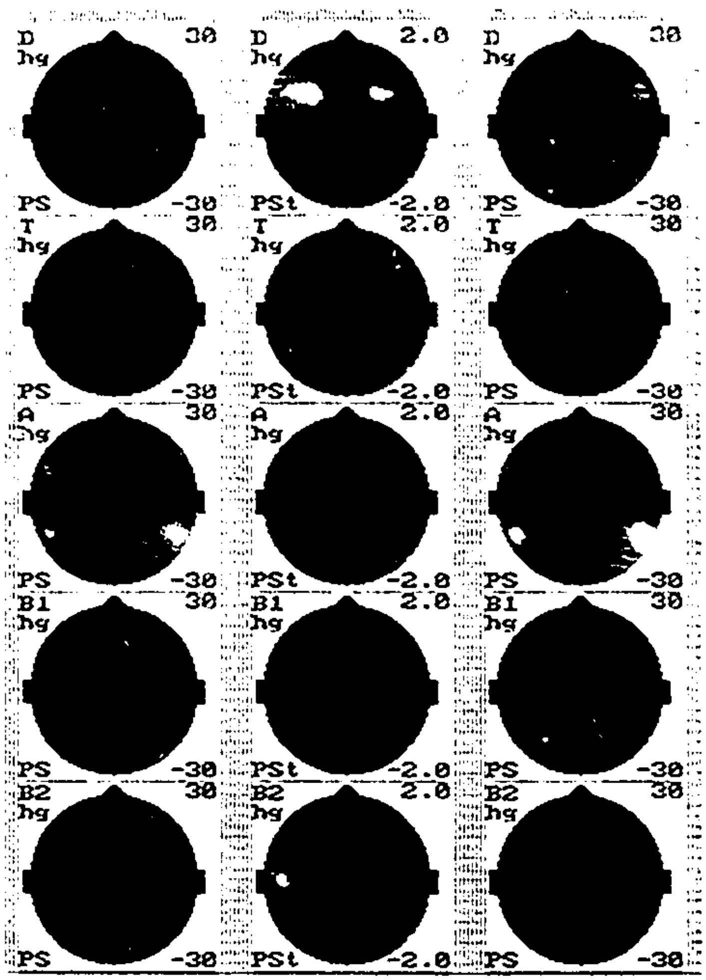

Figure 30 Comparison of topographic maps of asymmetry between the initial resting state EEG and the recognition task for the gifted clinical group.

Supplementary Analyses

Two additional analyses were done on the initial resting state EEG. The purpose of the first of these analyses was to explore a relatively little researched set of descriptive characteristics called the Hjorth parameters. The second of these supplementary analyses arose from the results obtained from the analysis of absolute power for the initial resting state EEG. The results of these analyses are presented in the following sections.

Hjorth Parameters

Hjorth (1970) suggested that one of the main problems in the quantitative description of EEG signals was to define the descriptive qualities for the representation of an "amplitude/time pattern" usually through the application of specific mathematical and/or statistical methods. This resulted in attempts to describe the EEG signal in terms of a small number of parameters. Hjorth argued that data reduction techniques used in frequency description such as the power spectrum neglect phase information (i.e. the time relationship between two identical points on a wave recorded at different derivations) which is an important descriptor of the EEG. In an effort to describe the dynamic properties of the EEG, Hjorth (1970) developed a series of formulae to examine variances in amplitude (i.e. the magnitude of the voltage) during the EEG epoch. Hjorth's method of signal analysis involves the measurement of three parameters over successive epochs of one to several seconds in duration (Cooper, Osselton, & Shaw, 1980). The three parameters are labelled activity, mobility, and complexity.

Activity represents the variance of the amplitude fluctuations in the epoch. The second parameter, mobility, obtained from the first derivative of the amplitude fluctuations in the EEG signal, represents the mean frequency of the EEG signal. Complexity is obtained from the second time derivative of the amplitude fluctuations in the signal and represents the skewness of the frequency distribution of the EEG or the spread of the frequency.

This method of signal analysis results in three values which represent the pattern of the signal for each epoch. Hjorth (1970) demonstrated that these parameters describe the shape of the signal wave and are mathematically associated with the power spectrum of the signal.

Gifted Non-Clinical Group Compared to the Database

The maps in Figure 31 illustrate the comparison of the Hjorth parameters of the resting state EEG for the gifted non-clinical group in column one to the database of age-matched peers in column three. Going down the columns from top to bottom, each row displays the parameters of activity, mobility, and complexity respectively.

There were no significant differences in activity as seen in the statistical probability map in the second column. There was a significant difference in the mobility parameter in the parietal region as illustrated in the statistical probability map. No significant differences were found in complexity as shown in the last of the statistical probability maps shown in column two.

Gifted Clinical Group Compared to the Database

The comparison of the Hjorth parameters of the resting state EEG for the gifted clinical group in column one to the database of 9 to 13 year-old peers in column three is shown in Figure 32.

No significant differences were found in activity as seen in the statistical probability map in the second column. As with the non-clinical group, there was a significant difference in the mobility parameter in the parietal region as shown in the statistical probability map. There were no significant differences found in complexity as illustrated in the statistical probability maps shown in column two.

