QUANTITATIVE MEASURES OF THE EEG AND THEIR IMPLICATIONS AS A DIAGNOSTIC ADJUNCT FOR DEPRESSION

By

ANTOLIN M. LLORENTE

Bachelor of Science in Electrical Engineering
The University of Texas at Arlington
Arlington, Texas
1984

Master of Science
Oklahoma State University
Stillwater, Oklahoma
1991

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of the Oklahoma State University
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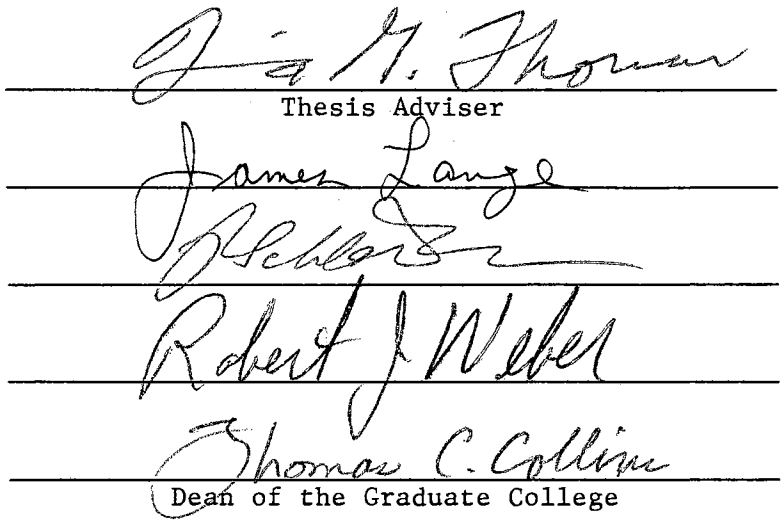

Thesis Adviser

Dean of the Graduate College

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Quantitative Measures of the EEG and Their Implications as a Diagnostic Adjunct for Depression

Antolin M. Llorente

Oklahoma State University

Abstract

Recent EEG studies utilizing alpha band power density asymmetry to investigate differences between groups of pathological and normal individuals suggest that asymmetry may serve as a good discriminator between these two groups.

Similar to previous studies, the present research attempted to investigate differences between depressed and normals using the alpha spectrum. Unlike previous studies, this research investigated differences between groups through examination within the alpha band rather than using the entire alpha band, while using very strict experimental controls. This analysis was conducted hoping to find differences between the two groups embedded inside the alpha spectrum that would otherwise be missed in an effort to increase the level of discrimination from that obtained with measures that examine the alpha band in its entirety or with presently existing physiological assessment measures.

Previous results, using overall alpha band measures, were not replicated in this study. The results from this research revealed that the finer, within alpha, examination is capable of discriminating individuals in the depressed group better than existing measures but lacks the specificity necessary to serve as a diagnostic measure.

Quantitative Measures of the EEG and Their Implications as a Diagnostic Adjunct for Depression

Ever since Berger (1929) demonstrated that it was possible to obtain a measure of brain wave activity through the use of the Electroencephalograph (EEG), researchers have attempted to utilize the EEG to investigate characteristics distinguishing normal individuals from those displaying varying degrees or types of psychopathology (Berger, 1938; Lindsley, 1944). Early studies (Ellingson, 1954; Lindsley, 1944) discovered differences primarily related to quantitative (e.g., frequency response), but not qualitative (e.g., shape, rhythmicity) variables. This seminal finding led to several subsequent studies which focused on measuring these variabilities. However, consistent or robust results remained elusive. Inconsistent findings were possibly due to the rudimentary nature and insensitivity of the technology available for detecting distinctive features between disordered and normal subjects (Lindsley, 1944). In addition to measurement problems, invalid and unreliable psychopathology taxonomical schemes available at that time probably prevented investigators from arriving at conclusive and consistent findings.

Four relatively recent developments are probably responsible for the present resurgence of quantitative EEG investigations examining the relationship between psychopathology and its effect on the EEG. One such development is the advent of technological advances in electroencephalographic equipment. For example, EEG equipment capable of providing greater and more accurate brain wave amplification and

measurements allow EEG researchers to study distinctive quantitative and qualitative features between normal and pathological groups with greater precision. The evolution of diagnostic classification schemes for the psychopathologies (Andreasen, 1983; APA, 1987; Matarazzo, 1983) is another development responsible for renewed interest in investigating psychological abnormalities and their sequelae on the EEG. Recently developed diagnostic schemes with increased validity and reliability in diagnosing psychological disorders enable researchers to obtain greater consistency when evaluating the relationship between these disorders and the EEG, although even these new taxonomical schemes leave us with much to be desired (Adebimpe, 1982; Hersen & Bellack, 1988; Kahn, 1973; Maracek & Kravitz, 1977). The third recent development is the analysis of the EEG with the aid of computers (computerized EEG analysis, CEEG) permitting researchers to analyze results with greater accuracy and efficacy. Finally, further impetus for modern investigations is furnished by current research suggesting that certain resting anterior EEG properties are more temporally stable than once thought (Tomarken, Davidson, Wheeler & Kinney, 1992), allowing for greater consistency of findings. These four recent advancements also propelled the present investigation.

Statement of the Problem

The present research was developed to assist in further understanding the relationship between psychopathology, specifically, chronic depression (unipolar, Gilbert, 1984; Willner, 1985; major depression, recurrent or single episode; APA, 1987) and its impact on the electroencephalogram. This study also attempts to employ the

effects of depession on the EEG utilizing large groups in an effort to build substantiating data for devising a simple, economic, noninvasive, endogenous, and reliable measure for chronic depression capable of serving as an adjunct diagnostic aid for individuals with this disorder.

This investigation benefits from the four previously described factors credited with the resurgence of EEG studies. Additionally, it advantageously uses as a backdrop abundant recent EEG investigations elucidating relatively stable measures of EEG asymmetry as robust quantitative variables capable of distinguishing normal from depressed individuals (Flor-Henry & Koles, 1981; Henriques & Davidson, 1990; Matousek, Capone & Okawa, 1981; Schaffer, Davidson & Saron, 1983; Tomarken, Davidson & Henriques, 1990; Tucker, Stenslie, Roth, & Shearer, 1981). Finally, this study, through the use of an endogenous method (EEG), addresses and eliminates various criticisms and liabilities (Hersen & Bellack, 1988; Morganstern, 1988) that have characterized verbal or clinician-based diagnostic classifications for the psychopathologies in psychology and psychiatry, in contrast to more technologically advanced and physiologically derived methods of assessing psychological disorders.

In summary, the purpose of the present investigation is to analyze the effects of chronic, unipolar major depression, single or recurrent episode, on the EEG and to use these results to build support for their possible use in creating a simple noninvasive, highly reliable, and economic non-verbal diagnostic aid for this disorder that would possess greater sensitivity than presently available endogenous (e.g.,

Dexamethasone Test (DST); Schildkraut, Green & Mooney, 1989) or verbally derived (e.g., DSM-III-R; APA, 1987) diagnostic methods.

Literature Review and Hypotheses

Depression has shared a preeminent position within clinical psychology (Jackson, 1986). No other disorder, except for schizophrenia, has been the topic of so much research, theorizing, and diagnostic classification. Without question, historically, depression and its related symptoms, have been the target of various assessment strategies and diagnostic schemes that attempted to account for the disorder in a valid and reliable fashion. Predominant assessment and diagnostic strategies, based on various theoretical models, include: psychodynamic approaches (Ariety & Bemporad, 1980; Freud, 1924, 1917), biochemical approaches (Murphy, Campbell & Costa, 1978; Schildkraut, 1978), cognitive-behavioral strategies (Beck, 1967; Ellis, 1972, 1973), and clinician-based multiaxial diagnostic and classification methods (APA, 1987). However, none of these approaches, except for biochemical assays, make use of a physiological marker as their pivotal source of data in diagnosing mood disorders. Moreover, this physiological approach is too cumbersome to be considered a simple diagnostic aid. It also requires an invasive procedure and it suffers from poor sensitivity (Flam, 1991). Therefore, it would be advantageous for clinical psychology to possess such a tool.

This review will briefly describe some of the existing assessment and classification schemes for depression and will then provide a rationale for developing a new noninvasive endogenous measure for this psychological disorder.

Freud (1917, 1924) postulated that anger and hostility turned inward were responsible for depression. Following his line of thought,

self-directed anger and hostility represented one of the key ingredients that a clinician would search for in order to diagnose a mood disorder. However, Freud lacked empirical data to accompany his theory of depression. In fact, research by Weissman, Klerman and Paykel (1971), refuted Freud's idea by demonstrating that depressed individuals exhibited greater hostility toward others, instead of expressing hostility towards themselves as theorized. In order to unify inconsistencies between theory and research findings, and to provide for better means of diagnosing depression, modern psychodynamically oriented researchers have postulated different theories. Recently, Ariety and Bemporad (1980) presented a model to account for a predisposition to depression, based on overdependency on a significant other, some goal, or incentive. The significant other or goal is relied upon to provide positive self-esteem and gratification; threat or loss of this source of gratification will lead to a predisposition for depression. However, this theory, as its predecessor, also lacks empirical data to support its basic tenets. In addition, a large number of dynamically oriented theorists have abandoned this perspective and currently utilize better methods for diagnosing depression (e.g., the atheoretical multiaxial diagnostic system DSM-III-R; APA, 1987; see below).

Contrastingly, Murphy et al. (1978), view depression as a neurobiochemical deficit. Specifically, these investigators postulate that low levels of the indolaminic neurotransmitter serotonin (5-HT) are responsible for symptoms found in individuals diagnosed with affective disorders. According to these authors, this theory has been recently

extended beyond the simple serotonin deficiency to a broader view of the etiology of the neurotransmitter imbalance, including alterations in monoamine enzymes and catecholamine/indolamine systems malfunctions. Nevertheless, viewing depression from this perspective, the assessment and diagnosis of the disorder consists primarily of determining abnormalities in these neurotransmitter systems or in subsequent plasmatic metabolites of these neurobiochemical substances. In fact, Murphy and his colleagues refer to their indolaminic representation of affective disorders as a "deficit state/reparative treatment model." Similarly, Schildkraut (1978) suggests that psychopathological symptoms present in the affective disorders, including depression, may in part be related to chemical transmitter dysfunctions. He postulates that deficits in catecholaminic transmitter systems, particularly related to norepinephrine metabolic mechanisms, may be responsible for the symptomatology observed in the affective disorders. Similar to the indolaminic hypothesis of depression, the catecholamine hypothesis suggests that diagnostic methods concentrate on determining abnormal levels of these transmitter substances or their metabolic by-products.

To this end, the DST Test (Schildkraut, Green, & Mooney, 1989) was developed to assess endogenous depression by examining cortisol concentration in the blood in response to Dexamethasone. Both of these theories, with their accompanying diagnostic schemes, have been very successful in generating substantial research and they are relatively accurate, although there has been some recent debate about the DST test's accuracy, reliability, and sensitivity as a gauge of endogenous

depression (Berger, Doerr, Lund, Bronisch & von Zerssen, 1982; Flam, 1991). However, the fundamental problem with this approach lies in its cost and its procedural invasiveness in order to assess depression through the use of biochemical traces (e.g., cortisol level, etc.) found in blood samples. Therefore, it is apparent from this criticism that client self-reported verbal measures of depression, although not endogenous, would be the swiftest and most economic method to assess mood disorders, including depression. To this end, we now examine several cognitive-behavioral theories, and their diagnostic approaches, that rely on a client's self-reported symptoms of depression.

Cognitive-behavioral representation of depression takes a different perspective than that presented above for the psychodynamic or biochemical approaches (Beck, 1967, 1974; Ellis, 1972, 1973). Beck (1967) feels that illogical and maladaptive cognitive processes interacting with affect are responsible for depression. In a similar vein, Ellis attributes depression to a set of faulty or "irrational" thought processes. Recognizing these inadequate ideations is critical to assessing mood disorders using Ellis' cognitive approach. Thus, negative thought processes are closely associated with depression. Through the use of self-report and paper and pencil instruments, a clinician is able to obtain a fairly good account (e.g., through the Beck Depression Inventory) of his or her client's affective status. This data is subsequently employed, by certain clinicians, in conjunction with other information, to assess, measure, and diagnose depression. However, clients' verbal reports are not always accurate (Lazarus, 1971) and may lack the stability and accuracy of a well

developed, valid, and stable endogenous measure for depression assuming that such a measure could be ascertained. Additionally, researchers such as Beck (Steer & Beck, 1988) have argued against using the BDI for diagnostic purposes and have emphasized that this instrument be used to determine the intensity of the disorder only. They further suggest that a clinical evaluation, with an instrument designed for diagnostic purposes, be conducted to establish a mood disorder diagnosis prior to using the BDI.

Clinical evaluations through the use of an atheoretical multiaxial method is the most common method currently in use to diagnose mood disorders, including major depression. This method makes use of a clinical set of psychological or behavioral syndromes self-reported by the client to the clinician to determine the absence or presence of depression (APA, 1987). Table 1 presents DSM-III-R's diagnostic criteria for major depression. Although the introduction of DSM-III-R in 1987 substantially assisted the diagnostic process (Andreasen, 1983; Small, 1987), clinician-based diagnoses suffer from some of the same criticism hurled against cognitive methods (Adebimpe, 1982; Matarazzo, 1983; Morganstern, 1988). Additionally, none of these paper and pencil

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Insert Table 1 about here

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language-based diagnostic methods are organically derived measures for chronic depression, and such an endogenous noninvasive assessment aid still evades researchers.

Rationale for Developing an Organically Based Noninvasive Measure of Depression

To date, clinical psychology or psychiatry has not been able to devise an endogenous, reliable, simple, economic, and noninvasive measure for chronic depression. If we speak in terms of reliability, ease, and noninvasiveness, currently existing biochemical methods for diagnosing chronic depression (e.g., DST Test; Schildkraut et al., 1989) fail to provide a highly sensitive, accurate, and valuable aid to diagnose this disorder (Berger et al., 1982; Flam, 1991). Similarly, current computer assisted neuroradiological techniques (CAT Scans, MRIs, PETs), although excellent at diagnosing structural brain pathology, are incapable of diagnosing psychological disorders. In fact, the EEG is a superior assessment tool when compared to computer assisted neuroradiological techniques in diagnosing psychological disorders (Lechtenberg, 1982). On the other hand, verbal report, by definition, is not an endogenous measure. Table 2 displays a comparison of all these approaches and their corresponding liabilities. From here, then, it is clear that the development of a reliable, valid, simple, and noninvasive organically-based diagnostic aid for depression would be of great value to clinical psychology for research and clinical purposes. Further,

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Insert Table 2 about here

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considering (1), that diagnoses of mental disorders based on symptoms have not been very accurate nor reliable in the past (Beck et al., 1962; Hersen & Bellack, 1988; Morganstern, 1988), or in guiding treatment

(Hersen & Bellack, 1988), and (2), comparing (see Table 2) these methods with simple, reliable, noninvasive, technologically advanced, and endogenous measures for depression, such as the computerized EEG, one has to wonder why the EEG has not been used in the past more frequently to aid in the diagnostic process. Granted that the EEG has been, in the past, and to a certain extent still considered unreliable in assessing affective disorders, recent research is beginning to suggest that certain EEG variables may be more temporally stable and internally consistent than once thought (Tomarken et al., 1992).

We have described and reviewed, thus far, some of the assessment and classification approaches currently available for depression and their respective shortcomings. It has also been suggested that the development of a noninvasive physiologically derived measure of depression would be desirable, and finally, that the EEG may perhaps be useful in providing such a measure, if a reliable and valid EEG variable(s) could be ascertained.[1] Logically, the next step would be to review the electrophysiological EEG literature to examine if there are any robust quantitative EEG group findings that may be utilized to help devise an organically-based diagnostic aid for individuals. Table 3 presents a tabulation of recent studies that will be reviewed and evaluated in the section that follows.