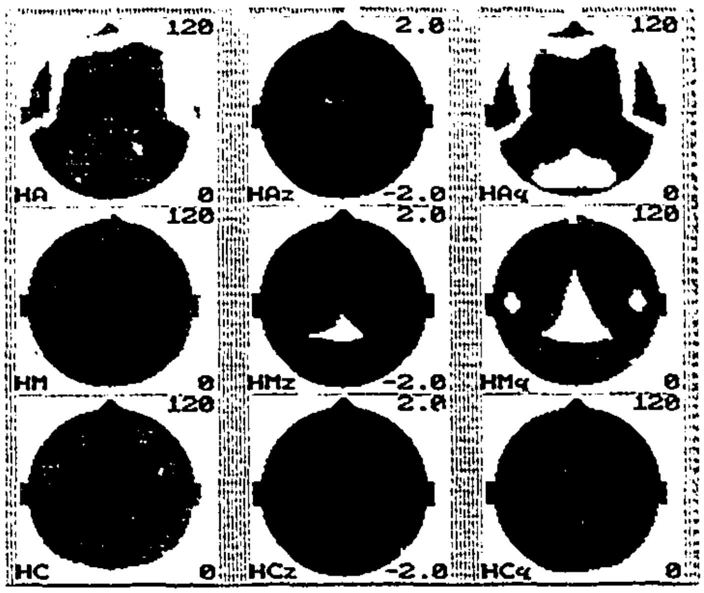

Figure 31 Comparison of topographic maps of Hjorth parameters of the initial resting state EEG for the gifted non-clinical group to the database of medically-healthy, age-matched peers (aged 9 to 13 years).

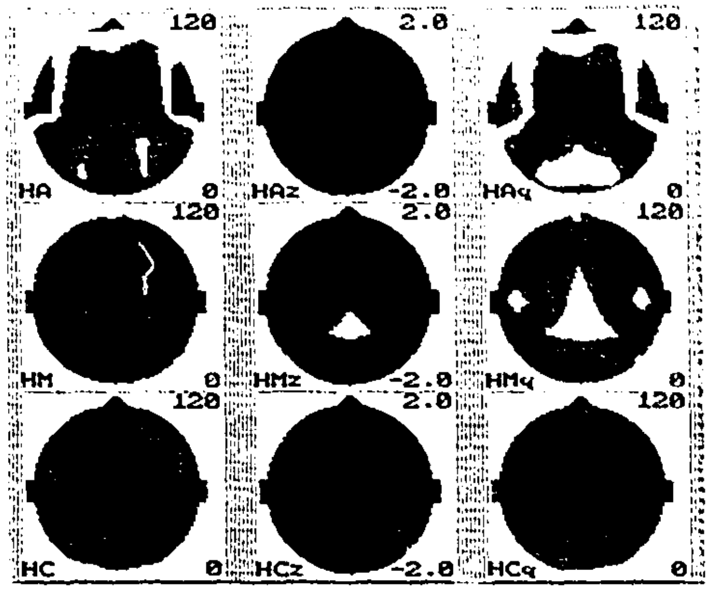

Figure 32 Comparison of topographic maps of Hjorth parameters of the initial resting state EEG for the gifted clinical group to the database of medically-healthy, age-matched peers (aged 9 to 13 years).

Maturational Dimension

The frequency composition of the EEG reflects the age and functional status of the brain. With maturation, the dominant frequency becomes more rapid, and brain dysfunction, brain damage, or deterioration can cause frequency-slowing in the regions involved (John, 1980).

As previously discussed in Chapter 2, there are characteristic developmental differences in the EEG between children and adults. The most striking difference is the posterior dominant rhythm which is slower and of higher amplitude in children.

Given that the gifted non-clinical group appeared to have lower absolute power than their normal age-related peers in all frequency bands, and particularly in the slower frequency bands, an additional comparison was made. The topographic maps of each group were compared to the database group of medically-healthy, young adults aged 20 to 29 years.

Gifted Non-Clinical Compared to Young Adults

As can be seen in the maps in Figure 33, most of the differences previously noted in the comparisons with their own age-related peers have disappeared. The topographic maps of absolute power for the gifted non-clinical group appear to be much more similar to the norms for medically healthy, 20-29 year-olds. This is particularly evident in the delta and alpha frequency bands. Note that in the specific regions where power was significantly lower when compared to the age-related peers, the statistical probability map shows no significant differences.

There appeared to be some differences in the theta band, particularly in the right temporal region, however, these were not significant.

Gifted Clinical Compared to Young Adults

While there were no differences in absolute power between the gifted clinical group and their age-related peers, in comparison to the young adult population the gifted clinical group showed much higher levels of activity in all the frequency bands (see Figure 34). These differences were significant in most regions.

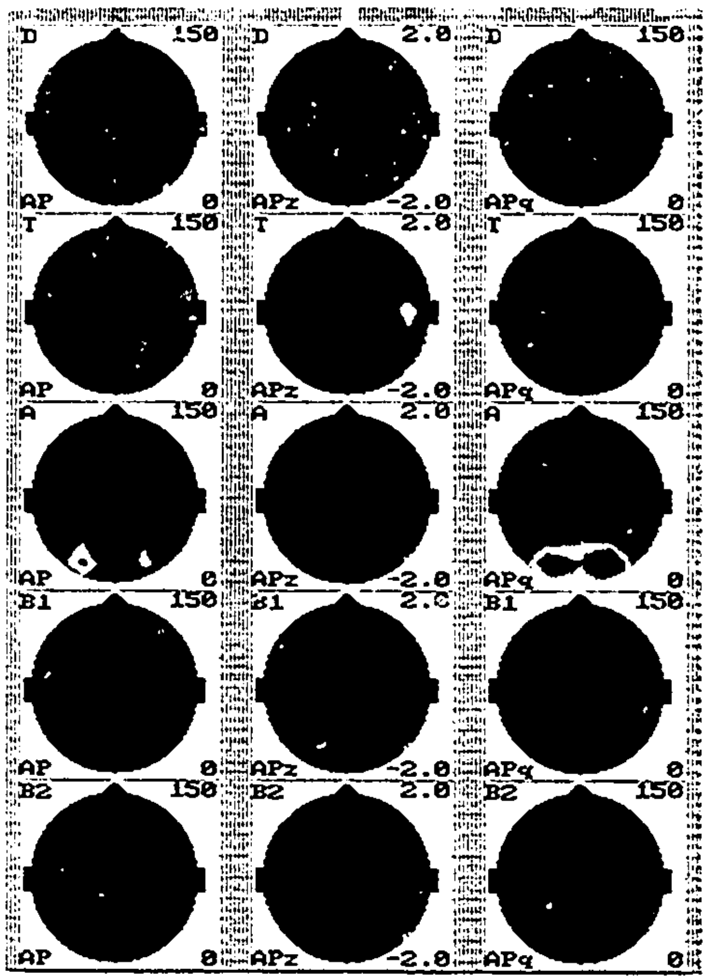

Figure 33 Comparison of topographic maps of absolute power from the initial resting state EEG for the gifted non-clinical group to the database of medically-healthy, young adults aged 20 to 29 years.

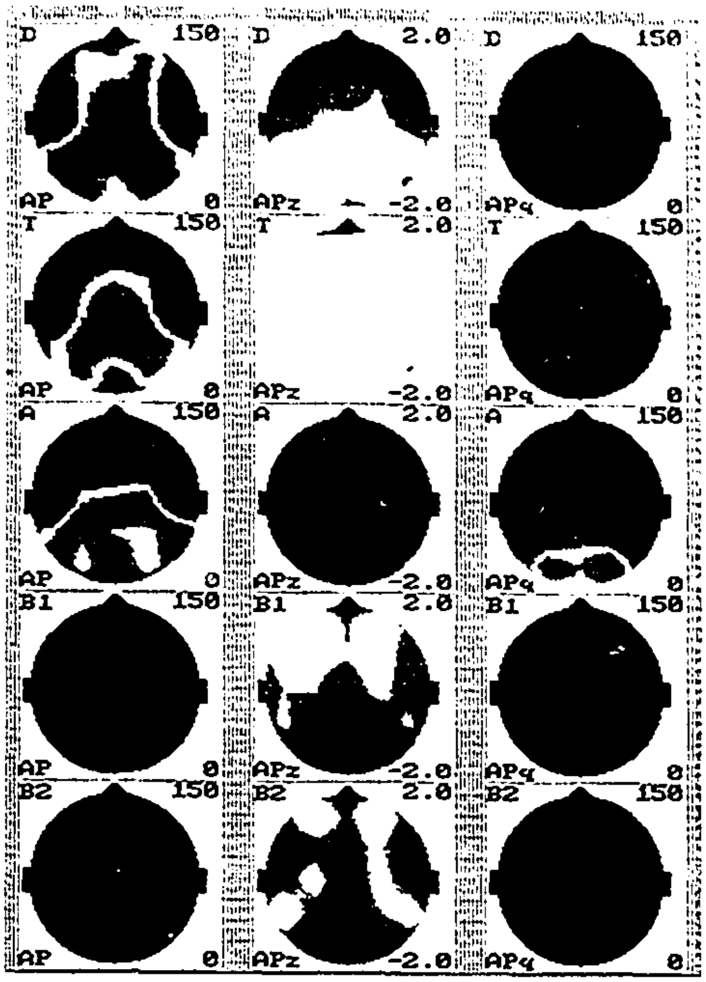

Figure 34 Comparison of topographic maps of absolute power from the initial resting state EEG for the gifted clinical group to the database of medically-healthy, young adults aged 20 to 29 years.

Summary of the Chapter

This chapter presented the results of the data analyses. It was found that there were significant differences in absolute power in the resting state EEG between the gifted non-clinical group compared to the database of medically-healthy, age-matched peers. There were no significant differences between the gifted clinical group compared to the database.

Although there were some significant differences in the individual maps for the cognitive tasks compared with their baseline records, these did not manifest themselves in the analyses for the gifted non-clinical group. Some significant differences were found for the gifted clinical group when comparing the EEG records for the various tasks with their baseline resting EEG.

Supplementary analyses indicated similar differences in the Hjorth parameter of mobility for both the non-clinical and the clinical groups when compared to the database of medically-healthy, 9 to 13 year-old peers. There is also some evidence to suggest a similarity between the resting EEG of the gifted non-clinical group and a database comparison group of young adults, aged 20 to 29 years.

5. DISCUSSION

This chapter discusses the results of the analyses presented in the previous chapter. In addition to interpreting the findings, some implications for education and suggestions for further research are presented. Some of the preliminary results were previously discussed in Coffin, Kaye, Gelcer, Maier, Cartwright, and Petrauskas (1991).