Insert Table 3 about here

Electroencephalographic Studies on Depression

In 1929, Berger demonstrated that placement of electrodes on the

surface of the skull and subsequent amplification of the electrical potentials emanating from the brain allowed him to obtain a signal representative of the brain's (primarily the cortex) electrical activity (Berger, 1929). This electrical activity is called brain waves and their record, the electroencephalogram or EEG. In order to differentiate the various types of waveforms observed in the EEG, waveform classifications have been created. One of these classifications subdivides brain wave activity using the frequency response of the waveforms. Delta activity is characterized by a band of frequencies from 0.1 to 3.5 Hertz (Hz; or cps, cycles per seconds). Theta activity is characterized by the frequency range from 4 to 7.5 Hz. Similarly, Alpha activity is denoted by a frequency band from 8 to 13 Hz, whereas Beta activity is faster, 14 to 30 Hz (Niedermeyer, 1987a; Scott, 1976). Electrophysiologically, slow waves (delta and theta) are usually considered clinically pathonomic if present while a person is awake (Glasser, 1963; Milnarich, 1958; Niedermeyer, 1987a). Conversely, they are commonly present while a person is asleep. In contrast, alpha activity is best elicited when awake, resting, and with eyes closed (Niedermeyer, 1987a). Similarly, beta waves are present in awake but alert states.

Utilizing these waveform frequency classifications, we now proceed to examine past use of the EEG in studies of psychopathology, specifically, for mood disorders. We will also attempt to employ robust and consistent findings from these large group electrophysiological EEG investigations to facilitate the process of discriminating normal from

depressed individuals, to assist in creating an endogenous diagnostic aid for individuals suffering from depression.

Initial Research

The use of the EEG to evaluate psychopathological characteristics in depressed individuals dates back to Berger's initial monographs in the late 1920s and 1930s (Niedermeyer, 1987a). Berger's fourteenth paper (Berger, 1938) reported differences between pathological and normal individuals. Lemere (Lindsley, 1944) as early as 1931 also reported the existence of certain differences between normals and schizophrenics, manic-depressives, and other pathological groups. Lemere postulated that "low amplitude alpha rhythm" in the psychoses was caused by "low activity in the cortex that permitted irrelevant ideas to exist side by side without the energy necessary for proper segregation and rational correlation" (Lindsley, 1944, p. 1081). Although several variations from normality were recognized at that time, consistent results, due to inaccurate electrical records or improper differential diagnosis, evaded researchers (Lindsley, 1944).

Several investigations were conducted after these seminal studies. Ellingson (1954) in an extensive review of the literature also concluded that certain abnormal alterations in the alpha frequency spectrum were apparent in depressed individuals but not found in normals; again, these findings were not very reliable.

Recent EEG Asymmetry Research

In a series of recent studies, investigators (Flor-Henry, 1976; Flor-Henry, Koles, Howarth & Burton, 1979; Flor-Henry & Koles, 1980; 1984; Goldstein, 1979) found that depressed patients exhibited greater

relative right versus left-sided EEG asymmetrical activation (less alpha activity) in various scalp regions. For example, Flor-Henry and Koles (1980) using depressed, manic, schizophrenic, and normal control subjects, recorded EEG activity in the 8-13, 13-20, and 20-50 Hz frequency ranges from homologous parietal and temporal regions P3[2], P4, T3, and T4 (Figure 1 shows location of electrode placement). Their results revealed greater right-than-left parietal acivation and a decrease in right-sided temporal activation for depressives compared to controls, when relaxed, at rest, with their eyes open[3] (alpha). A similar study performed by these same investigators (Flor-Henry & Koles,

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Insert Figure 1 about here

1984), using depressives (unipolar and bipolar), schizophrenics, manics, and normal controls, revealed the same results for the depressed group when compared to the control group. Unfortunately, no frontal electrodes were used as part of the montage utilized by these studies to provide a one-to-one topographic comparison with other recent studies (e.g., Schaffer et al., 1983; see below) where frontal leads were used. Nevertheless, the studies conducted by these researchers were well designed in the sense that they used Feighner's (Feighner, Robins, Guze, Woodruff, Winokur & Munoz, 1972) psychiatric diagnostic research criteria to categorize psychiatric patients and normals, thus assuring the validity and integrity of the experimental and control groups. However, a liability of this investigation rests on the fact that they utilized both unipolar and bipolar depressives as a single depressed

category when, in fact, these two types of mood disorders display different psychological symptomatology (APA, 1987) and may indeed display distinctive patterns of EEG activity. In addition, the subjects' large age range (53 years) comprising both the experimental and control groups may have been responsible for the slowing of the alpha spectrum since decrements in alpha activity have been observed with increasing age (Niedermeyer, 1987b).

In a study with inpatients suffering from severe depression, Perris, Monakhov, von Knorring, Botskarev and Nikiforov (1978) reported lower alpha (9.5-10.5) per cent amplitude for the "endogenously" depressed patients when compared to "reactively" depressed patients. Specifically, Perris et al. (1978) recruited patients diagnosed as endogenously or reactively depressed (unipolar and bipolar) using the Chronholm and Ottosson Rating Scale for Depression (CORSD) and measured their alpha, beta, and theta spectrum from scalp regions F3, F4, P3, P4, O3, and O4. Analyses of the results revealed that those individuals diagnosed as endogenously depressed exhibited greater interhemispheric amplitude differences than the reactive group in the alpha (9.5-10.5 Hz) frequency range. These results suggest, according to the authors, "that these hemispheric differences manifest themselves differently in relation to the severity of the depressive syndrome" (p. 227), with endogenously depressed subjects exhibiting more asymmetry than the reactive group. Although the results are as expected, this study also suffers from various experimental liabilities, some of which the authors refer to themselves. These investigators used subjects in their study comprising an age range of 50 years (23 to 73 years). This large age

range possibly affected their results, since the EEG proper varies as a function of age, most probably due to structural changes occurring in the cortex (Milnarich, 1958; Scott, 1976), with increasing decrements in alpha activity as age increases, in most cases (Niedermeyer, 1987b). The alpha spectrum definition employed by these investigators (9.5-10.5 Hz) is also too narrow by any standard (Niedermeyer, 1987a) when compared to the standard alpha spectrum definition; (8-13 Hz), missing a large portion of this spectrum. Finally, as the authors pointed out, the recruitment of endogenously depressed psychotics and non-psychotics also obscured their results since their findings could have been caused by the psychosis rather than the mood disorder without a way of teasing apart the impact of each disorder on the total outcome. Additionally, recruiting an unequal number of males (n=17) and females (n=28) for the experimental and control groups is inappropriate, since females have been observed to possess greater EEG activation than males (Flor-Henry & Koles, 1980). Nonetheless, the finding related to asymmetry in the alpha range is in accord with results from other laboratories. In fact, several recent independent studies have confirmed this right/left interhemispheric activation asymmetry for the alpha frequency band, although in distinct regions (frontal rather than parietal-occipital; Henriques & Davidson, 1990), as was the case with this investigation.

In 1979, Shagass and associates found correlations between psychiatric diagnoses and EEG variables. In particular, these researchers investigated EEG quantitative differences (amplitude, frequency variability, etc.) between a group of "non-patients" and

groups of schizophrenics, manics, depressives, and personality disordered individuals. Their results were enumerated in a later paper (Shagass, Roemer & Straumanis 1982). Although the EEGs of non-patients were found to differ from those of schizophrenics in terms of lower amplitude variability, greater frequency variability, greater wave asymmetry, and less reactivity to eye movement, their results did not support the findings found for depressives, when compared to non-patients, reported by earlier investigators (Matousek et al., 1981; Perris, 1975). In particular, they did not replicate the hemispheric asymmetric differences between depressives and normal subjects found by other researchers.

Whereas the results were not as expected, the reader must be cautious in interpreting these findings as contradictory, since the diagnostic criteria employed by Shagass and his associates were different (and more stringent) than that used by various previous investigators. In fact, Shagass was one of the first to use the original Feighner or Spitzer Research Diagnostic Criteria (Endicott & Spitzer, 1978) to determine group inclusion criteria for the different psychiatric diagnoses. The liability of this research lies in the types of subjects comprising the experimental groups. Shagass' treatment groups were too heterogeneous in terms of intra-group variability (he categorized mania and major depression under the major affective disorders category) which may have deleteriously affected his results. It is possible, considering the complexity of the human EEG, that each mood disordered subgroup may have exhibited different patterns of activation (c.f., Perris & Monakhov, 1979). Therefore, when distinct

diagnostic mood disorder categories are amalgamated, as in Shagass et al.'s (1982) investigation, the distinctions forced upon the EEG by the different disorders may have created inconsistencies. Additionally, Shagass and his associates alluded to differences in methodologies used in their study, compared to similar studies, possibly responsible for some of the apparently contradictory results. Nonetheless, since certain variabilities were found between major depressives and manic-depressives (not normals), Shagass and his colleagues postulated the notion that these differences, if reliable and robust, could serve as an aid in diagnosing psychiatric disorders (Shagass, 1982, p. 1434). As will be seen throughout this chapter, few investigators recognize this fact (see Matousek et al. (1981) for exception), yet this is perhaps one of the most plausible and fruitful applications for the EEG.

In a more recent study Schaffer, Davidson and Saron (1983) recruited six depressed and nine nondepressed college students, from an original pool of 415 students. The subjects were subsequently categorized on the basis of their scores on the Beck Depression Inventory (BDI), and their EEGs (alpha, 9-11 Hz) were measured as a dependent variable on scalp regions F3, F4, P3, and P4. The results revealed greater right frontal region (F4) activation (less alpha activity) for the depressed group in comparison to the nondepressed group. No distinctions could be made between the treatment and control groups on the basis of activation levels in the parietal regions. Figure 2 presents the results graphically. Although the results are as anticipated, various important methodological problems are evident in this research. These include the use of only the BDI to categorize

depressive subjects in the experimental group against recommendations by the inventory designer not to use the BDI, for this purpose (Steer &

Insert Figure 2 about here

Beck, 1988). In addition, the narrow alpha spectrum definition (9-11 Hz instead of 8-13 Hz), the small number of subjects employed (n=15), and the absence of assessment for other concomitant psychiatric disorders in the depressed group to ascertain that they suffered from depression alone also represent liabilities for this study. However, despite these methodological problems, the right frontal hyperactivation (less activity in the alpha band) and the presence of asymmetry was established and it appears to be a robust finding. Additionally, these investigators performed an interesting analysis. They correlated BDI scores with frontal alpha laterality activation ratio (F4-F3/F4+F3) and found "greater relative right frontal activation," or in other words, "lower ratio scores," correlated with "greater self-reports of depression" as measured by higher BDI scores. This is a notable result in that it supports evidence suggesting that relative right vs. left frontal alpha activation asymmetry (F4-F3/F4+F3), an endogenous measure, may indeed be correlated with other measures of depression, in this case, a subjective self-report assessment instrument (BDI), suggesting concurrent validity between the language-based paper and pencil measure (BDI) and the electroencephalographic (alpha) assessment for this sample. It also tentatively suggests that this asymmetry index may serve as an index of depression.

Henriques and Davidson (1990), in another recent study, attempted to support the hypothesis that resting anterior asymmetry was a "state-independent marker" for depression. In their investigation, individuals who had been previously depressed (n=6), but were not at the time of the experiment (normothymic) exhibited greater left-sided anterior (F3) and right-sided posterior (P4) EEG alpha (8-13 Hz) activity than the never-depressed (n=8) group. Additionally, these researchers assured that all subjects did not differ in emotional state at the time of testing, thus were able to support the state-independence asymmetry hypothesis since the normothymic group's higher activation levels could only be accounted for by the fact that they had been depressed in the past. Even though these researchers controlled for socioeconomic status (SES), age, homogeneity and validity of diagnoses using the Schedule for Affective Disorders and Schizophrenia (SADS; Endicott & Spitzer, 1978), laterality, and utilized subjects who had never received pharmacological treatment (excellent controls), their subject pool was very small, possibly biasing their results. In addition, their depressed group consisted of one individual who had previously suffered from major depression and five subjects who had suffered from minor depression as diagnosed by these investigators. Although these investigators utilized the SADS and the depressed subjects were all classified as depressed, the intra-variability of the depressed group, due to different types of depression (minor vs. major depression) may also have influenced their results. Nevertheless, even when one considers these liabilities, the results are promising in the sense that the investigators were able to discriminate between the

previously depressed (normothymic) and the never-depressed group from their EEG asymmetry indices alone. Interestingly enough, even in a predictive study of this nature these researchers make no reference to the diagnostic usefulness of their findings.

Studies Using Treatment Methods to Assess Their Impact on EEG Asymmetries

Next, several experiments will be reviewed that have examined certain treatments capable of reducing depression with subsequent effects of this reduction on the EEG. The rationale for all these studies is similar: changes in the level of depression, due to these treatments, should be positively correlated with pre-to-post treatment changes (decreased right anterior alpha activation) in the EEG. To the extent that this relationship is present, it suggests that the EEG is a valid and reliable measure of brain state changes caused by these treatments and their associated reduction of mood disorders. Finally, a biochemical explanation is presented below that may account for these psychophysiological EEG changes.

Electroconvulsive Therapy (ECT) and Indoklon Therapy (ICT). D'Elia and Perris (1973) conducted EEG studies with depressed inpatients, before and after they received bilateral electroconvulsive therapy (ECT; n=8) or Indoklon Therapy (shock treatment induced through the use of the drug hexafluorodiethyl; ICT; n=10) which had been administered in a random order. Using "depressed psychotics (n=18)," between the ages of 19-64, D'Elia and Perris (1973) compared left/right central and occipital region (Jasper, 1958) ratios before and after ECT and ICT treatment. Their results revealed lower left/right ratios after

treatment indicative of greater alpha activity of the right hemisphere, than the left, for these depressed inpatients. However, this study lacked a control group and the researchers had to utilize a control group from a different investigation. When comparing their results after treatment with that of other investigators, whose research used a control group, D'Elia and Perris (1973) found their treatment group not to differ from the "normal" control group of other investigators. This result is not surprising, considering the deleterious effects of bilateral ECT on patients (Weiner, 1989), specially, when it is used as a prolonged treatment (Milnarich, 1958; Scott, 1976). Notwithstanding, from these investigators' perspective, ECT reduced the level of depression, thus reducing the abnormalities found in the EEG in the experimental group, after treatment. Nevertheless, the results from this investigation are tentative at best, specially considering the small number of subjects utilized. In brief, if this paradigm is to be employed in the future, a normal control group, which also receives ECT, should be recruited. Further, to reduce the deleterious effects of bilateral ECT, unilateral ECT should be employed. Given these criticisms, this is one of the few modern studies alluding to the existence of the alpha spectrum asymmetry subsequent to bilateral ECT treatment.

Psychopharmacological Treatments. A similar line of research that points to the validity of the EEG as a plausible assessment aid for depression has been investigations that examine electroencephalographic hemispheric asymmetries as a function of the effects of psychotropic medications. If asymmetries are present during chronic depression, it

would be reasonable to postulate that drugs that reduce depressive symptomatology should be capable of reducing EEG asymmetries, if these asymmetries are produced by the underlying abnormal biochemical brain mechanisms being diminished by the psychopharmacological treatment. Using this paradigm, to demonstrate through the use of the EEG that lithium carbonate was capable of reducing depression, Heninger (1978) measured EEG (alpha, delta, theta) activity, from central and occipital regions in 22 to 61 year-olds psychiatrically diagnosed as "manic depressives" (n=15) and "schizoaffective schizophrenics" (n=3), prior to and after the administration of the medication. The subjects were diagnosed with the Short Clinical Rating Scale (SCRS) by an independent nursing staff and psychiatrists, prior to EEG measurement and drug treatment, indicating that the subjects exhibited clinical levels of depression (as measured by one of the categories of the SCRS). Comparing pre-to-post pharmacotreatment results, Heninger (1978) was capable of identifying slowing of the mean peak alpha rhythm for central and occipital regions; however, the increase in alpha power (1/alpha activity=activation) asymmetry was not significant, although the change was in the predicted direction. Nevertheless, the insignificant results might be explained in terms of the heterogeneity of the experimental subjects (bipolars and schizophrenics), the small sample size and the fact that several of the inpatients had received drug treatment for depression prior to the pre-treatment EEG recording session, and finally, that no frontal EEG leads were employed, this being the region most recently implicated with mood disorders (see below). Similarly, Matousek, Capone and Okawa (1981), in their study of the effects of

Thioridazine on interhemispheric activation differences, discovered left/right asymmetry ratio changes to vary as a function of the level of depression. These investigators used the EEG to determine the amount of asymmetry for a broad spectrum of frequencies (1.5 to 25 Hz) and locations on the scalp (anterior, F7-T3, F8-T4; temporal, central, and parietal). They used a group of endogenously depressed (n=27), paranoid schizophrenics (n=16), and healthy controls (n=373) as measured by the Comprehensive Psychiatric Rating Scale (CPRS). Their findings revealed decrements in left/right ratios (left-sided activation) after treatment with thioridazine, mainly for temporal areas but not for parietal regions and for beta, delta, and theta frequencies but not for the alpha spectrum. However, several weaknesses detract from their study's integrity. For example, the montage utilized was not similar to that of most investigators (F3-A1A2, F4-A1A2). They also separated the alpha spectrum into two components, and they did not use an endogenous measure to diagnose depression, yet they defined their depressed group as endogenously depressed. Nevertheless, the important findings of the study rest on the insignificant parietal alpha band asymmetry and in the increased left-sided amplitudes, when compared to right-sided amplitudes, for the depressed group, since similar conclusions from other laboratories have been observed. Finally, data on 373 normals indicated lower left-sided amplitudes than found in the depressives. Commenting on the effects of pharmacotherapy on the EEG, related to depression, Dimitrakourdi and Jenner (1975) concluded, in a review of the literature related to studies of lithium carbonate, that it was "probably correct to conclude that lithium" caused a "slowing of the

EEG." However, these authors also warned that "sometimes lithium had no effect on the EEG," compounding any generalizations that could be reached from this line of research.