Summary of the Research

The purpose of this study was to compare the spectral characteristics of the EEG of two different groups of gifted children to determine whether (QEEG) can be used to discriminate between these particular groups. Additionally, comparisons were made to ascertain whether differences emerged when performance on cognitive tasks were compared.

The study involved twelve subjects between 9 and 13 years of age: five from a gifted underachieving clinical population and seven subjects identified as gifted high achievers from a non-clinical population. The groups were defined by performance on standard psychometric tests and academic achievement.

An initial resting recording of five minutes was made with eyes closed, and another five minutes of eyes open, awake but relaxed. Following this, three specific cognitive tasks were presented consisting of listening to a list of words, memorizing a list of words, and recognizing familiar words from a list. The EEG was continually recorded with eyes closed during the tasks.

The EEGs were artifacted and an FFT performed on each of the records. Topographic maps of the electrical activity were generated and comparisons were made using statistical probability maps. The topographic maps of absolute power, relative power, and amplitude asymmetries for the resting state EEG of the gifted clinical group and the gifted non-clinical group were compared to the normative database of medically healthy, age matched, non-gifted peers. Comparisons were also made between the two groups of gifted children on the same measures.

The topographic maps of absolute power, relative power, and asymmetry for each of the cognitive tasks were compared to the resting state EEG for both groups of subjects. Supplementary analyses were carried out examining the Hjorth parameters for both groups and comparing the resting state EEG of each of the groups to the normative database of young adults.

Interpretation of the Findings

Based on the results of the analyses presented in the previous chapter, the following interpretations can be made.

The Gifted Non-Clinical Group Compared to Age-Matched Peers

The results supported Hypothesis 1 that there would be differences in the spectral parameters between the gifted non-clinical group and the database of medically healthy, age matched, non-gifted peers. However, significant differences were found only in absolute power suggesting that although the proportion of activity in each of the frequency bands is the same as their non-gifted peers, the intensity of the activity is much lower for the gifted children.

Since the intensity of the EEG activity decreases when individuals are engaged in mental activity, it is possible that these gifted children are usually not mentally "at rest" and thus show patterns of mental engagement in their resting state EEG. However, another possible explanation is that of maturation. In addition to changes in the posterior dominant rhythm associated with development, the intensity of the activity also tends to decrease with age. Thus it may be that the differences noted between the gifted non-clinical group and their age-related peers may be a result of precocious development. This was explored further in the supplementary analysis presented in Chapter 4 which will be discussed in a later section in this chapter.

Although asymmetries were found in the ratio of activity between the left and right hemisphere supporting Beck (1975) who found differences in asymmetry in visual evoked potentials in bright children, the levels of asymmetry did not significantly differ from non-gifted peers.

The Gifted Clinical Group Compared to Age-Matched Peers

Hypothesis 2 was not supported: no significant differences in absolute power, relative power, or asymmetry were found between the gifted clinical group and the database of medically healthy, age-matched, non-gifted peers.

The Gifted Non-Clinical Group Compared with the Gifted Clinical Group

It was anticipated that since the gifted clinical group were identified as gifted and learning disabled they would show some similarity in spectral characteristics to their gifted peers because of their giftedness. Languis, Bireley, and Williamson (1990) found that gifted learning disabled children displayed similar characteristics as the gifted non-learning-disabled, as well as characteristics of the learning disabled in their EEG. This was not the case, however, and therefore the results did not support Hypothesis 3. In fact the gifted clinical group were very similar to the non-gifted peers and did not show the low absolute power found in the gifted non-clinical group.

The Cognitive Tasks Compared to the Resting EEG

Despite the fact that no significant differences were found for either group in comparisons of the listening and memorizing tasks to the resting EEG, comparisons of the recognition task to the baseline resting EEG yielded significant results and thus provided some support for Hypothesis 4 that there would be differences between the cognitive tasks and the resting EEG.

Significant increases in absolute power in the frontal and anterior temporal regions and significant decreases in relative power in the left and right frontal regions were found for the gifted non-clinical group. For the gifted clinical group a significant decrease in relative power was found in the left posterior temporal region and an increase in asymmetry was found between left and right in the frontal region.

The results obtained for the gifted non-clinical group support the findings of Stigsby, Risberg, and Ingvar (1977) particularly as they relate to changes in the frontal region in absolute and relative power. Given the nature of the tasks these results were expected. It is interesting to note that the gifted clinical group did not show similar results in absolute and relative power in the frontal region and that the only characteristics in which there was a significant shift was in asymmetry, a characteristic which was not significantly different for the gifted non-clinical group. This result may be due to some learning problem, since there is evidence that gifted learning disabled individuals often show weaknesses in memory skills (Baum, 1984; Ganschow, 1985). However, any further interpretations are limited due to the lack of a non-gifted comparison group.

Hjorth Parameters

As previously stated the Hjorth parameters were originally designed to describe the dynamic characteristics of the EEG. Since they are not derived from the FFT they were not included in the set of electrophysiological measures investigated initially. The Hjorth parameters were examined in supplementary analyses which yielded significant results. The results of these analyses revealed the only measure on which both the gifted non-clinical group and the gifted clinical group showed significant differences from the non-gifted peers and in which both groups of gifted children were similar.