In another investigation, Laurian, Gaillard, Le, and Schopf (1983), utilized Diazepam, and found very specific topographic effects on the EEG caused by the influence of this drug's treatment. In particular, these researchers found a decrease in alpha activity appearing mainly in the anterior and central scalp regions. This result validates the hypothesis that psychotropics that are capable of reducing depression can also have differential effects on the EEG in the frontal hemispheric regions; but more important, according to these authors, these results can be explained in terms of the underlying biochemical processes producing the EEG. According to these researchers, several investigators (c.f., see Oke, Keller, Mefford, & Adams, 1978) have shown asymmetries of some neurotransmitters in the human brain, particularly, norepinephrine in the thalamus. It is possible that these psychopharmacologic systems underlying brain wave activity (EEG), could affect the two hemispheres differentially, thus producing EEG asymmetries linked to these differentially distributed biochemical mechanisms. In fact, Pribram and McGuiness (1975), discussing attention-control circuits of the human brain that determine brain activation, found noradrenergic pathways controlling electrical activity in the cerebral hemisphere to be asymmetrical, with noradrenergic systems more pronounced in the right hemisphere (Oke et al., 1978). With this knowledge about the asymmetrical distribution of neurotransmitters in the human brain, it is conceivable how these

biochemical systems could possibly be responsible for differential activation asymmetries, specially for the psychopathologies. Finally, Fink (1978) in a review of research performed between 1966 and 1976 with different psychopharmacological compounds alluded to utilizing the EEG as a tool to aid the development of new psychotropic medications for the treatment of psychiatric disorders. This recommendation is only possible due to the EEG's discriminative response to the effects of certain drugs, but not others. The EEG's discriminative and relatively consistent response to medication therapy allows measurements of the effects of these compounds validly and somewhat reliably through the drugs' effect on EEG measures, such as asymmetry or other variables. It must also be noted that these results are in accord with chemical theories like those previously discussed (Schildkraut, 1978) in this chapter, providing concurrent validity between those biochemical theories and EEG asymmetry hypotheses. It is noteworthy, however, that although certain replicable and stable findings were obtained in these investigations, only Matousek and his colleagues (Matousek et al., 1981) hinted to using these findings as a plausible diagnostic aid for the psychopathologies.

Studies Examining the Elicitation of Emotions and Its Sequelae on Electroencephalographic Asymmetries

The investigations that follow in this section attempted to examine the effects of eliciting positive and negative emotions, through hypnotic states or visual media, in normal individuals and in measuring the impact of these emotional elicitations on EEG asymmetry.

The Elicitation of Depression Hypnotically. The reduction of anterior, though not of parietal activation, during induced depressed moods in normal subjects has also been observed (Tucker, Stenslie, Roth & Shearer, 1981; Tucker, 1981). Tucker (1981) induced depression hypnotically on normal subjects, and measured EEG on anterior areas (F3, F4) and parietal regions (P3, P4) pre-post induction. The results showed EEG changes during the induced depressed mood period, specific to right frontal hemispheric regions only. This outcome paved the way for Tucker (1981) to suggest, like Davidson (1978), that each hemisphere is specialized for processing different emotions as follows: the right hemisphere is responsible for evaluating negative emotions, while positive emotions are processed by the left hemisphere. Unfortunately, Tucker (1981) did not specify in his monograph in which band (alpha, beta, etc) had the EEG changes occurred.

The Elicitation of Positive and Negative Emotions in Normal Adults. Tomarken and associates (Tomarken, Davidson, & Henriques, 1990), bolstered by the stability of relative right vs. left hemisphere asymmetry evidenced in their research and that of other investigators (Tucker et al., 1981), and in particular that of the alpha rhythm in frontal regions, utilized resting frontal asymmetries to predict the outcome of affect eliciting-films. Specifically, these researchers measured frontal (F3 and F4) alpha band EEG in 32 adult females before and after an emotion eliciting film presentation. Resting relative right vs. left frontal alpha activation predicted self-reported negative affect in response to negative affect-eliciting films. The opposite result, higher left frontal activation to positive emotion-eliciting

film clips was also present. Therefore, these two results suggest that the two hemispheres are indeed specialized, with the right frontal area in charge of processing negative emotions and the left anterior area responsible for processing positive emotions, in accord with results form other laboratories (Tucker, 1981; Tucker et al., 1981).

These results would appear to argue against a state-independent right vs. left frontal asymmetry hypothesis for depression or negative affect, as had been postulated before by Henriques and Davidson (1990). However, the levels of depression exhibited by the previously endogenously depressed subjects, with their associated asymmetry, are far more severe and elevated, as depicted by their higher activation scores, (Henriques & Davidson, 1990), than those exhibited by normal subjects in emotional situations, such as when viewing a film clip.

Similar studies suggesting the specialization of the right frontal region for processing negative emotions were conducted by Davidson, Ekman, Saron, Senulis and Friesen (1990), and by Ekman, Davidson and Friesen (1990). Davidson et al. (1990) simultaneously assessed patterns of EEG activity (alpha spectrum only) on scalp regions F3, F4, C3, C4, T3, T4, P3, and P4 and facial expressions while using film clips eliciting disgust or happy expressions, as assessed by the Facial Action Coding System (FACS; Ekman & Friesen, 1978) in right handed subjects (n=37). The results revealed that films eliciting disgust were found to be associated with right frontal and temporal, but not parietal or central alpha frequency activation, supporting previous studies. The opposite was true for the homologous left-sided frontal-temporal areas for happiness. These results are in accord with studies performed by

other investigators (e.g., Tucker, 1981). Similarly, Ekman and his associates (1990), found Duchenne smiles, "smiling involving the muscle that orbits the eye and pulls the lip corners up," to be associated with higher anterior asymmetrical activity also. In this study, patterns of EEG alpha activity for scalp regions F3, F4, P3, P4, C3, C4, T3, and T4 were simultaneously recorded with self-reported emotional experience and facial expressions as elicited by either pleasant or unpleasant film clips in right-handed normal subjects (n=37; facial expressions assessed by the FACS). The results revealed that Duchenne smile (positive smile) was closely related to more left-sided anterior-temporal alpha wave activation. In summary, these studies further suggest the lateralized specialization of the frontal areas in normal subjects for affective cognitions, their linked activational patterns to alpha waves in anterior regions, and more important, the left-right hemispheric dichotomy in the processing of positive and negative emotions respectively.

EEG Asymmetry Investigations With Infants

If in fact differential activation levels in the right vs. left frontal regions of the brain coexist with the presence of depression or negative emotions, it would stand to reason, from an evolutionary perspective, that this phenomena should then be observable at a very early age in infants. Following this line of thought, Davidson and Fox (1982) found that asymmetry of emotional funcion appears to be present very early in life. In their research, 10-months-old infants (n=18) were presented with either a videotape of an actress' spontaneously generated happy or sad face, while EEG brain activity (1-12 Hz) was

being recorded from the left and right anterior and parietal scalp regions (F3, F4, P3 & P4). Their results demonstrated that the sight of a happy face was found to activate the left frontal area greater than the right frontal region. Parietal asymmetry failed to discriminate between the videotaped conditions. No differential response to sad facial expressions was evident. However, these results should not be cause for concern since Niedermeyer (1987c) claims that the alpha spectrum is not well developed yet in the anterior regions at this early stage of life. It is also possible that the negative images used were not powerful enough to cause the right anterior regions to display high enough levels of activity due to negative affect. However, since there was greater left-sided activation for happy faces, Davidson and Fox (1982) stated that the result argues for left frontal hemisphere specialization for positive emotions at this early age.

In a subsequent study with infants, Davidson and Fox (1989) examined crying responses to mother separation in 10-month-olds (n=13) and its effect on EEG (6-8 Hz) resting frontal, and parietal (F3, F4, P3 & P4) activation asymmetry. Infants who cried in response to maternal separation exhibited higher baseline right frontal activation compared to those infants who did not cry. Figure 3 presents these results in a graphic fashion. Although the results are as expected, the rate of attrition of subjects was very high for this study (63%) to reach any solid conclusion. Nevertheless, these researchers, drawing from similar

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Insert Figure 3 about here

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results from previous studies with infants (Fox & Davidson, 1987, 1988) in which they obtained higher right-sided than left-sided activation to negative emotions concluded that right frontal activation to emotional reactivity for stressful events may be a state-independent measure for negative affect.

EEG Asymmetry Studies With the Elderly

Studying older populations, Pollack and Schneider (1990) and Brenner et al. (1986) obtained similar results as studies performed with infants (Davidson & Fox, 1989) and younger adults (Schaffer et al., 1983), hinting to the presence of right-left anterior alpha activation asymmetry for depression or at least for negative emotions throughout the life span, and as a fundamental aspect of depression (marker). These researchers compared laterally homologous scalp regions, F3, F4, P3, and P4, in a group of 55-75 year-old depressed and normal controls, for their amplitude in the frequency bands delta, theta, alpha, and beta (.3-40 Hz). They found depressed subjects to display statistically significant increased absolute alpha amplitude when compared to controls. Although higher absolute, but not relative alpha amplitude differences were found in the depressed in contrast to the control group, the homologous anterior or posterior regional differences did not specifically distinguish between groups in terms of their relative right-left levels of alpha activation. As it has been pointed-out for previous investigations, this result may be due to the known fact that alpha rhythm decreases with increments in age (Niedermeyer, 1987b; Scott, 1976). Therefore, although the two groups of subjects were equivalent with regard to age (55-75), this large age range (20 years)

is probably still too broad and capable of attenuating the alpha output even though all depressed subjects had been diagnosed with depression via DSM-III-R. In brief, the large age span may be responsible for the insignificant differences in relative right/left anterior alpha rhythm activation asymmetry. Additionally, several (n=11) subjects had received pharmacotherapy in the past. It is plausible that the medication effect may have attenuated asymmetry values. Nevertheless, absolute alpha amplitude distinction between the depressed and control groups was established. Further, a correlation conducted by these investigators between the depressed group's absolute alpha amplitude EEG scores and their BDI scores revealed significant ($p<.05$) positive correlations for the anterior scalp regions, both left and right but not for other regions. Thus, the associations between the variables are partly as expected and enough to cause a predictive difference between the two groups. Reducing the age range of the two groups (reducing the EEG variability due to age) and ascertaining subjects without a past history of drug treatment would possibly have distinguished between anterior right vs. left activation asymmetry.

A Summary of EEG Studies and Their Implications for Diagnosis

Thus far, we have presented several EEG studies enumerating their results but we have not examined, in detail, how these studies could have aided the diagnostic process. Table 3 depicts a summary of all the recent studies reviewed above. Perusal of Table 3 makes it evident that several of these investigations (Davidson & Fox, 1989; Flor-Henry et al., 1979; Henriques & Davidson, 1990; Schaffer et al., 1983) point to the tentative robustness of relative right vs. left frontal activation

asymmetry as a possible variable that could be employed as a diagnostic aid. Figures 2 and 3 demonstrate pictorially the results obtained by Schaffer et al. (1983) and Davidson and Fox (1989) respectively. From the investigation of Schaffer et al. it is clear that they were able to categorize 83% of the depressives correctly based on their level of right-sided frontal alpha activation. Note this is not a near perfect prediction; conversely, it is higher than the 60% reported for the DST Test (Flam, 1991). Similar results can be stated about Davidson and Fox's study (Davidson & Fox, 1989). Davidson and Fox (1989) could have categorized criers vs. non-criers based on their level of right frontal alpha power (power=1/activity). In fact, based on the evidence suggesting that right vs. left activation differences of the EEG is relatively stable as indicated by all these studies, several investigators have postulated that these characteristics may be capable of serving in developing a diagnostic aid for psychological disorders (Matousek, Capone, & Okawa, 1981; Shagass et al., 1982). This is the course to be taken by the present study. In addition, cognizant that certain consistent findings have been established, yet attributing a large number of the inconsistent results to inappropriate experimental methodology (Davidson & Fox, 1989), methodological problems will now be enumerated and examined before proceeding with our study, where an attempt will be made to eliminate all the liabilities labeled against previous studies.

Methodological Issues: A Synopsis

Various criticisms were leveled against several of the studies presented above. These included problems with diagnostic heterogeneity

used in creating the experimental groups that participated in the various investigations (e.g., utilizing schizophrenics and depressed as the same group), mixing of psychopathological subtypes within the same classifications (e.g., bipolar disordered and unipolar depressed subjects under the same category of depression), utilization of the BDI to classify subjects as depressed rather than using an instrument specifically designed for this purpose, too low a level of intensity on the BDI to warrant clinical levels of depression, small treatment group sizes, too broad an age range for the control or experimental groups, too narrow a definition of the alpha spectrum, unequal number of males and females, and other similar issues. Although the overall results tentatively suggest that relative right vs. left frontal activation asymmetry may be a stable and valid measure of negative mood, even under the influence of certain of the aforementioned violations, all of these issues, in one way or another, compromised the results of several of these investigations at times (c.f., Henriques & Davidson, 1990). Therefore, the present study will attempt to eliminate and control for these methodological problems while employing more in-depth EEG measures to examine variabilities between depressed and control normals.

Purpose of the Present Investigation

The purpose of the present research is to analyze the effects of depression on EEG asymmetry in the alpha (8-13 Hz) frequency range in the frontal and parietal hemispheric regions (F3, F4, P3, and P4, respectively; see Figure 1 for location of electrodes). In addition, the present study will seek to investigate the possibility that contrasting the even and odd power density (energy) frequency components

within the alpha band (i.e., 8+10+12 and 9+11+13) between normals and depressed will serve as a better discriminator in assessing depression than frontal asymmetrical alpha rhythm power density activation levels, as measured by the ratio (F4-F3/F4+F3; see Endnote 8), alone. Moreover, this research, in an effort to control for critical methodological factors (Davidson, 1988) affecting electrophysiological studies using EEG asymmetry paradigms, will use various strategies to reduce probable sources of error that affected several of the studies cited earlier and that may deleteriously affect this investigation.

This research, similar to Pollock and Schneider's (1990) and Flor-Henry and Koles' (1980) research will use very stringent criteria for the determination of depression. Following Kendall, Hollon, Beck, Hammen, and Ingram's (1987) advice, who report that the classification of depression "should probably be reserved for individuals with BDI scores over 20" and their subsequent suggestion that the scores of depressives in undergraduate student populations are slightly lower, the mean criterion score of 10 used by Tomarken, Davidson, and Henriques (1990) appears to be too low to be used as a measure of depression in undergraduate subjects. Although these researchers obtained significant results using a score of 10 on the BDI, the present study, to assure that substantive clinical levels of depression will be achieved, will employ higher levels of intensity on the BDI.

The present study proposes to utilize the Zung Self-Report Depression Scale (Zung, 1965) and the BDI initially to screen subjects. The criteria for determining depression will be increased relative to that of past studies. When screening students for possible

participation, a score of 0.50 or above on the Zung SDS will qualify students as depressed. Additionally, a cut-off score of 16 on the BDI will be used as the criterion for participation in the treatment group. This criterion level is congruent with the standards suggested by Kendall et al. (1987).

To further control for diagnostic confounds that may have affected other studies (Henriques & Davidson, 1990; Schaffer et al., 1983), the current investigation will only make use of subjects who satisfy DSM-III-R's (APA, 1987) major depression, recurrent or single episode criteria (APA 1987; Pollock & Schneider, 1990) but no other diagnosis, since mixing distinct categories of depressed subjects has had less than acceptable results (Shagass, 1982). This will be accomplished through the use of the Structured Clinical Interview for DSM-III-R: Non Patient Edition (SCID-NP; Spitzer, Williams, Gibbon & First, 1990) which will be administered by the same graduate clinical psychology student trained in the administration of this instrument to all participants in the study.

In addition to the examination of alpha wave activation asymmetry as a function of group (normal; depressed) for frontal and parietal areas F3, F4, P3, and P4 respectively, the present research further proposes to conduct the following two analyses: (1) the frequency distributions of the per cent alpha band power spectral density (see Dependent Variables section for definitons) moments (mean, standard deviation, skewness, and kurtosis) between the depressed and normal groups will be compared to determine if their respective distributions are capable of differentiating the two groups; (2) this research will further examine the effects of contrasting the even-odd frequency

components (8+10+12 Hz; see Appendix F) vs. (9+11+13 Hz) that make up the alpha wave range for frontal (F3 and F4) and parietal (P3 and P4) areas. This will be performed to determine if differences exist between the control and experimental groups in these two sets of spectral components or in their difference (even-odd), capable of having higher sensitivity than the frontal alpha Asymmetry Index alone.

The rationale for these complex analyses rests on several concepts including: (1) the relatively stable finding from studies presented earlier indicating that there is an increase in activity in a very narrow range of frequencies (alpha 8-13 Hz). This increase in activity is present in depressed but not in normal individuals. (2) contrasting the frequency distributions of the average even vs. odd power spectral density components for the depressed and normal controls is a more encompassing and fine-grained analysis, recommended by certain investigators (Perris et al., 1978), than a simple asymmetry index as used by the several studies previously described. It is more encompassing in the sense that it does not collapses over the entire alpha frequency range as the Asymmetry Index ratio (F4-F3/F4+F3) does. Therefore, it is more likely that variability found within the alpha band between the two groups may be better differentiated by this method than through a simple asymmetry measure. The rationale for the examination of even vs. odd frequency components also rests on criticisms against the use of asymmetry indices. In calculating an asymmetry index (e.g., F4-F3/F4+F3) for a specific frequency range, a collapse over the range of frequencies occurs without further internal analysis inside this frequency range. It is felt that collapsing over

an entire frequency range disregards a great deal of information that would otherwise be analyzed if one examined the different frequency components, or sets of these components, that make-up the frequency band in question. This fine-grained examination, if reliable, could serve as a better discriminator between pathology and "normality" than an asymmetry index alone. If positive results are found for this analysis, it will be difficult to interpret the mechanisms underlying the even-odd frequency components. However, although an explanation of its method of operation may be welcomed, it is not necessary. If this measure proves to be a stable measure for depression, it could be utilized as a diagnostic aid without knowledge about its method of operation when sensing differences between pathology and its absence. This has frequently been the case for other diagnostic aids, and this one is no different.

Dependent Variables - A Caveat

Studies using psychophysiological methods to investigate psychopathology suffer from a plethora of nomenclature and dependent variables. Therefore, an attempt will be made in this section to describe and define the dependent variables discussed and utilized in this study.

1. Alpha band power density (energy) or total alpha band power density: This is the total power density or energy output by a subject from a specific skull region (e.g., F3) for the alpha band only. A subject's EEG output consists of energies from the various frequencies comprising his or her EEG. However, alpha band power density refers only to the energy circumscribed within the alpha spectrum (8-13 Hz).

Figure 4 presents graphically the concept of total alpha band power density. When the alpha band power density is discussed in this thesis, it is assumed that the total alpha band power density is being addressed unless another dependent variable (e.g., per cent alpha band power density) is explicitly used.

Insert Figure 4 about here

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2. Per cent alpha band power density (per cent alpha band energy): Similarly, per cent alpha band power density is an individual's total EEG output expressed in percentage of alpha band energy relative to the total frequency band (.5-32 Hz for this study) energy {(alpha band energy/total energy) x 100%}, for a specific skull region (e.g., %F3; see Figure 4).

3. Per cent or total alpha band even, odd, or even-odd, frequency components power density: This is the per cent or total power density or energy output from a subject's specific skull region (e.g., F3) for the set of even (8+10+12 Hz; see Endnote 8), odd (9+11+13 Hz) or even-odd {(8+10+12 Hz)-(9+11+13 Hz)} frequency components of the alpha band respectively. A subject's EEG output consists of energies from the various frequencies comprising his or her EEG. However, the even alpha band power density refers only to the energy circumscribed within the set of even (8+10+12) frequency components within the alpha spectrum (8-13 Hz). Similarly, the odd alpha band power density refers only to the energy circumscribed within the set of odd (9+11+13 Hz) frequency components within the alpha spectrum.

4. The dependent variables described above may be used in various ways as when an asymmetry index ratio is formed with the output from two regions (e.g., total alpha band power density asymmetry index ratio, F4-F3/F4+F3; or per cent alpha band power density asymmetry index ratio %P4-%P3/%P4+%P3; or per cent alpha band (even-odd) components power density asymmetry index ratio (%F4(e)-%F3(o)/%F4(e)+%F3(o)) or when the log of a power density (e.g., log alpha band power density) is computed to allow for a direct comparison between this study and other research. Whenever the log of the power density or an asymmetry ratio is computed, it will be stated in the text explicitly to avoid confusion.

Hypotheses of the Present Investigation

Hypothesis 1. The relatively stable asymmetries exhibited by depressed subjects compared to controls in the alpha range in the right hemisphere (in frontal but not in parietal areas) observed in several previous studies, (e.g., Henriques & Davidson, 1990; Schaffer et al., 1983) are also expected to be observed in this study. Therefore, it is hypothesized that the depressed and the control groups will display different interhemispheric wave activation (per cent alpha band power density), with depressives displaying more anterior alpha activation in the right hemisphere. The basis for this hypothesis rests on the evidence from the aforementioned studies and on the data related to the asymmetrical distribution of neurotransmitters in the human brain (Oke et al., 1978). An alternative hypothesis would suggest a lack of frontal alpha wave activation asymmetry difference for the depressed subjects relative to the normal subjects. If present, this result will be explained in terms of the population of subjects selected (primarily

students rather than a clinical population). This result could also be explained in terms of the differences in dependent variables utilized in other studies (e.g., Schaffer et al., 1983) compared to this investigation, the greater number and stricter controls (e.g., no difference in the time at which the EEG will be collected for all subjects), or the use of a diagnostic measure (SCID) utilized by this study but lacking in similar research. Similarly, it is possible that insensitivity on the part of the EEG to find differences between the groups, as has occurred with past investigations (Shagass et al., 1982), could be responsible for the insignificant results in the current research. Alternatively, problems with other studies in selecting their subject pool, or the fact that a history of depression was not ascertained for previous generations of relatives for the depressed subjects selected for this research, as has been recommended by other investigators (Henriques & Davidson, 1990), could be the cause for the inability to replicate the findings from other laboratories with this research.

Hypothesis 2. It is also hypothesized that the per cent alpha rhythm power spectral density distribution for the control group will differ quantitatively (descriptive statistics; moments of the distributions) from the depressed group's distributions for all regions (F3, F4, P3, P4). This hypothesis is also based on the rationale that any distinctions will most likely be due to the theorized imbalanced biochemical distributions found in the brain possibly responsible for the asymmetry in the EEG. If differences between the distributions are not observed, it could be argued that the complexity of the disorder

being analyzed and its overlapping characteristics with normal behavior, not allowing the two distributions (depressed and normals) to differ as measured by the EEG (Lindsley, 1944), may be responsible for the insignificant results. These insignificant results, coupled with the pending need for a valid and stable EEG assessment measure, argue for a hypothesis based on different methods of analysis capable of sensing distinctions between groups of normal and depressed. A plausible candidate would be a hypothesis based on a method that looks at more detailed information within the alpha frequency band, in contrast to the gross data provided by an entire frequency distribution for a particular frequency range, which collapses over the entire spectral range as is the case with the Asymmetry Index. This is the case presented next.

Hypothesis 3. It is postulated that frontal activation differences will bve observed between the alpha band odd (9+11+13 Hz) frequency components power density and the alpha band even (8+10+12 Hz) power density frequency components, for the depressed vs. the controls. Depressed will display activation primarily in the odd frequency components as compared to normals. Conversely, it is plausible that the affective disordered group will primarily display right frontal activation in the even than in the set of odd frequency components. The logic behind this hypothesis follows from the two postulates presented above and as stated earlier. Also, note that, at this stage, there is nothing special about the utilization of the even-odd analysis; rather, the comparison between even and odd components is warranted on the basis of its ability to look within the alpha range proper for differences that may be missed by the two methods described above. It may well be

that this fine-grained analysis would yield data that will better discriminate between the two groups.

Hyppothesis 4. This hypothesis predicts that the correlation between activation asymmetry ratios from the log even-odd per cent and total power density (e.g., even-odd; log F4(odd) - log F3(even)/log F4(odd) + log F3(even)) frequency components asymmetry ratios and their respective BDI scores will display higher magnitude than the log alpha activation asymmetry ratio (log F4-log F3/log F4+log F3) alone and their correlations with their respective BDI scores. It is also postulated that the asymmetry ratios from the even-odd analysis will be better at predicting group membership (percentage of prediction from asymmetry ratios), than the activation asymmetry index.

Hypothesis 5. Finally, it is postulated that females would display equal levels of alpha rhythm activation in the anterior region as males. Although some investigators have found differences between the two genders (Flor-Henry & Koles, 1980), these distinctions have been obtained for temporal areas rather than frontal areas as assessed by this study. Additionally, gender differnces have also been found, while normal subjects were performing verbal and visuo-spatial tasks, in contrast to this investigation, which places relaxed subjects at rest, with their eyes closed. Other researchers have also found differences between males and females but these differences have been obtained when an unequal number of individuals have been employed for each gender. Table 4 presents a summary of all the hypotheses postulated in this investigation.

Insert Table 4 about here

Method

Subjects

Initial screening, from August 1991 to October 1992, of 1008 individuals from Stillwater, Oklahoma yielded 32 subjects used in the present study. Subjects were 20 undergraduate students currently enrolled in psychology courses at a State University in the Southwest United States, 9 undergraduate students from other departments within the University, and 3 individuals from the Stillwater community. The 32 subjects in the study were divided into two groups of 16 subjects (8 females and 8 males). One group (experimental) consisted of subjects diagnosed as depressed during the study; subjects in the other group comprised the control "normals" lacking any diagnosable psychological disorder. The depressed group included subjects who reported moderate to severe depressive symptoms due to chronic depression only and were diagnosed with major depression under DSM III-R taxonomy. The control group comprised subjects who reported mild or no depressive symptomatology and could not be categorized as depressed or with any other DSM-III-R diagnosis (see Materials below for selection criteria for both groups).

Subjects for both groups (controls and depressed) were selected with consideration to the following criteria: (1) they had no known neurological impairments since alpha waves are affected by these pathologies (Fischer-Williams, 1987); (2) they had never received psychotropic treatment or electroconvulsive therapy for depression; they

were not using non-prescription drugs for at least 14 days since all these factors affect the EEG (Bauer, 1987; Fink, 1978; Milnarich, 1958; Scott, 1976); (3) all subjects corresponded to the same socioeconomic status (SES) classification (Level III) using Hollingshead's (1974) SES criteria and instrument to insure that any variability between the depressed and control groups was not due to differences in SES; (4) they were right-handed as measured by the Edinburgh Handedness Inventory (Oldfield, 1971), since evidence exists to suggest that varying patterns of hemispheric specialization for affective functioning may exist between dextrals and sinistrals (Bryden, 1982); (5) an equal number of males and females were selected for each of the groups since different EEG activation patterns have been exhibited by females in contrast to males (Flor-Henry & Koles, 1980), although these gender distinctions have been observed in studies utilizing a different paradigm or an unequal number of males and females unlike this research; (6) the depressed subjects satisfied the criteria for depression only, without any other superimposed or comorbid psychological disorder(s), such as anxiety disorders or substance abuse or dependence, both of which tend to have a high comorbidity with depression (Barlow, DiNardo, Vermilyea, Vermilyea, & Blanchard, 1986; Breier, Charney & Heninger, 1984; Stein, Tancer, Gelerntner, Vittone & Uhde, 1990), whereas the normal control group was undiagnosable with any psychiatric disorder as determined by the Diagnostic and Statistical Manual of Mental Disorders, DSM-III-R (APA, 1987); (7) the entire subject pool was of similar age with an age range of not more than 5 years (18 to 22 year-olds), since variabilities

in the EEG have been observed in normal elderly adults in comparison to younger normal adults (Niedermeyer, 1987b; Pollock & Schneider, 1990); and (8) the EEG was collected approximately during the same time of the day for all subjects since differences in the EEG throughout the 24-hour day cycle have been observed (Scott, 1976). The group inclusion criteria are presented in Table 5.

Materials

Measures of Depression. Initial screening for the presence of depressive symptoms was accomplished by means of the Zung's Self-Rating Depression Scale (Zung SDS; Zung, 1965) and the Beck Depression Inventory (BDI; Beck et al., 1961). To screen for the intensity of depressive symptoms, the Beck Depression Inventory trait form (Form B)

Insert Table 5 about here

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was utilized. Also, the DSM-III-R (APA, 1987) Axis IV, Severity of Psychosocial Stressors, was administered to ascertain that the depressive symptoms exhibited by any subject were not due to a reactive event, since reactive and chronic characteristics of mood disorders may differentially affect the EEG (Perris & Monakhov, 1979) obscuring the results. To assess for the presence of only one diagnosis (major depression, recurrent or single episode) without any other concurrent or concomitant disorder (anxiety, panic, or other disorders; i.e., substance abuse or dependence, eating disorder, etc.), and to diagnose the absence or presence of depression proper, a DSM-III-R Structured

Clinical Interview (SCID-NP; Spitzer, Williams, Gibbon & First, 1990) was conducted.

The Zung SDS (see Appendix A) was designed to provide a quantitative, self-administered, brief screening for depression (Zung, 1965). It is comprised of 20 items, each requiring the subject to rate the contents on a four point scale for the presence of depressive symptoms. Scores on the Zung SDS range from 0.00 to 1.00. As was the case for the BDI, a stringent criterion score was employed for this study. Those subjects who attained a score between 0.50 and 1.00 were classified as potential depressed subjects. Scores of 0.25 to 0.45 served as classification for potential control subjects. Blumenthal (1975) reported that the Zung SDS was positively correlated (+.76) with the BDI.

Similar to the procedure used by Schaffer et al. (1983), the BDI was utilized to empirically screen the intensity of depressive symptoms in the control and mood disordered groups. However, unlike the Schaffer et al. (1983) study, the BDI alone was not used to categorize subjects as depressed since this instrument was not constructed for this purpose. Instead, the BDI was designed to measure the intensity of depressive symptoms once the diagnosis of depression has been established (Steer & Beck, 1988) by other instruments created for diagnostic purposes. The BDI (trait instrument or Form B; see Appendix B) is composed of 21 Likert-type questions. BDI scores range from 0, suggesting lack of depressive symptoms, to 63, indicating severe depressive symptoms. The BDI was designed to assess behavioral manifestations of depression along a continuum of severity (Beck et al., 1961). Subjects who attained a

score from 0 to 9 on the BDI were classified as nondepressed. However, in an effort to increase the heterogeneity between the control and experimental groups and the sensitivity of the study through the severity of depressive symptomatology in the depressed group as measured by the BDI, only subjects who attained a score of 16 or above continued to be considered part of the depressed group and were further evaluated with the DSM-III-R Axis IV scale and the SCID to establish a mood disorder diagnosis, if warranted. The validity of the BDI when utilized with college populations has been previously assessed (Bumberry, Oliver & McClure, 1978).

The DSM-III-R Axis IV, Severity of Psychosocial Stressors, is not a measure of depression. Instead, it is a rating scale with ratings from 0 (for no information or no change in condition) to 6 (depicting catastrophic events leading to the present situation). It was designed to assess the severity of a single or multiple psychosocial stressors that have occurred during the year preceding the present screening that may have had an effect on an individual's current mental status. The scale has been subdivided into "predominantly acute events" (< 6 mo) and "predominantly enduring events" (> 6 mo). The scale was utilized to ascertain that depressive symptoms, exhibited by individuals comprising the depressive group, were not subsequent to a reactive event or stressor, but rather, that the symptoms were primarily due to chronic depression since distinctions between groups of reactively and chronically depressed subjects have been observed (Perris & Monakhov, 1979). The cut-off scores were as follows: scores from 0 to 2 were considered as non-significant to the present condition. Scores from 3

to 6 were considered as significant and affecting the present mental condition of each participant. Subjects with scores in the latter range were dropped from the study.