Both groups demonstrated increased mobility in the parietal region as compared to the database of age-matched peers. Since mobility represents the mean frequency of the EEG an increase in mobility means that the frequency of the activity tends to be higher in this region for the two gifted groups. While these differences are not apparent in either absolute or relative power, it may be that this parameter provides a measure of cortical maturity, since it is known that the dominant rhythm increases in frequency as children develop. This has been suggested previously by Chavance and Samson-Dollfus (1978) who found mobility in conjunction with the peak alpha frequency to be the best indicator of maturation.

Comparison of Resting EEG to a Young Adult Population

Supplementary analyses also revealed that the topographic maps of EEG activity were not significantly different from a database comparison group of medically healthy, non-gifted, young adults between the ages of 20 to 29 years. They did still show some of the characteristics of youth, specifically greater theta intensity in the right hemisphere (Kiloh, McComas, Osselton, & Upton, 1981) but they remained within normal limits in comparison to the adults.

This similarity lends support to the notion of early maturation in this sample of gifted children. However, the maps for the gifted clinical group were significantly different in all areas from the database of young adults. Given the results of the analyses on the Hjorth parameters, the results obtained in this comparison do not necessarily negate the possibility of early maturation in the gifted clinical group. Just as it has been found that in cases of damage to a particular region of the brain the same region in the opposite hemisphere may begin to take on the functions of the damaged region (Springer & Deutsch, 1985), it is possible that the higher levels of activity compared to the gifted non-clinical group are related to learning problems and may be indicative of some type of compensatory action of the brain. Once again, the absence of other comparison groups necessarily limits any conclusions which can be drawn.

Summary of the Results

The results of the data analyses reported in Chapter 4 are summarized in Table 3.

Implications for Cognitive Research

Currently, knowledge of how individuals learn and solve problems is primarily inferred on the basis of observation of performance (Languis & Kraft, 1985; Languis & Wittrock, 1986). Gale and Edwards (1983) have suggested that electrophysiology may provide a direct method of measuring what is happening in the brain during mental activity. Although these techniques do not "brain-read" thoughts or plans, as Churchland (1986) pointed out, they do reveal things such as increases and decreases in activity in different regions. This information can be combined with that obtained in other areas of cognitive science to assist in formulating hypotheses concerning the relationship between cortical functioning and problem solving and/or information processing.

The goal of understanding how the mind/brain works is shared by both cognitive science and neuroscience (Churchland & Sejnowski, 1988). In attempting to arrive at such an understanding the explanations provided at the cognitive level and the findings originating at the neuronal level have come closer together in the emerging field of cognitive neuroscience. Techniques such as

Table 3

Summary of the Results of the Data Analyses

	Absolute Power	Relative Power	Amplitude Asymmetry	Hjorth Parameters
Comparisons of *gifted non-clinical* group with age-matched peers	significantly lower in the delta band in the mid-occipital, mid-parietal, and left anterior temporal regions.	no significant differences	no significant differences	significant increase in mobility in the parietal region
Comparisons of the cognitive tasks with the resting EEG for the *gifted non-clinical* group	*Listening Task* no significant differences	*Listening Task* no significant differences	*Listening Task* no significant differences	
	Memorizing Task no significant differences	*Memorizing Task* no significant differences	*Memorizing task* no significant differences	
	Recognizing Words significant increase in the left and right anterior temporal and frontal regions in the delta band	*Recognizing Words* significant decreases in the left and right frontal regions in the theta, alpha, and beta 2 bands, and significant increase in the left and right frontal regions in the delta band	*Recognizing Words* no significant differences	

Table 3 cont'd

Summary of the Results of the Data Analyses

	Absolute Power	Relative Power	Amplitude Asymmetry	Hjorth Parameters
Comparisons of *gifted clinical* group with age-matched peers	no significant differences	no significant differences	no significant differences	significant increase in mobility in the parietal region
Comparisons of the cognitive tasks with the resting EEG for the *gifted clinical* group	*Listening Task* no significant differences	*Listening Task* no significant differences	*Listening Task* no significant differences	
	Memorizing Task no significant differences	*Memorizing Task* no significant differences	*Memorizing Task* no significant differences	
	Recognizing Words no significant differences	*Recognizing Words* significantly lower in the left posterior temporal and right occipital regions in the theta band	*Recognizing Words* no significant differences	

Table 3 cont'd

Summary of the Results of the Data Analyses

	Absolute Power	Relative Power	Amplitude Asymmetry	Hjorth Parameters
Comparisons of *gifted non-clinical* group with *gifted clinical* group	most regions are significantly lower in the non-clinical group in all frequency bands	no significant differences	significantly greater asymmetry between the left and right anterior temporal and temporal regions in the delta band for the non-clinical group (left lower than right).	
Comparisons of *gifted non-clinical* group with young adults	no significant differences			
Comparisons of *gifted clinical* group with young adults	significantly higher in most regions in all frequency bands in the gifted clinical group			

topographic brain mapping provide a method for direct observation of covert learning processes (Languis & Wittrock, 1986). The application of these techniques to the study of learning, problem solving, and/or information processing may make it possible to form a link among specific physiological markers and cognitive processes. This information may well provide the "windows" to the mind and "windows" to the brain suggested by Coles (1989), contributing valuable clues for extending our knowledge and understanding of brain functioning and its relationship to cognitive functioning.