Finally, the Structured Clinical Interview (SCID-NP) is intended to cover a group of DSM-III-R (Axis I) diagnoses. Its primary objective is the differential diagnoses of these disorders (Spitzer et al., 1990). This interview was utilized to diagnose subjects in the depressed group and to verify that they could be classified as depressed only. It was also administered to all of the subjects in the control group to assure that they did not satisfy criteria for any psychiatric disorder. The validity and reliability of the SCID has been described previously (Spitzer, Williams, Gibbon & First, 1992; Williams et al., 1992).

SES Measure. Although very few EEG studies have used SES measures (see Henriques & Davidson (1990) for exception), it was felt that SES should be controlled to insure greater homogeneity for both the depressed and control groups and to ascertain that differences in the results would not be attributed to differential levels of SES between the experimental and control groups. In order to accomplish this task, the Hollingshead Inventory (Hollingshead, 1974) was employed to assure that subjects did not differ in terms of SES. This inventory is based on the premises that SES class structure exists, that it is primarily determined by symbolic characteristics, and that SES status could be measured and scaled using statistical procedures (Hollingshead, 1974). In addition, it provided an index of "social position" using two-factors, namely head of household's education and occupation. These two factors allowed for SES level computation for each subject in the

experiment (see Appendix C). All subjects were restricted to Hollingshead's Level III criteria (Hollingshead, 1974).

Measure of Laterality. As in other studies, this investigation utilized dextral subjects only, for reasons stated earlier (see Bryden, 1982). Therefore, all subjects were screened for right-handedness through the Edinburgh Handedness Inventory (Oldfield, 1971). This inventory consists of a 10 item questionnaire that assesses laterality based on subjects' responses to statements about their performance on a number of tasks. The questionnaire also assesses laterality through two other factors, namely use of dominant ocular and lower extremities activity, although these two factors are not used in the computation of the laterality quotient (see Appendix D).

Personal Questionnaire. The Personal Questionnaire (see Appendix E) was developed for this particular study. It assesses, using 10 questions, past history of traumatic brain injury, history of neurological disorders or other organic brain pathology, such as cerebrovascular disorders, seizures, tumors and encephalitis. Additionally, the Personal Questionnaire screens, in a face valid fashion, current intake of prescribed medications and controlled substances. It also evaluates whether women participating in the study are in the 14th day of their menstrual cycle, in order to control for hormonal effects on their electroencephalographic output, since changes in their EEG have been observed as a function of varying position within the cycle (Harding & Thompson, 1976; Pitot & Gastaut, 1954).

Measure for Level of Alertness. The level of arousal for each subject, prior to and after EEG recording, through her/his verbal

report, will be recorded based on a scale from 1 (very drowsy) to 5 (very alert). An overall alertness score (prior EEG + after EGG recording) will then be computed for each subject. This data will be collected to obtain a gross measure of alertness for the depressed and control groups.

EEG Recording Time Measurement. The time at which the EEG was recorded will be chronicled to obtain a measure of the differences between the two groups.

EEG Data Recording, Reduction, and Quantification

The EEG data was recorded (see Appendix F for example of EEG record) with four gold plated disc electrodes affixed to sites F3, F4, P3 and P4 according to the International 10-20 System (Jasper, 1958; see Figure 1). These electrodes were referenced separately to linked earlobes (A1 and A2), with an electrode placed on the forehead serving as ground (Davidson, 1988; Nunez, 1981). Electrode impedances were kept at or below 5 Kohms and were checked at the time of placement and removal from the scalp to insure that the integrity of the electrode-to-scalp connection had been maintained through the EEG data recording period. Homologous sites' impedance differences were kept at no more than 600 ohms. Although myogenic contamination is minimum for the alpha rhythm (Davidson, 1988; Flor-Henry & Koles, 1984), eye movement artifact was monitored by means of two electrodes, one placed over the outer canthus of the left eye and the other super-orbitally. A Grass Model 79 polygraph with band passes of 3 to 100 Hz and 60 Hz notch filters was used to amplify the EEG since this range covers the peak alpha frequency for adults (Doyle, Orstein & Galin 1974). A MetraByte

DASH 16 A/D conversion board digitized the EEG. Data acquisition was synchronized by an IBM PC-XT. Data were sampled at a rate of 64 samples per second for 30 seconds. In addition, the EEG and EOG were monitored to help identify portions of the data not to be used due to eye movements, gross muscle, and movement artifact, and other sources of artifact. Data were collected in 2 second segments. If artifact occurred in a segment, defined as a potential of $\pm$ 75 microvolts in any of the 5 channels, the data from the entire segment were rejected and replaced by a new segment. When artifact occurred on any given channel, data from all channels were removed. Therefore, equivalent epochs were extracted for analysis across all channels. Possible phase shifts could have occurred from replacing artifact-ridden 2-second chunks with artifact-free 2-second chunks. These phase shifts tend to introduce high frequency components into the subsequent FFT analysis. However these high frequency components are usually higher than the maximum frequency utilized in this study (32Hz).

The 30 seconds of artifact free EEG (1920 samples=30 seconds x 64 samples/seconds) were extracted[4] through a degree 10 Supergaussian windowing with weight of .1 on the last point. A Fast Fourier Transform (FFT[5]; see Appendix F for typical FFTs), which decomposes a complex time-domain waveform into its constituent sine or cosine frequency-domain components (Brigham, 1988; Weaver, 1983; 1989; see Figure 5), was used to obtain estimates of spectral power in microvolts-seconds (μV-s) as a function of frequency within the alpha wave range. Power values within the 30s epoch were converted to per cent[6] power density (%μV^2/Hz) and power density proper (μV^2/Hz),

Insert Figure 5 about here

both which are measures of the power within a given frequency band or range (energy). For this study, we focused our analysis on measures of power density in the alpha frequency band (8 to 13 Hz). The log of the per cent alpha rhythm power density and the total alpha spectrum power density was used (stated in the text whenever it occurs) when required to compare the results of this experiment with other investigations and in the case of the total alpha band power density to normalize the power density distribution since it is positively skewed (e.g., Davidson, 1988).

Log alpha power density and log per cent alpha power relative to total power density across the 30 second artifact-free segments of the eyes-closed resting period were computed separately for sites F3, F4, P3 and P4. When employed, asymmetry was calculated as the ratio[7] of the difference between log alpha power density (or per cent log alpha power density) in the left hemisphere leads (F3 and P3) and log alpha power density (and log alpha power percentage) in the homologous right hemisphere leads (F4 and P4, respectively) for both anterior and parietal regions (F4-F3/F4+F3; P4-P3/P4+P3[8] or %F4-%F3/%F4+%F3; %P4-%P3/ %P4+%P3). Since alpha power is inversely related to activation (Davidson, 1988), higher scores on this asymmetry index indicated lower relative left hemisphere activation (greater alpha activity). As stated above, these indexes were computed for the two regions of interest, frontal (F3 and F4) and parietal (P3 and P4). Additionally, the per

cent spectral power density distributions' moments (mean, std. dev., skewness, and kurtosis), for both depressed and normal groups and across all regions were computed to be used when testing Hypothesis 2. The odd (9+11+13) and even (8+10+12) frequency components log per cent power density and log alpha band total power were extracted through a FFT, as described above, to be used when testing Hypotheses 3 and 4. EEG data for all subjects were collected at approximately the same time of the day (08:00am-02:00pm), since the EEG changes as a function of time throughout the day (Scott, 1976). Control for hormonal effects in females was achieved by having their EEG data sampled during the middle of their menstrual cycle (n=1 21-day cycle; n=15 28-day cycle). Verbal report of their monitoring efforts was used to assess women who were not using contraceptives. Women on birth control medication participated the day their pill dispenser indicated that they were in the middle of their menstrual cycle if their menses was stable and coinciding with their dispenser. Women whose menstrual cycle was unstable or irregular were dropped from the study regardless of the etiology for the irregularity.

Procedure

Prior to initial screening, subjects were asked to sign a consent form. Initial screening was then performed by administering the Zung SDS, the Edinburgh Handedness Inventory, the Hollingshead SES Inventory, and the Personal Questionnaire to 1008 individuals, as described above, who were either recruited from psychology classes at a major university in the Southwest United States or who responded to the laboratory fliers that were placed on announcement boards throughout the university

campus, Stillwater, and Oklahoma City, Oklahoma. Subjects scoring in the depressed range on the Zung SDS were classified as prospective subjects for the depressed group. Similarly, persons scoring within the normal range were considered prospective control subjects. Subsequently, Zung scores obtained which fell into one of these respective groups were rank ordered from the highest to the lowest. Subjects whose scores fell in the highest (depression) and lowest (lack of depression) 10th percentile range were then contacted for further participation in the study, if their responses to the Personal Questionnaire revealed an acceptable history (e.g., no head trauma and no substance abuse, etc.). The experimenter then proceeded to contact individuals on the determination of rank order until the required number of subjects was achieved. Additionally, only those subjects that were dextrals and satisfied the restricted SES Level III were selected for further participation within a 4-week period (mean=4 weeks; range=0 to 12 weeks) from the moment of initial assessment.

Subjects selected on the basis of their scores on the Zung scale, the Edinburgh Handedness Inventory, the Hollingshead Inventory, and the Personal Questionnaire were contacted for further screening and categorization into groups. First, the BDI was administered and only subjects who qualified for either group continued as part of the study. Subsequently, the DSM-III-R Axis IV, Severity of Psychosocial Stressors, was administered and only subjects who did not suffer from a reactive event that may have been responsible for their current mental status qualified as prospective subjects for the depressed or normal group. All other subjects were dismissed. Finally, a Structured Clinical

Interview was conducted with each participant, by the same graduate clinical psychology student, to assess that only a diagnosis of depression, without any other concomitant disorder, was present in the depressed group's subjects or that no diagnosis could have been assigned to any of the control group's subjects. Subjects satisfying a depressive diagnosis, but no other, were included in that group. All others were dismissed. It is critical to note that only subjects who obtained consistent (pathological) scores across the Zung SDS, the BDI, and the SCID and without any other concomitant disorders became part of the depressed group. Similarly, only subjects who attained consistent below threshold scores across the Zung, BDI, and SCID became part of the control group. In addition, any subject who was being medicated (except for allergy medication; n=2) or who had received or was currently undergoing ECT treatment, verbally admitting to using nonprescribed drugs 14 days prior to participation in the study, or who had suffered from brain trauma or disease were not allowed to participate in the experiment (see Personal Questionnaire for further restrictions).

Following the completion and scoring of the BDI, the DSM-III-R Axis IV rating scale, and the Structured Clinical Interview, students who qualified as subjects were asked to participate. Those who accepted were seated in a comfortable reclining chair in a sound-attenuated and electronically shielded room. At this point in the study, a second informed consent for the EEG segment was obtained from each student prior to the placement of electrodes at the appropriate sites on the scalp. No stimuli were presented; instead, subjects were asked to remain in a relaxed resting state with their eyes closed while being

observed through a closed circuit television (CCTV) system. As in previous studies (Schaffer et al., 1983), subjects were asked to attempt to think about nothing in particular. These requests were required to secure the elicitation of alpha waves (Niedermeyer, 1987a). More important, no stimuli were presented since simplicity was the key objective of this study's paradigm, if the results were to be used to assist in developing a simple, economic, and efficient diagnostic aid for depression. Recording of EEG data began shortly thereafter until 30 seconds of artifact-free EEG was collected. At the end of the experiment, each subject was debriefed as to the nature of the experiment. Additionally, as part of the debriefing procedure and as an ethical consideration, any clinically depressed subject who attended the experiment, whether used as a subject whose brain waves had been collected or not, was provided with three psychological counseling referral sources in case that they wished to seek help for their depressed mood. This was also the case for those who were depressed but could not participate in the experiment for whatever reason. Refer to Figure 6 for a flow-chart depicting the experimental procedure pictorially.

Insert Figure 6 about here

Analyses and Results

Demographics

Demographic data was analyzed through the use of descriptive statistics in order to compare and contrast the depressed and control groups. Data from the two groups was also evaluated through the use of inferential statistics, specifically, Fisher's Exact *t*-tests (Wilkinson, 1989), in order to determine the level of statistical significance of observed differences between the two groups.

Comparisons between the depressed and normal groups using Fisher's Exact *t*-tests revealed that the two groups did not differ significantly in terms of age [$t(2, 30)=.55$, $p<.59$], SES [$t(2, 30)=0$, $p=1.0$], laterality quotient [$t(2, 30)=.46$, $p<.65$] or in the time at which the EEG was recorded [$t(2, 30)=-.61$, $p<.55$]. Contrastingly, the two groups displayed statistically significant differences in all measures of depression (Zung SDS [$t(2, 30)=-9.3$, $p<.001$]; BDI [$t(2, 30)=-16.2$, $p<.001$]). In addition, all subjects in the depressed group were diagnosed with depression only, whereas all subjects in the normal control group did not qualify for any DSM-III-R (APA, 1987) diagnosis. No subject in the experiment suffered from any reactive event as measured by DSM-III-R Axis IV or from neuropathology as measured by the Personal Questionnaire. Statistically meaningful results were obtained for the self-reported overall level of alertness [$t(2, 30)=2.7$, $p<.011$] verbally provided by each subject during the experiment. The results are tabulated in Table 6.

Insert Table 6 about here

Analyses and Results for All Hypotheses

Table 7 shows all dependent variables, hypotheses (see also Table 4), and their subsequent analyses. It is recommended that a perusal of Table 7 be conducted prior to examining the results (since it will serve as a guide to the reader when examining findings).

Insert Table 7 about here

Hypothesis 1

A preliminary Group (normal; depressed) x Region (frontal F3, frontal F4, parietal P3, parietal P4) x Sex (male, female) Analysis of Variance (ANOVA) was performed on the dependent EEG variable (per cent alpha band power density in microvolts squared/frequency, $\%\mu V^2/Hz$) to provide an initial overall statistical test of significance and to provide appropriate mean squared error terms for subsequent post-hoc comparisons via Tukey's HSD statistic (Kirk, 1982). Specific hypotheses were predicted (see Table 4). The first hypothesis predicted that the depressed and control groups would show significant activation differences (the greater the activation, the less the alpha activity) in their levels of per cent alpha band power density. It was also predicted that the depressed group would show significantly higher per cent power density activation in the right anterior region (F4) than the control normals and that no significant differences would be observed between the groups in their activation levels in the parietal regions (P3 & P4) for the same dependent variable.

This postulate was, in part supported by the data from this experiment. Although the Group (normal vs. depressed) x Region (frontal vs. parietal) interaction for the Group x Region x Sex ANOVA was not significant $F(3, 112)=0.00$, $p=0.99$, the Sex x Group interaction was significant $F(3, 112)=5.16$, $p=0.025$. No other interaction was significant. None of the main effects were statistically significant either, except for region $F(3, 112)=4.27$, $p=0.007$. Post-hoc comparisons were performed using Tukey's HSD statistic (Kirk, 1992) to test the Group x Sex interaction and the Region main effect since both had provided significant overall F tests. These tests revealed that differences between the normal and depressed females were responsible for the Sex x Group interaction $t(HSD; 4, 112)=4.09$, $p<.05$ with depressed females displaying greater activation than normal females as expected. Back to our original assertion, whether differences would be observed between the depressed heterogeneous and the normal group, it is concluded that it depends whether males or females are being considered. If referring to normals vs. depressed males, no differences were observed. Conversely, when referring to females, the results partly support the prediction. Depressed females displayed greater activation than normal females. However, contrary to the stated hypothesis, this activation was not linked to a particular region, since neither the Region x Sex nor the Group x Region x Sex interactions were significant.

The left frontal region vs. the right parietal area contrast was responsible for the region main effect $t(HSD; 4, 112)=4.11$, $p<.05$; the right parietal electrode (P4) displayed higher activation than the left frontal (F3) lead.

Additional Analyses and Results for Hypothesis 1

Three additional analyses were conducted to examine what effect it would have, on the overall result, to separate the dependent variable per cent alpha band (8-13 Hz) power density into its even (8+10+12 Hz) and odd (9+11+13 Hz) frequency components. As in the previous analysis, a Group x Region x Sex ANOVA with even, odd, and even-odd components as dependent variables was performed.

Even Components as a Dependent Variable. The even components analysis utilized per cent alpha band even components (8+10+12 Hz) power density as a dependent variable with the same independent variables as had been used for the initial analysis. The results for the even components analysis did not reveal a statistically significant outcome, except for the Group x Sex interaction $F(1,112)=8.26$, $p=0.005$, and for the Region main effect $F(3, 112)=3.10$, $p=0.030$, as had been the case for the entire alpha (8-13 Hz) band analysis.

Odd Components as a Dependent Variable. Similarly, for the odd components analysis, per cent alpha band odd components (9+11+13 Hz) power density was employed as the dependent variable. For this evaluation, the results indicated significant Group $F(3, 112)=7.74$, $p=0.006$, and Region $F(3, 112)=3.95$, $p=0.010$, main effects with all other results being statistically insignificant. The depressed group displayed higher activation than the normal group as expected.

Even-Odd Components as a Dependent Variable. Finally, for the even vs. odd analysis, per cent alpha band even-odd (8+10+12)-(9+11+13) components power density was used as the dependent variable. The even-odd ANOVA revealed a significant Group $F(1,112)= 7.74$, $p=0.006$, and

Region $F(3, 112)=3.95$, $p=0.010$ main effects; all other results were insignificant for this analysis as well. It is interesting to note that the even component analysis could only provide significant effects between the groups as part of the Group x Sex interaction and only when the odd and even-odd components ANOVAs were utilized were the ANOVAs capable of discriminating between the depressed and control groups as a main effect (see results for Hypothesis 3).

Since the results from this research did not reveal right frontal activation differences between the depressed and control groups, additional analyses were performed to assist in directly comparing the results from the current investigation and those from previous research (e.g., Schaffer et al., 1983).

The Frontal Total Alpha Power Density Asymmetry Index Ratio (log F4-log F3/log F4+log F3) as a Dependent Variable. This analysis involved a Group x Sex ANOVA with frontal Asymmetry Index ratio as a dependent variable. This ANOVA revealed insignificant results for all independent variables $F(1,28)=0.01$, $p=0.927$ for Group; $F(1,28)=0.56$, $p=0.459$ for Sex; $F(1,28)=3.68$, $p=0.066$ for Group x Sex interaction. A Group x Sex MANOVA was also performed with log alpha power density Asymmetry Index ratios (log F4-log F3/log F4 +log F3 and log P4-log P3/log P4 +log P3) as a bivariate dependent variable. The results from this analysis revealed a statistically insignificant Group Wilks' Lambda F-Ratio $F(2, 58)=0.057$, $p<.94$. The results also revealed a statistically insignificant Sex Wilks' Lambda F-Ratio $F(2, 58)=0.986$, $p<.34$.

The Frontal Per Cent Alpha Power Density Asymmetry Index Ratio (log %F4-log %F3/log %F4+log %F3) as a Dependent Variable. The second analysis involved a Group x Sex ANOVA with per cent alpha power density Asymmetry Index ratio as a dependent variable. This ANOVA also revealed insignificant results for all factors [$F(1,28)=0.62$, $p=0.438$ for Group; $F(1,28)=0.88$, $p=0.357$ for Sex; $F(1,28)=1.10$, $p=0.303$ for Group x Sex interaction]. A Group x Sex MANOVA was also performed with log per cent alpha power density Asymmetry Index ratios (log %F4-log %F3/log %F4 +log %F3 and log %P4-log %P3/log %P4 +log %P3) as a bivariate dependent variable. The results from this analysis showed a statistically insignificant Group Wilks' Lambda F-Ratio $F(2, 58)=0.405$, $p<.669$. The results also revealed a statistically insignificant Sex Wilks' Lambda F-Ratio $F(2, 58)=0.899$, $p<.413$.

In summary, these analyses revealed that using the same dependent variables as used by other investigators did not provide replicable findings for the right frontal asymmetry as had been obtained in previous research. On the other hand, although not linked to any specific area, depressed females displayed greater activation than normal females. Finally, the results indicated significant Group and Region main effect when using the odd and the even-odd components. The depressed group displayed higher activation than the normal group for the group main effect.

Hypothesis 2

The second hypothesis, that the per cent alpha band power spectral density distributions for the two groups (normals vs. depressed) would differ, was tested by descriptively contrasting the density

distributions' first, second, third, and fourth moments (mean, standard deviation, skewness, and kurtosis) for all regions (F3, F4, P3, P4). When testing this postulate, it was predicted that the percent alpha power spectral density distributions, for all regions, for the depressed and normals would show distinctive distribution moments. Explicitly, it was hypothesized that the means, standard deviations, skewness, and kurtoses for the respective normal and mood disordered groups' distributions for regions F4, F3, P3, and P4 would differ. Table 8 presents the results. The results indicated that the distributions did indeed display distinct means, standard deviations, skewness, and kurtoses, but more strikingly, certain patterns became apparent in the data.

Insert Table 8 about here

In particular, the means for the depressed group's distribution appeared higher across all regions (F3, F4, P3, P4) than the controls' means, suggesting higher activation values across all regions for depressed subjects when contrasted to controls, according to expectations. For both groups, the means from the parietal areas were greater than those for the frontal areas, suggesting greater parietal power density than anterior power density. Unfortunately, preceding statistical tests conducted for Hypotheis 1 revealed that these differences were not significant when only the entire alpha band was considered.

Similarly, the affective disordered group's distributions, across all regions, displayed greater variability than the controls' distributions. Put differently, the depressed group's power density scores showed greater fluctuation from their mean than the control's power density score from their mean for all hemispheric regions. Greater variability was also observed in parietal areas than in frontal areas for both groups, with the greatest variance occurring in the left parietal area for both groups.

With regard to the third moment of the distributions, the anterior region distributions for both the left and the right hemispheres, for the depressed group, were all negatively skewed. In contrast, the frontal region distributions for the normal group were all positively skewed. With regard to the parietal areas, the right hemisphere for the depressed group displayed a negatively skewed distribution while the opposite result was found for the right hemisphere for the normal controls. The left parietal distribution for the normal group was also positively skewed.

All the distributions for the normal group were more platykurtic than those for the depressed group for all regions. Further, frontal regions for both groups indicated negative kurtoses, although twice as high for the depressed group, whereas only the depressed group's parietal distributions for both sides displayed negative kurtoses.

Hypothesis 3

To test the third experimental hypothesis, that the depressed group would show differences in frontal alpha (8-13 Hz) band power density activation in the odd (9+11+13 Hz) rather than the even (8+10+12 Hz)

frequency components than the control group, the dependent variable, per cent alpha band power density, was decomposed into its odd (9+11+13 Hz) and even (8+10+12 Hz) frequency components creating two dependent variables. Subsequently, a Multivariate Analysis of Variance (MANOVA) was performed with Group x Region (F3 and F4 only) x Sex as independent variables and per cent alpha power density (even frequency components, 8+10+12 Hz) and per cent alpha power density (odd frequency components, 9+11+13 Hz) as dependent variables. It was predicted that the MANOVA would yield significant results. In particular, the Group's Wilks's Lambda F-Ratio of the MANOVA for the bivariate dependent variables, per cent alpha band power density even frequency components and per cent alpha band power density odd frequency components, would be significant. Additionally, it was postulated that the Group's Wilks's Lambda F-Ratio of the MANOVA for the bivariate dependent variables, per cent alpha power rhythm density even frequency components and per cent alpha rhythm power density odd frequency components, would be significant. Subsequently the Univariate F-tests for each of these two independent variables (Group and Region) would be significant for the dependent variable per cent alpha band power density odd frequency components but not for the dependent variable per cent alpha band power density even frequency components.

Hypothesis 3 was partly accepted as predicted. The Multivariate Analysis of Variance (MANOVA) was performed with Group, Sex, and Region (F3 and F4) as independent variables and per cent alpha band power density (even frequency components) and per cent alpha band power density (odd frequency component) as dependent variables. Table 9 shows

Wilks' Lambda F-tests, the Univariate ANOVA F-tests, and means for the MANOVA. The results revealed a statistically significant Group Wilks' Lambda F-Ratio $F(3, 32{,}000)=6.34$, $p<.01$ and a statistically significant

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Insert Table 9 about here

Group Univariate F-Ratio $F(1, 126)=7.66$, $p<.01$ for the per cent alpha band odd frequency component only. All other Wilks' Lambda F-Ratios and Univariate F-Ratios were statistically insignificant (see Table 9). Hence, this postulate was accepted with modifications as follows: Although differences between the depressed and the normal controls were observed for the dependent variable, per cent alpha band odd frequency components, these differences were not linked to any specific region as had been postulated. Nevertheless, this result, congruent with the results from Hypothesis 1, is important since it begins to show a stable pattern of distinction between the two groups whenever the odd frequency components alone are utilized as a dependent variable.

Hypothesis 4

The hypothesized (fourth hypothesis) log per cent alpha (even frequency components) power density - the log per cent alpha (odd frequency components) divided by the log percent alpha (even frequency components) power density + the log per cent alpha (odd frequency components) power density asymmetry ratios' (log even right - log odd left/ log even right + log odd left) ability to display higher correlation magnitudes between normals and depressed than the log total alpha power density Asymmetry Index ratio (log F4-log F3/log F4+log F3;

P4-P3/P4+P3; Schaffer et al., 1983), was tested through the use of these ratios in conjunction with the BDI scores for both groups (normals and depressed). The dependent measures, asymmetry index ratios (log even-log odd) total and per cent alpha band and Asymmetry Index ratios (total power), for all groups were obtained through the use of the log total alpha power density, the log per cent alpha power density, the log total alpha (even frequency components) power density, the log total alpha (odd frequency components) power density, the log per cent alpha (even frequency components) power density, and the log per cent alpha (odd frequency components) power density, for both groups and across all scalp regions to construct the corresponding asymmetry ratios (log F4-log F3/log F4+log F3; log F4(e)-log F3(o)/log F4(e)+log F3(o);log %F4-log %F3/log %F4+log %F3, log %F4(e)-log %F3(o)/ log %F4(o)+log %F3(o);log P4-log P3/log R4+log P3; log P4(e)-log P3(o)/log P4(e)+log P3(o); log %P4-log %P3/log %P4+log %P3, log %P4(e)-log %P3(o)/ log %P4(o)+log %P3(o)) for both normal and depressed subjects. These ratios were then correlated with each groups' respective BDI scores (Pearson Product-Moment Correlation; Wilkinson, 1989). It was predicted that the correlations between all the power density asymmetry ratios and the normal subject's BDI scores should be negative, depicting the fact that the power ratios were defined as the differences between right hemisphere power density (F4) minus left hemisphere power density (F3) divided by right hemisphere power density (F4) plus left hemisphere power density F3; (F4-F3/F4+F3). Therefore, as BDI scores <u>decrease</u> ("lack of depression") the right hemisphere alpha activity (F4) should show <u>increments</u> in magnitude ("normality", F4 $\geq$ F3), thus the negative

correlation. If the correlations are positive, their magnitude should then be as small as possible. Similarly, for the depressed group, increasing BDI scores (depression) should be associated with decreasing or even negative values for the asymmetry index ratios since it is being defined as F4-F3/F4+F3 indicative of hyperactivation on the right hemisphere (pathology) or hypoactivation on the left hemisphere, a negative correlation also. It was also predicted that the percentage of group membership discrimination from these ratios would be superior for the even-odd frequency components than for the simple Asymmetry Index ratio.

Hypothesis 4 was partially validated. The predictive ability of the odd-even components asymmetry ratios was superior when discriminating depressed subjects, using percentages from the actual per cent alpha band power density activation asymmetry index ratios, better than the Asymmetry Index ratios. This was also the case when actual total alpha band power density was used to construct the even-odd ratio. The problem arose when classifying the total number of subjects (normal and depressed), in which case, only the total alpha band even-odd power density asymmetry ratio percentage of classification {see Table 10; (100%+19%)/2)=59%} was capable of surpassing the standard Asymmetry Index ratio classification percentage {see Table 10; (81%+31%)/2)=56%} when classifying both groups of subjects. Another problem became apparent when using total alpha power density and the correlations between the Asymmetry Index ratios and their respective BDI scores since they were of greater strength and postulated direction than those from the odd-even analysis for both anterior and parietal areas.

Table 10 presents in tabulated form all the dependent variables utilized and the correlations and percentages obtained from these analyses.

Insert Table 10 about here

Anterior Region Correlations for Depressed and Normals. For anterior regions, perusal of Table 10 reveals that power Asymmetry Index ratios had lower positive or even negative correlations than the odd-even frequency component asymmetry ratio for the depressed group for total alpha power (r=.024, df=1, p=.930; r=.458, df=1, p=.075) and for per cent alpha power (r=-.290, df=1, p=.291; r=.511, df=1, p=.043). The same results were obtained for the normal groups for both total alpha (r=-.212, df=1, p=.432; r=-.193, df=1, p=.474) and per cent alpha power (r=-.275, df=1, p=.302; r=-.104, df=1, p=.701). None of the correlations were significant, except for the odd-even harmonic per cent alpha power asymmetry ratio as noted above.

Parietal Region Correlations for Depressed and Normals. For the parietal areas, for the depressed group, again the Asymmetry Index revealed stronger associations for both total alpha power (r=.247, df=1, p=.356; r=.239, df=1, p=.374) and per cent alpha power (r=.081, df=1, p=.765; r=.580, df=1, p=.039). Similar findings were obtained for the normal groups for both total alpha power (r=-.275, df=1, p=.364; r=.164, df=1, p=.544) and per cent alpha power (r=.027, df=1, p=.922; r=.230, df=1, p=.391). None of the correlations was significant. One important finding was the fact that only one correlation was negative for the parietal areas as compared to four correlations of negative magnitude

for the anterior areas. This result is important since research from other laboratories (Schaffer et al., 1983) has yielded similar results and certain researchers (e.g., Davidson, 1978) have argued that only anterior, but not parietal, areas are responsible for processing affect. Another interesting finding was the result indicating that maximizing results were only obtained when the even-odd contrast (F4e-F3o/F4e+F3o) was used for the depressed group whereas only the odd-even contrast (F4o-F3e/F4o+F3e; see Table 10) maximized the predictive power of the contrast for the normal group. Although these tests are not shown but other correlations were conducted, for example between odd-odd or even-even components, suffice it to say that their correlations were extremely low, as well as their percentage of prediction. In brief, an inverse relationship like the one employed between the normal and mood disordered subjects must be used when utilizing the even-odd component contrasts to maximally differentiate between the groups.

Percentage of Prediction. Contrasting results were obtained for the ability of the two different indices to classify the depressed and normal groups on the basis of total alpha power density and per cent alpha power density asymmetry ratios.

Anterior Area Percentage of Prediction for Depressed and Normals. For frontal areas, Table 10 and Figures 7-10 show that the odd-even component asymmetry ratio classification percentages were superior (63 and 75%) than the total alpha band Asymmetry Index ratio classification percentages (31 and 31%) at predicting the percentage of depressed subjects (see Table 10) for both total alpha power density asymmetry and per cent alpha power density asymmetry respectively, from the actual

Insert Figures 7-10 about here

alpha activity levels (not from the proportion of variance from each correlation). The inverse result is true when the even-odd asymmetry ratio classification percentages (13 and 19%), for depressed subjects only, was compared to the total alpha band asymmetry ratio classification percentages (31 and 31%) for total alpha band power density and per cent alpha band power density. Similarly, when classifying total number of depressed and normal subjects (all subjects) only the total alpha band even-odd power density asymmetry ratio classification percentage (100%+19%)/2)=59%. was capable of surpassing the standard Asymmetry Index ratio classification percentage { see Table 10; (81%+31%)/2)=56%}.

A Final Analysis

Since some of the results presented above were not very promising, combined with the significant odd frequency components Group main effects per cent alpha band power density from Hypothesis 1, a decision was made to conduct another analysis utilizing the means from the depressed and control groups, collapsed across region, that had been responsible for the odd frequency component analysis main effect. The mean from each of the two groups was used to compute a grand mean. This grand mean was then employed as the criterion for classification. The results revealed that 81% of the normal and 56% of the depressed subjects could be classified using this analysis. In addition a correlation between each subject's alpha activity score and his or her

respective BDI was conducted for both groups. The results revealed that the correlation between the normal group and the BDI was insignificant r=-.397, df=1, p=.128. Contrastingly, the correlation between the depressed subjects alpha activity scores and their respective BDI score was significant r=.502, df=1, p=.048.