Implications for Education

The primary area in which education may be affected is in the use of quantified electrophysiology for the identification of special populations of children. This technology may be used to identify individuals, who by virtue of their superior abilities or because of learning problems, may be considered candidates for special programs. QEEG analysis provides a method of testing which eliminates cultural bias and differences in verbal ability (Restak, 1979) and its potential in the area of learning disabilities has already been noted (Fuller, 1977, 1978; John et al., 1985, 1989; Lubar et al., 1985). This is particularly important for those who are both learning disabled and gifted, a group which presents a challenge for traditional methods of identification and whose learning problems may go completely unrecognized because of their superior intellectual abilities.

This type of information may be of value to special education particularly in the area of program planning which is a critical component in the development of an individualized education program (IEP). The IEP is a formal educational plan designed for an individual student on the basis of assessment information and based on the specific instructional needs of the student (Lewis & Doorlag, 1991). The use of information obtained from QEEG and spectral analysis in identifying areas of weakness for remediation has already been demonstrated with some success (H. Kaye, personal communication, March, 1990)

A further area of impact will be on research in education. Educational research has traditionally focused on the influence of various factors such as teaching methods, classroom environments, interactions between the teacher and the child, and the external observation of students as they interact with tasks (Languis & Kraft, 1985). Quantified electrophysiology provides a method of observing the ongoing activity of the brain while children are actively engaged in different learning tasks. Combining this psychophysiological information with that obtained from more traditional methods of observation will provide a much broader and more vigorous approach to research (Languis & Kraft, 1985) and may lead to a better understanding of the learning process.

Limitations of the Study

The limitations of this study affect the conclusions which can be drawn. The first of the limitations is small sample size. Although in this type of research sample sizes are typically not large, the size of this sample particularly with a heterogeneous group such as the gifted learning disabled must have had an effect on the results of the comparisons to the non-gifted peers.

The heterogeneity of the gifted clinical group is a serious concern. This particular sample of subjects was recruited from a group of children who were identified by a team of clinical psychologists at the Clarke Institute of Psychiatry as gifted learning disabled. However, as noted in the review of the literature, the identification of individuals as gifted and/or gifted learning disabled is somewhat subjective. Of particular relevance are the cutoff values for IQ scores and the use of WISC-R subtest scores. Since the cutoff scores for the gifted clinical group were lower than for the gifted non-clinical group, they may not have been a very strong comparison group for the gifted non-clinical group.

The following limitation is related to the cognitive tasks. The tasks were very simple and thus the level of challenge, particularly for the gifted non-clinical group, was not very high. Changes in the eyes closed EEG may be very subtle and if, as suggested by Schafer (1982), high intelligence is associated with neural adaptability or efficiency, the cognitive tasks may not have been sufficiently challenging to demonstrate this.

Finally, although the normative database of medically healthy, age-matched peers provided a reliable comparison group for the resting state EEG, the lack of data on the cognitive tasks for a control group of non-gifted peers limited the comparisons which could be made.

Suggestions for Further Research

The results of this study raise a number of interesting questions which may be explored in future studies. One of the first questions deals with the maturational dimension. Although individuals in the gifted non-clinical group were found to have topographic maps of absolute power which were similar to non-gifted young adults, there is no such information available concerning gifted adults. Therefore it is not possible to determine whether the topographic maps of the brain activity of gifted adults look like those of non-gifted adults, and thus it is not possible say whether the similarity between the maps of the gifted children and the non-gifted adults is related to precocious development or whether the gifted have a different developmental pattern from the non-gifted.

Further exploration of the Hjorth parameters should be conducted, particularly since this was the one characteristic in which the two groups of gifted children were identical. The Hjorth parameters were designed to described the dynamic properties of the EEG and thus it may be that they can provide an alternative method for exploring the relationship between EEG and different abilities.

Studies that examine the differences in cortical activity related to different cognitive tasks as well as differences in difficulty level within the tasks may enabled researchers to better explore the concept of neural adaptability or efficiency in individuals with high IQ as suggested by Schafer (1982). These studies, in combination with studies looking at mental work load, may provide additional information concerning information processing in highly able individuals.

Conclusion

Despite the small sample size, there is evidence to suggest that there are differences between diverse groups of gifted children and between gifted, high-achieving children and their non-gifted peers. At present, there is insufficient data to indicate whether these differences represent early maturational or different developmental patterns. One of the central questions of this study was whether QEEG could be used to differentiate between different groups of gifted children as well as between the gifted and the non-gifted. The results of the analyses provide sufficient evidence to suggest that QEEG can be used to differentiate between gifted high achievers and their non-gifted peers. The utility of QEEG for differentiating between gifted underachievers and non-gifted peers has not been adequately demonstrated. Although based on the results of the present study it may be argued that QEEG could provide a method to successfully differentiate between different groups of gifted children, it is recommended that further studies be undertaken before drawing any definite conclusions.

The lack of significant findings in the comparisons of the listening and the memorizing tasks to the baseline recordings does not necessarily imply that there are no differences in brain activity during the performance of different cognitive tasks since the tasks themselves may not have been sufficiently challenging to elicit significant changes. There is some support for this notion given that when subjects were asked to try to recognize words from a list (representing an increased challenge), significant differences emerged in comparison to the resting EEG.