Parietal Area Percentage of Prediction for Depressed and Normals. Similar results as shown in Figures 11-14 and Table 10 were ascertained for the parietal areas for both normals and depressed and for total power density asymmetry ratio and per cent alpha power asymmetry ratio. Again problems in discrimination became apparent when predicting not just the depressed but all subjects. The percentage of prediction was higher for the anterior than the parietal areas as expected.

Insert Figures 11-14 about here

Hypothesis 5

Finally, similar to Schaffer et al.'s (1983) result, coupled with the imposed strict subject selection criteria of this research and the fact that an equal number of subjects was utilized for both genders, it was theorized that males and females would display equal levels of alpha rhythm activation. In order to assess this hypothesis, the mean squared error terms from the ANOVA and post-hoc comparisons were utilized.

The results supported this hypothesis. The post-hoc comparison for the Sex x Group interaction, conducted while testing Hypothesis 1, suggested that no differences existed between males and females, but rather that the interaction occurred due to differences in the

activation levels of normal vs. depressed females with depressed females displaying greater alpha power density than normal females. Since the post-hoc comparison, which utilized per cent alpha band power density, or the MANOVA from Hypothesis 3, did not reveal statistically significant variability between men and women, five additional analyses, beyond these comparisons, were conducted to explore the reason(s) for the observed insignificant result between genders.

Additional Analyses and Results for Hypothesis 5. All five additional analyses employed Fisher's Exact t-tests to compare the two groups. One test examined differences between males and females in terms of total log frontal alpha band power density, rather than using per cent anterior alpha rhythm power density, as had been the case for the post-hoc comparison.

Fisher's Exact t-tests With Log Total Alpha Band Power Density and Log Total Alpha Band (Even-Odd) Power Density as Dependent Variable. The t-test using log total alpha band power density as a dependent variable revealed insignificant results [$t(2, 30)=.285$, $p=.777$]. Similarly, the t-test comparing males vs. females using frontal log alpha band (even-odd) frequency components also yielded insignificant results [$t(2, 30)=1.43$, $p=.162$]. Since all these psychophysiological tests yielded insignificant results, a shift was made towards testing the two groups in terms of their BDI scores (verbal report) to assess if differences in this measure could be ascertained.

Fisher's Exact t-tests With BDI Scores for Both Groups as Dependent Variable. A t-test comparing the BDIs of all males vs. all females revealed insignificant results [$t(2, 30)=-.171$, $p=.865$]. Similar

results were obtained for tests comparing the BDIs of normal males vs. normal females [$t(2, 30)=-.919$, $p=.374$], and depressed males vs. depressed females [$t(2, 30)=0.0$, $p=1.0$]. In summary, neither the psychophysiological nor the paper and pencil measures discriminated between the genders.

Discussion

The normal and depressed groups were identical in the number of total, male, and female subjects comprising each group (see Table 6). The two groups were also not statistically different in age, SES, laterality and in the time of the day at which the EEG was recorded. History of neuropathology or neurological diseases, as measured by the Personal Questionnaire, were identical for both experimental and control groups alike. These results are critical to the integrity of the study since the experimental findings observed could not be attributed to these factors since they are identical for both groups.

The two groups were quite different in their level of depression, as intended. The number of experimental controls (see Table 5), strict group inclusion criteria, and the consistency utilized in the selection of subjects, paved the way for such a distinction in the levels of depression between the normal and affective disordered groups. The two sets of subjects also differed significantly in their level of arousal as measured by their verbal report. At first glance, this finding is troublesome, since it suggests that differences in the level of alpha wave elicitation between the two groups may be due to differences in the level of arousal at the time the EEG was recorded. In other words, the environmental conditions in which alpha waves were elicited were different for both groups; hence, differences between the two sets of subjects may have been due to their respective differential level of arousal. However, this interpretation is unlikely. Examination of the environmental conditions in the experimental room, which were monitored to assure that the conditions were identical for all subjects, through a

CCTV system, requires an alternative explanation to this result. A more reasonable interpretation to this finding, suggests that differences in arousal between subjects in the experimental and control groups were due to varying levels of pathology, or lack thereof, that subjects brought with themselves to the experiment. This interpretation is congruent with previous research (Zung, Wilson & Dodson, 1964) suggesting that depressed subjects suffer from abnormal arousal levels and it is more plausible than the former suggestion.

It is interesting, but not surprising (see Shagass, 1982 for the same results), that the predicted right frontal activation asymmetry observed between depressed and normals in other laboratories (Schaffer et al., 1983; Tomarken et al., 1990) was not replicated here. It is interesting in the sense that it appears, from the existing literature that hemispheric asymmetry is a stable measure of pathology (Tomarken et al., 1992). Although at first it appeared that using a different dependent variable from that utilized by other studies would be responsible for the inability to obtain frontal asymmetry, the Asymmetry Index ratio (log F4-log F3/log F4+log F3), employed by Tomarken et al. (1990) and Schaffer et al. (1983), was computed and utilized as a dependent variable. However, this analysis revealed that when the same dependent variable as that used by other investigators was employed, the current research was unable to yield significant results either. The result, however, can be explained invoking several of the alternative postulates presented under Hypotheses for the Present Investigation for Hypothesis 1. First, as explained earlier (see Endnote 6), when an EEG (time-domain) function is transformed (FFT; frequency domain) certain

energy (power density) is lost in the process. This amount of energy is difficult to ascertain for each subject, and it appears in the FFT of each individual, yet several studies have utilized total alpha power density as their dependent variable, instead of using per cent alpha band power density, as is the case with the present study. Therefore, it is possible that the differences observed between groups of subjects from past investigations may be due to these energy losses, which in many cases are not insignificant, causing deleterious and systematic biases affecting their results. This unfortunately would suggest that the positive results obtained by previous investigations may be due to procedural artifact rather than from differences in the levels of pathology proper between normal and depressed individuals.

It is also feasible that the population of subjects utilized by this experiment was responsible for the insignificant results. The fact that the subjects did not come from a clinical population, or that a past history for depression in relatives of the subjects comprising the depressed group was not ascertained, as recommended by Henriques and Davidson (1990), may be the cause for the insignificant results. On the other hand, it is also conceivable that the stringent experimental controls utilized by this experiment may account for the insignificant outcome. This conclusion applies to the study by Schaffer et al. (1983) who, against criticism by certain researchers (DePue & Monroe, 1978), did not employ an actual diagnostic test to diagnose their depressed subjects. It also applies to the study by Henriques and Davidson (1990), where the cut-off for the BDI was set at 10 (too low) and no diagnostic measure was used to diagnose the depressed subjects. In

fact, the depressed subjects from the current research not only were diagnosed as depressed using an instrument designed for this purpose (SCID), but further, it was ascertained that only depression, without any comorbid disorder, was present in the affective disordered group. It follows that experimental designs in past studies that have not employed such a strict subject selection criterion may have utilized individuals with disorder(s) superimposed upon their depression, and this extant concomitant disorder(s) is what could have caused the frontal asymmetry. Hence, when the only difference between two groups of subjects is their level of depression, as is the case with this study, the distinctions between the two groups vanish.

Another possibility is that those studies that did not use a diagnostic evaluation to assure that their experimental subjects actually suffered from clinical levels of depression (c.f., Henriques & Davidson, 1990) obtained significant but erroneous results. The erroneous results could be a reflection of differences between groups of subjects who did not suffer from clinical levels of depression at the time of the experiment, but who suffered from "unhappiness or loneliness" (Schaffer et al., 1983, p.760), or from other unknown disorders.

The result obtained is also interesting when evaluated and examined from one of the alternative hypothesis' vantage point, suggesting that simply contrasting the alpha band power density for the two groups may be too weak an index of statistically significant differentiation between diagnosed depressed (without a comorbid disorder) and normals. It is for this reason that a distinct asymmetry measure, the even and

odd frequency components per cent power density analysis, was postulated as another, plausibly more powerful, index of pathology. In fact, examination of the results show that differences between the groups (main effect) became apparent with the use of the odd and the even-odd frequency component contrasts only. Since the contrasts between the even minus odd and the odd components analyses revealed significant distinctions for the Group independent variable but the even components alone did not reveal statistically significant results, there must be something about either the odd component or the even-odd components that is capable of sensing differences between the two groups. In a sense, at this stage, there is nothing special about choosing the even-odd components other than its ability to search inside the alpha range and draw out differences between groups of depressed and normals that may be covert when the entire alpha band as a dependent variable is used. Viewed differently, taking into account the results from Hypothesis 3, and since no significant Group main effects were observed when the even component analyses were utilized, but significant results for this independent variable main effect became apparent only when the odd or subtraction of the even components from the odd components of the alpha band was used, lends itself to suggest that this more complex analysis may be sensing certain biological differences underlied by neurochemical asymmetrical distributions in the brain as has been stated earlier (see Oke et al, 1978). Therefore, it is tentatively concluded from this analysis that comparing the even-odd components or using the odd components may prove to be a more powerful and sensitive index of differences between mood disordered and normal individuals than using

the entire spectrum of the alpha band power density. This conclusion is also supported by the results obtained from correlating the per cent alpha band (odd component) power density values collapsed across all regions from each depressed subject with his/her corresponding BDI score. This correlation was statistically significant ($p<.05$) again suggesting that the odd components may be capable of sensing pathology better than an Asymmetry Index. However, only further research using random sets of frequency components and comparing their results with those from odd or even-odd analyses will allow for a systematic examination of the impact of discrimination afforded by the odd or even-odd analyses. This point is followed further when conclusions about Hypothesis 3 are discussed.

An important finding from testing hypothesis 1, since it validates this and previous research as well as partially replicating previous results (Henriques & Davidson, 1990), was the Group x Sex interaction. The fact that depressed females displayed greater activation than normal females is an important result since it is in line with results from previous work. In particular, Henriques and Davidson (1990) utilized only females in their study and found normothymic females (previously depressed) to yield higher levels of right frontal activation than their never depressed counterparts. Therefore, although not tied to any specific region, as was the case with Henriques and Davidson's (1990) study, the current investigation supports the hypothesis that depressed females tend to display higher activation or lower alpha band power (energy) than normal females. Another important result supporting the validity of the present research is the lack of asymmetry obtained for

parietal areas, since this result has been very consistent throughout past studies (Davidson et al., 1990; Ekman et al., 1990; Tomarken et al., 1990; Schaffer et al., 1983) and it is replicated here. In other words, since frontal asymmetry was not replicated by the current study, the validity of the present investigation would be further threatened had this research yielded significant parietal differences between the experimental and control groups since these differences have not been found by the majority of asymmetry studies.

The results from testing hypothesis 2 indicated that the distributions between the controls and the affective disordered subjects apparently yielded distinct means, standard deviations, skewness, and kurtoses (see Table 8). In particular, the means for the depressed group's distributions were of greater magnitude across all regions than the control group's means, suggesting higher activation values across all regions. It would only be correct, based on the EEG asymmetry research data (e.g., Flor-Henry and Koles, 1981), to presume that the percent alpha power density distributions for the depressed and normals would show distinctive distribution moments, including its first moment. However, when statistical analyses were performed, the differences were not statistically significant between the two groups, for the dependent variable per cent alpha band power density[9], except for females where depressed females displayed higher frontal activation than normal females, according to expectations and as had been observed in other studies (Henriques & Davidson, 1990).

Due to the established criteria used in this experiment, depressed subjects' BDI scores were more variable (16-27) than the BDI scores for

the normal subjects which had a more restricted range (0-9). It is acceptable to state that this broader range would explain the higher variability of the depressed subjects' alpha rhythm (high standard deviation) output compared to controls.

Since the frontal distributions for both the left and the right hemispheres for the depressed group were all negatively skewed in contrast to the frontal distributions for the normal group, which were all positively skewed, psychophysiologically, this result suggests that the alpha activation scores of depressed subjects for frontal areas tend to cluster away from the mean in the positive direction (negatively skewed; Glass & Hopkins, 1984), opposite of the normal controls, which tend to segregate themselves close to the mean (positively skewed; Glass & Hopkins, 1984). In other words, the distributions of both depressed and normals are both asymmetrical; the asymmetry for the depressed subjects is due to segregation of scores away from the mean; the asymmetry for the normal group is due to convergence of the scores close to the mean of the overall distribution. Unfortunately, it is difficult to explain this result in terms of the subject matter in order to avoid conjectures.

All the distributions for the normal group were more platykurtic than those for the depressed group for all regions (which were more leptokurtic), suggesting that the scores from the depressive group tend to be under the tails of the distribution, far from the mean, as compared to the normal group's scores which tend to be closer to their mean. This result follows directly from the previous mentioned skewness, since skewed distributions tend to be more leptokurtic than

less skewed distributions. Back to the subject matter, the depressed group's alpha activation scores tend to be further away from their measure of central tendency (see Lemere in Lindsley, 1944) than the normal controls scores from their mean. Put differently, the depressed group have higher second moment (std. dev.) than the normal group as stated earlier partially due to their greater range of pathology.

Hypothesis 3 was partially validated. Differences between the groups were obtained for the per cent alpha band (odd frequency components) power density dependent variable but not for the per cent alpha band (even frequency components) power density of the bivariate MANOVA as postulated. Unfortunately, an effect for Region was not obtained and it contradicts the assertion for Hypothesis 3. Nevertheless, the results are welcomed since they continue to suggest that either the odd frequency component or the difference odd-even frequency component may be capable of differentiating between the two groups. Additionally, no effects were obtained either for parietal areas. The consistency of this result is in line with what would be expected for an EEG marker to be utilized for developing an assessment adjunct.

Hypothesis 4 was also partially validated. Under this postulate, it was predicted that the correlations between the even-odd component asymmetry index ratios and their respective BDI scores would be of greater strength and in the proper direction than the correlations between the Asymmetry Index ratios and their respective BDI scores. It was also speculated that the percentages obtained from the even-odd component asymmetry index ratios would discriminate better the depressed

and the control groups than the percentage of prediction from the Asymmetry Index ratios. For these results to occur all the correlations between the power density distribution asymmetry ratios and the normal subject's BDI scores had to be negative depicting the fact that the power ratios were defined as the differences between the right hemisphere minus the left hemisphere/right hemisphere plus left hemisphere. Therefore as BDI scores decreased, depicting lower levels of depression ("normality"), the right minus left/right plus left frontal ratio (log F4-log F3/log F4+log F3) would show increments in magnitude displaying either equal levels of activation between the two hemispheres or greater right frontal alpha activity in the right hemisphere ("normality"), thus the negative correlation as seen in previous studies (c.f., Schaffer et al., 1983). Similarly, for the depressed group, increased BDI scores, or said differently, increased pathology (depression) would be associated with decreased or even negative values for the asymmetry index ratios, since it was defined as F4-F3/F4+F3, and indicative of unequal levels of activation between the hemispheres with the left hemisphere outputing greater alpha activity; hence, a negative correlation also.

According to expectations, the results partly supported the even-odd components ability to better discriminate using percentages on the basis of actual alpha activity even-odd components asymmetry (see Table 10) than the Asymmetry Index, but the correlations from the alpha power density Asymmetry Index were higher than those from the even-odd analysis for both anterior and parietal areas, except for the depressed parietal alpha power asymmetry correlation, where the even-odd component

value was positive, like it was for the Asymmetry Index, however of lower significance since they were in the incorrect direction. Only two of all the correlations were significant. Unfortunately, these correlations were in the improper direction opposite to that hypothesized, suggesting a relationship between increments in BDI scores with increments in power. Conversely, an important and expected finding was the fact that more correlations were in the correct direction for the frontal area than for the parietal areas. Again as in previous studies (Davidson et al., 1990; Davidson, 1978) and as postulated by several investigators (Ekman et al., 1990; Davidson et al., 1990), it appears that the anterior, but not the parietal, areas are involved in processing emotions through displayed asymmetrical activation levels associated, vectorially correct (magnitude and direction), with verbal measures for these pathologies, since the BDI was utilized as the other correlating variable. Nevertheless, most of the results from this analyses must be suspected since these correlations, as stated above, were not statistically significant.