The results of this study provide a foundation for further research and the extension of this methodology to other problems. Future studies might explore early markers in exceptional children or monitor children during development and during various training and treatment regimens.

Applied to education, such studies may provide insight into the processes of learning and problem solving. This approach may provide a method for discriminating among children of differing cognitive abilities by eliminating cultural bias through profiling the brain activity for different subgroups (e.g. the gifted and the learning disabled). In addition, the merging of neuroscience research with educational research may provide more rigorous methods for exploring individual differences in learning and problem solving.

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GLOSSARY

Absolute Power: Absolute power refers to the intensity of the electrical activity occurring in each of the frequency bands.

Activity: Activity is the Horth parameter which represents the mean power or standard deviation of the EEG.

Alpha Band: Alpha is the activity which occurs within the 8 to less than 13 Hz frequency band and is usually denoted by the Greek letter α.

Alpha Rhythm: Refers to the rhythmic activity occuring at 8 to less then 13 Hz usually over the posterior regions of the head and typically with higher amplitude over the occiptial region. The alpha rhythm predominantly occurs during wakefulness with the eyes closed, and usually when an individual is in a relaxed physical or mental state. The activity is attentuated when the eyes are opened or by attention or mental activity.

Amplifier Gain: The electrical signal output by the brain is relatively small (in the microvolt range), thus it is necessary to use a series of amplifiers to augment the signal for recording purposes. The number of times the signal is amplified or increased is referred to as amplifier gain. The recording amplifiers were conventionally set using a constant gain of 80K (representing an aplification of 80,000 times, or a maximum gain of $\pm$ 64 μV).

Amplitude: Amplitude is the magnitude of the voltage of the EEG signal and is expressed in microvolts (μV) which is equivalent to millionths of a volt.

Artifact: Artifact is any activity in the EEG recording from a non-cortical source. The sources of artifact may be classified into different types: instrumental, environmental, electrical, and physiological.

Asymmetry: Asymmetry refers to the power relationships between the two hemispheres. This can be computed based on total power as well as for each frequency band. Power relationships may be determined for each lead (electrode) compared to every other lead, for each lead and every other lead within a single hemisphere, or for homologous leads, in which each lead is compared to its corresponding lead in the opposite hemisphere.

Band-Pass Filter: A band-pass filter allows electrical signals which fall within selected frequency bands to pass through unchanged, while decreasing the signal of frequencies flling outside the selected bandwidth.

Beta Band: Beta is the activity occuring above 13 Hz. The beta rhythm typically includes activity from 13 up to 35 Hz recorded from the fronto-central regions during wakefulness, and is denoted by the Greek letter β.

Bipolar Montage: A montage in which no electrode is common to all combinations. Typically in bipolar montages, the electrodes pairs are linked in chains of contiguous electrodes either going from front to back (longitudinal bipolar) or across the head left to right (transverse bipolar).

Complexity: Complexity is the Hjorth parameter which represents the sharpness of the EEG or the spread of the frequency.

Delta Band: Delta is the activity which occurs within the 0.4-3.5 Hz frequency band and is usually denoted by the Greek letter Δ.

Fast Fourier Transform (FFT): The FFT is a mathematical computation which breaks down the EEG signal into its frequency components (i.e. delta, theta, alpha, and beta). The FFT is based on the Fourier series analysis and was designed to reduce the number of computations required.

Hertz: A unit of frequency.

Hjorth Parameters: The Hjorth parameters are derived from a series of mathematical formulae which examine variances in amplitude during the EEG epoch and were developed to describe the dynamic properties of the EEG. The three parameters are Activity, Mobility, and Complexity.

Inion: The inion is a protrusion or bump at the back of the head just above the neck.

Mobility: Mobility is the Hjorth parameter which represents the mean frequency of the power spectrum of the EEG.

Montage: Montage refers to the arrangement of electrodes which determine the number of derivations which are displayed simulateously on an EEG record.

Nasion: The nasion is the indentation where the nose meets the forehead.

Preauricular Point: The point at the top of the ear where it joins the head.

Power: Power provides a measure of the amount of electrical activity occurring in different regions of the brain. Power is expressed as amplitude squared and provides an average of the amplitude of the electrical activity in the EEG.

Quantified Electrophysiology: The use of computers to record, store, and analyse the EEG and/or EP is referred to as quantitative electrophysiology.

Referential Montage: In a referential montage each scalp or "active" electrode is compared to a common reference electrode. Electrode locations used as neutral references include the contralateral ear, the nose, the chin, or linked ears (joined electrically). Reference electrodes are generally not completely neutral reference since electrodes placed on the ear, nose, or neck may potentially pick up signals from a non-cerebral source such as muscle activity or a component of the electrocardiogram.

Relative Power: Relative power is the proportion of electrical activity in each frequency band, relative to the total power.

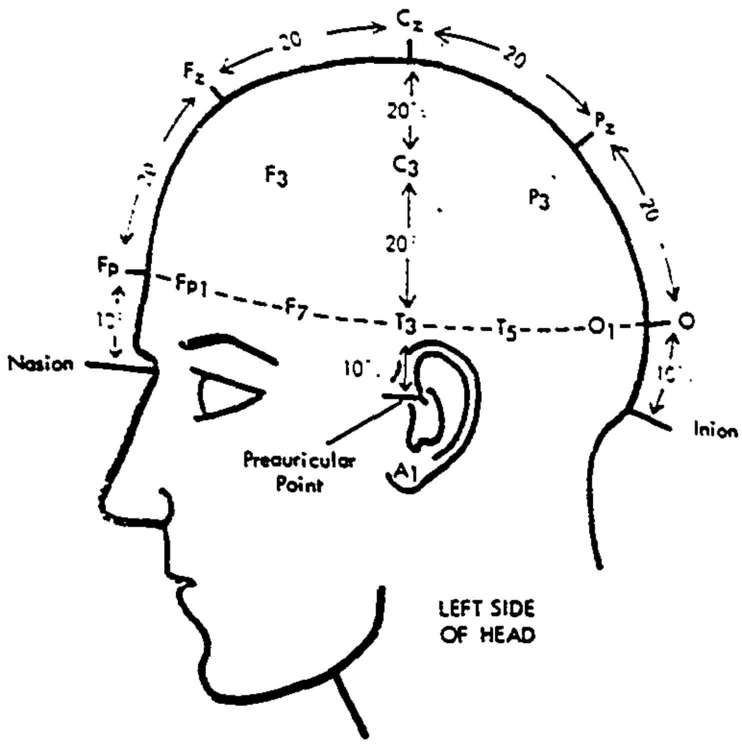
Spectral Analysis: A procedure frequently used in quantified electrophysiology to break down the complex patterns of the EEG into its different frequency components. The mathematical technique used in this analysis is known as the fast Fourier transform (FFT) which results in a series of amplitudes for the different frequency components of the EEG for the entire EEG recording. When the amplitude of each component is expressed in terms of its mean square value, it is possible to determine the proportion of the analyzed waveform which is attributable to each particular frequency.

Theta Band: Theta is the activity which occurs within the 4 to less than 8 Hz frequency band and is usually denoted by the Greek letter θ.

Total Power: Total power is the sum of the absolute power of the electrical activity in each frequency band for all regions of the head.

APPENDIX A

International Ten-Twenty System of Electrode Placement



IN THE 10 - 20 SYSTEM, ELECTRODES ARE PLACED EITHER 10% OR 20% OF THE TOTAL DISTANCE BETWEEN SKULL LANDMARKS

Harner, P. F., & Sannit, T. (1974). *A review of the international ten-twenty system of electrode placement*. Quincy, MA: Grass Instrument Company.

APPENDIX B

Letter of Consent

Consent Form

We would like to have your child participate in a research study. The study will compare the brain activity and behavior of several groups of children, among which will be children selected because of their school performance and learning ability. For this study brain activity refers to the electrical activity produced continuously by the brain, which we will measure in a standard fashion, but will analyze through the use of a new computer program. The purpose of this study is to determine if there are specific differences in the brain activity of different groups of children. This will greatly contribute to our knowledge about children of differing abilities, and in particular about giftedness.

As part of the study your child will be given a standard EEG while sitting quietly at rest, and while doing a simple memory task. This procedure is non-invasive, painless, and is used in routine evaluation of children, hundreds of thousands of times each year in North America. If at any time your child no longer wishes to continue, the procedure will be terminated and he or she may withdraw from the study.

The entire procedure will take approximately 2.5 hours. Your child will be met at the Clarke Institute by Ms. Coffin, who will be conducting the test, and escorted to the adjoining building for the EEG test. If you wish, you may accompany your child and remain throughout the EEG testing. In addition, your child will be administered the Halstead Reitan Neuropsychological Test Battery. As these tests take a day to complete they will be scheduled separately from the EEG test.

All personal and medical information will remain confidential, and for purposes of anonymity, your child will be assigned an identification number. Your child's name will not appear on any publications. Nor will your child's name be used in any of the analyses, either group or individual, unless you specifically request us to do so, in the event that we note any unusual problems that warrant your attention or that of your child's physician.

This study is carried out under the auspices of the McGill University Department of Educational Psychology and Counselling, the Clarke Institute of Psychiatry, and the Faculty of Education of the University of Toronto.

If you would like any further information, please feel free to contact Lorraine Coffin, 496-0808. Thank you for your participation.

I the undersigned give permission for my child ________________ to participate in this study.

______________________________ ______________________________

Parent's signature Date

I the undersigned give permission for my child ________________ to participate in this study and I request that any clinically relevant information be brought to me or to my child's physician.

______________________________ ______________________________

Parent's signature Date

Child's
Physician: ________________________ Tel. No.: ______________

APPENDIX C

Word Lists for Cognitive Tasks

List 1 Listening Task	List 2 Memorizing Task	List 3 Recognition Task
music	trouble	surprise
eagle	cheese	*happy*
river	work	nature
then	horizon	*bread*
pencil	dark	*even*
bottle	cradle	watch
moon	fun	gown
finger	ocean	success
deep	bread	*cheese*
glutton	cliff	*dark*
window	handle	*cliff*
road	lamp	*fun*
imply	dollar	between
open	salt	split
table	even	*animal*
block	quality	correct
letter	spell	shout
size	weather	train
awake	tray	*lamp*
milk	animal	circle
city	chin	*horizon*
shape	order	*spell*
light	must	escape
reach	kitchen	*order*
explain	happy	*jar*
cook	better	believe
exhaust	jar	hand
make	stretch	*chin*

Note: In the third list the "old" words (i.e. those which were previously presented during the memorizing task) appear in italics.