Contrasting results were partially obtained for the ability of the two different asymmetry indices to predict between the depressed and normal groups on the basis of their total log alpha power density asymmetry and per cent log alpha power density asymmetry values obtained from the two groups. It must be emphasized that these percentages are obtained utilizing the actual log alpha power density and log per cent alpha power density scores and not the percentages obtained from the proportion of variances accounted for by the correlations. Additionally, the percentage of prediction is defined as follows: Each subject's

laterality ratios (using the even-odd component analysis asymmetry index ratio and the Asymmetry Index ratio) was computed for frontal and parietal areas as shown on Table 10. Positive values indicate normality (left-sided hypoactivation; greater alpha activity on the right side) while negative coefficients indicate depression (right-sided activation; greater alpha activity on the left side). With this information a priori, coupled with close observation of Table 10, it becomes clear that the even-odd log alpha power density asymmetry ratio values for both, the log total alpha power density and the log per cent alpha power density (Figures 9 and 10) are superior at predicting percentage of subjects depressed than the Asymmetry Index ratios (log F4-log F3/ log F4+log F3; Figures 7 and 8). In all cases the even-odd predictive percentage values surpassed the Asymmetry Index values for the depressed group. The problem arises when an attempt is made to discriminate both normals and depressed. In this case only the total alpha band even-odd power density asymmetry ratio was capable of surpassing the standard Asymmetry Index ratio when predicting both groups of subjects. The aforementioned partially positive result is expected if it is believed that the comparison between the even minus odd component asymmetry index is better at predicting between the two groups than a simple Asymmetry Index alone. Figures 7-14 show these results graphically.

The measure of a good diagnostic test is not only its ability to predict pathology but to predict when pathology is absent. It appears from the results obtained that the even-odd analysis is superior at predicting the absence of pathology than its presence. It is also evident the test fails to provide adequate specificity when diagnosing

both normals and depressed. For example, the log total alpha even-odd power density asymmetry ratio, where 19% of the depressed and 100% of the normals were identified (total percentage of prediction= (100%+19%)/2=59%) was decreased when the odd-even component (25%+75%)/2=50%) of the formula was used to classify the two groups between the normals, providing an overall effective rate of prediction of 55%. If examining the depressed group only, using per cent alpha even-odd and odd-even power density frontal asymmetry ratios, a 62% false negative rate would have been obtained for the depressed. The 62% prediction for the depressed group is definitely not acceptable from a research or clinical standpoint, although the percentage of prediction for the depressed group from the current investigation is similar to the DST Test's 40-60% (Flam, 1991) but inferior to Schaffer's et al. (1983) 83% of prediction where only 6 depressed subjects were utilized, however, compared to the 16 employed by this experiment. The results from the odd components analysis provided similar values.

Another problem with low classification percentage rate for the depressed group is that it is probably lower than diagnostic base rates found in certain clinics. Nevertheless, from these results it is tentatively concluded that further research would have to be performed as a way of learning how to increase the sensitivity of the even-odd assessment.

For parietal areas, the data revealed, as expected (see Schaffer et al., 1983), that the ratios were mostly incapable of predicting above chance when utilizing the Asymmetry Index function or the asymmetry ratio. All ratios were equal to or less than 50%. This again is

according to expectation since it is being postulated that only frontal areas are involved in the processing of affect and since it is also being hypothesized that only frontal areas are involved in processing emotions.

Hypothesis 5 was also partially supported as theorized. Males and females displayed equal levels of alpha rhythm activation. Although some researchers had previously found differences between the two sexes (c.f., Flor-Henry & Koles, 1980), these distinctions had been ascertained under different experimental conditions than those comprising this research. In fact, Flor-Henry and Koles' (1980) findings applied to activated temporal areas in normal subjects, while they performed verbal and visuo-spatial tasks, as compared to this investigation, which assessed subjects at rest, with their eyes closed, for activational differences in frontal and parietal areas. In addition, although Flor-Henry and Koles' (1980) experiment was well designed (see Table 3), their subject selection criteria was not as strict or as sound as is the case with this research (see Table 5) and the dependent variables utilized by Flor-Henry and Koles (1980) were distinct from those utilized in this experiment. When proposed, Hypothesis 5 was postulated with this strict criteria in mind, based on the assumption that the experimental and control groups, and their respective male and female subjects, would possess the same characteristics, except for their levels of depression. It is then no wonder that the post-hoc comparison, which utilized percentage of anterior alpha band power density relative to total power density, the male vs. female contrast using their log total anterior alpha band power

density, and the comparison of males vs. females using even-odd component anterior log alpha band power density, all yielded insignificant results as expected (this was the case for the MANOVA utilized to test Hypothesis 3 also). To further support the assertion that males and females would display similar levels of anterior alpha rhythm activation, and since all the psychophysiological tests yielded insignificant results, testing for gender differences using BDI scores ensued. Comparisons of the BDIs of all males vs. all females, of normal males vs. normal females, and of all depressed males vs. all depressed females also produced insignificant results as anticipated. Again, it is contended that the restrictions placed on subjects by the strict selection criteria assured that the groups of normals and depressed, and their respective males and females, differed only on their level of depression but not on other variables. Additionally, this result was anticipated on the basis of previous research. Other investigators (Schaffer et al., 1983), employing a similar experimental paradigm, have not reported sex differences. Schaffer et al. (1983) also used similar, but more relaxed criteria, than the present investigation. Therefore this study supports Schaffer et al. (1983) earlier findings and provides concurrent validity for the present investigation.

A result that was unexpected and modifies the gender difference conclusions stated above, although partly confirmed by previous studies (Henriques & Davidson, 1990), was the difference observed between the depressed and normal females. Henriques and Davidson (1990) utilized females only in their study and found differences between normal (never depressed) and normothymic (previously depressed) females when presented

with emotion eliciting films. The fact that depressed females displayed greater activation than normal females would be expected based on the postulated hypothesis. Therefore, the results support this finding for females. What was surprising was the inability of men to show the same difference.

Finally, the result from the gender evaluation supports the EEG's concurrent validity with the BDI. If the EEG's log per cent anterior alpha band power density assesses affective disorders as good or better than existing assessment methods, as it has been claimed in this investigation, it is acceptable to expect from the BDI and EEG activation levels to yield similar results, although they may be measuring the same pathology through different methods. As it turns out, examination of the results revealed that the BDI means for the depressed male and depressed female subjects for this experiment are identical (mean=19.13). A statistical test would not yield significant results using the BDI scores from the two groups. Likewise, no gender alpha band EEG activation differences were obtained, as was the case with the BDI scores. Further, in contrast to other studies, where an unequal number of males and females were utilized, the present investigation used an equal number of subjects from both genders.

Conclusions

The following conclusions could be provisionally drawn from the present investigation: (1) This study was unable to replicate anterior interhemispheric asymmetry between groups of depressed and normal individuals using per cent alpha band power density (energy). The inability to replicate frontal asymmetry may be linked to the number of

strict controls used in this investigation compared to previous investigations. (2) The use of the odd frequency components or the even-odd frequency components differentiated between depressed and normal subjects when testing two hypotheses. (3) Due to the observed consistency of the odd-even or odd frequency components for Hypotheses 1 and 3 to differentiate between the experimental and depressed groups, it is recommended that further research be conducted using this measure to investigate if it is a stable marker for depression; if it turns out to be a stable marker, it could then be employed to create an adjunct assessment measure for depression. (4) Gender differences were not found except as part of an interaction between Group x Sex indicative of differences between depressed females and normal females, depressed females exhibiting greater alpha power than normal females without significant differences between males. (5) The odd-even frequency components asymmetry index ratios of the per cent and total alpha band power density were not able to serve as a good classification measure since they show little specificity. In addition, the correlations between the Asymmetry Index and BDI scores are superior to those between the odd-even asymmetry index and BDI scores. (6) The odd-even predictive analysis maximizes the percentage of prediction of depressed subjects while the even-odd analysis maximizes the percentage of prediction for normal subjects. This inverse relationship fails to categorize a large number of subjects when used with the opposite sets of components.

Endnotes

[1]The development of an EEG diagnostic assessment adjunct by no means devalues existing valid and reliable diagnostic approaches. It must be emphasized that the EEG data would be utilized by the clinician as an aid in the diagnostic process, and its result interpreted within the context of other assessment information.

[2]All electrode lead placements and montages for studies referenced after 1958 are based on the International 10-20 system (Jasper, 1958).

[3]The fact that subjects maintained their eyes open places into question the elicitation of alpha waves proper, since alpha waves are best elicited under relaxed, eyes closed conditions (c.f., Niedermeyer, 1987a; Scott, 1976).

[4]The 1920 samples were first padded with zeroes to create a data set of 2048 samples which is a power of 2 value (2 to the eleventh power). Padding was performed in order to be able to perform the FFT which requires a power of 2 value for the data set.

[5]The FFT was performed using a software program by Van Zandt (unpublished software program). The -S parameter (Supergaussian windowing) was selected when performing the FFT. The program can be obtained from James R. Van Zandt, 27 Spencer Drive, Nashua, NH 03062.

[6]When the EEG is transformed through the FFT, minimal, although in some cases significant, power losses occur that can not be ascertained unless cumbersome loss analyses are performed for each subject, since each subject's EEGs power losses are unique. Conversely, these losses have no effect on the per cent alpha band power, since the percentage of alpha band from the total power for each subject is obtained. For this

reason, per cent alpha band power density, instead of total alpha band power density, was utilized throughout the study, unless a comparison with existing studies required that total power be used.

[7]Davidson, Chapman, Chapman & Henriques (in-press) claim that utilizing the ratio (F4-F3/F4+F3), rather than the simple subtraction of F4-F3 values, controls for activation differences caused by differences in the thickness of the skull of the subjects participating in the experiment. This is the rationale utilized in this experiment, when using the ratio as an asymmetry index.

[8]From here on we refer to the asymmetry index ratio (F4-F3/F4+F3) as the Asymmetry Index and use upper case letters to denote that this is the index utilized by other laboratories (Davidson, 1988; Tomarken et al., 1990). The index utilized by this investigation is usually composed of the alpha rhythm even (e=8+10+12) or odd (o=9+11+13) frequency components as noted, unless otherwise specified. Additionally, although a nominal value is used to denote each of the frequency components, each component was created through the use of their entire frequency range. Therefore, odd frequency component 9 is actually composed of the arithmetic sum of frequencies from 8.50 to 9.49. This is the case for all other frequencies as well (see Appendix F).

[9]Note that this result does not apply when the dependent variable per cent alpha band odd component power density was used where significant Group main effects were observed.

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Table 1

The DSM-III-R Classification for Depression

Diagnostic Criteria for Major Depressive Episode

A. At least five of the following symptoms have been present during the same two-week period and represent a change from previous functioning; at least one of the symptoms is either (1) depressed mood, or (2) loss of interest or pleasure. (Do not include symptoms that are clearly due to a physical condition, mood-incongruent delusions or hallucinations, incoherence, or marked loosening of associations.)

(1) depressed mood (or can be irritable mood in children and adolescents) most of the day, nearly every day, as indicated either by subjective account or observation by others

(2) markedly diminish interest or pleasure in all, or almost all, activities most of the day, nearly every day (as indicated either by subjective account or observation by others of apathy most of the time)

(3) significant weight loss or weight gain when not dieting (e.g., more than 5% of body weight in a month), or decreased or increase in appetite nearly every day (in children, consider failure to make expected weight gains)

(4) insomnia or hypersomnia nearly every day

(5) psychomotor agitation or retardation observable by others, not merely subjective feelings of restlessness or being slowed down)

(6) fatigue or loss of energy nearly every day

(7) feelings of worthlessness or excessive or inappropriate guilt (which may be delusional) nearly every day (not merely self-reproach or guilt about being sick)

(8) diminished ability to think or concentrate, or indecisiveness, nearly every day (either by subjective account or as observed by others)

(9) recurrent thoughts of death (not just fear of dying), recurrent suicidal ideation without a specific plan, or a suicide attempt or a specific plan for committing suicide

Table 1. (Continued)

B. (1) It can not be established that an organic factor initiated and maintained the disturbance

(2) The disturbance is not a normal reaction to the death of a loved one (Uncomplicated Bereavement).

C. At no time during the disturbance have there been delusions or hallucinations for as long as two weeks in the absence of prominent mood symptoms (i.e., before the mood symptoms developed or after they have remitted).

D. Not superimposed on Schizophrenia, Schizophreniform Disorder, Delusional Disorder, or Psychotic Disorder NOS.

Major Depressive Episode Codes: fifth-digit code numbers and criteria for severity of current state for Major Depression (used in this study):

2 -- Moderate: Symptoms or functional impairment between "mild" & "severe"

3 -- Severe, without Psychotic Features: Several symptoms in excess of those required to make the diagnosis, and symptoms markedly interfere with occupational functioning or with usual social activities or relationships with others

Adapted from DSM-III-R (American Psychiatric Association, 1987).

Table 2

Comparison of Current Diagnostic Approaches

	Factors				
Approach	Simplicity	Cost	Invasiveness	Endogenous	Reliable
Verbal Report	v	v	v	x [1]	x [2]
Current Biochem. Methods	x [3]	x [3]	x [3]	v	x
Multiaxial	v	v	v	x [1]	x [2]
Neuro-radiological	x	x	x	s	n/a [4]
EEG	v	v	v	v	x [5]

Legend

v = denotes strength for marked factor, except as noted.
x = denotes a liability for the marked factor.

Notes

1. Verbal report is not endogenous; this is a liability for this method since it is responsible, in part, for its unreliability.

2. The reliability of verbal report or clinician based methods is questionable, although new approaches (e.g., DSM-III-R) have increased the stability of these methods.

3. Complexity, cost and invasiveness are the three liabilities of diagnostic techniques based on biochemical approaches.

4. These methods are not usually employed to diagnose psychopathology since they lack validity.

5. This is one of the major liabilities presently preventing the EEG from serving as an aid in the diagnostic process.

Table 3

Summary of EEG Investigations

Study	Results Classify	N	Possible Classification Scheme	Comments
Flor-Henry & Koles (1980)	yes*	N=251 53 schiz. 75 manics 63 depress. 60 normals	Based on patterns of greater right vs. left-sided anterior activation	Well designed experiments w/ use of psychiatric criteria for selecting subjects--good reliability
Perris et al. (1979)	no	N=45	Classified endogenous from reactive subjects not between depressed and normals	"
Shagass et al. (1982)	no	N=336 242 experim. 94 controls 159 schiz. 30 depress. 13 manics 36 neurotics 25 pers. dis.	Based on asymmetry (between schizoph. and normals not depressed and normals	Inability to find differences between normals and depres. probably due to heterogeneous depres. category
Schaffer et al. (1983)	yes	N=15 6 depress. 9 non-dep.	Based on frontal activation (asymmetry)	Well designed experiment except it used BDI to classify subjects as depressed and small N. See Figure 2
Henriques & Davidson (1990)	yes	N=14 6 prev. dep. 8 normals	Based on EEG asymmetry	Study classified normothymic from normal controls--excellent paper.
D'Elia & Perris (1973)	n/a	N=18 dep. psych.	Study did not attempt to classify subjects	Attempted to determine EEG response to ECT treatment--Did not use control group
Henniger (1978)	n/a	N=18 15 manic-dep. 3 schiz.	"	Attempted to determine EEG response to drug treatment--Used dipolars--Did not use F3 & F4.
Matousek et al. (1981)	n/a	N=416 16 par. schiz 27 end. dep. 373 normals	"	"
Tucker (1981)	n/a	not described	"	Study showed that EEG asymmetry can be induced by inducing depress. hypnotically

Table 3. (Continued)

Study	Results Classify	N	Possible Classification Scheme	Comments
Tomarken et al. (1990)	yes	N=32 32 normal adult females	Based on right anterior asymm.	Self-reported negative emotions correlated with anterior alpha activation
Davidson et al. (1990)	yes	N=37 37 normal adults	Based on right vs. left frontal asymmetry	Disgust associated with right frontal alphan activation--positive emotions associated with left frontal activation
Eckman et al. (1990)	yes	N=37 37 normal adults	"	Positive affect associated with higher left activation
Davidson & Fox (1982)	no	N=18 18 normal infants	None	Results not in hypothesized direction--negative affect associated with right frontal activation
Davidson & Fox (1989)	yes	N=13 13 normal infants	Based on right frontal activation	Distinguished criers from non-criers based on baseline alpha right frontal activation--High rate of attrition 63%--See Figure 3
Pollock & Schneider (1990)	no	N=32 16 depress. 16 normals	Class. possible using absolute EEG alpha amplitude	No differences between groups on relative EEG possibly due to large age span of subjects--50% males & 50 % females--Diag. via DSM-III-R

*The yes-no decision is based on the ability to classify normals from depressed through EEG alpha band asymmetry.

Table 4

Postulated Experimental Hypotheses for the Present Study

Hypotheses	Postulated Results
1	- Per cent alpha rhythm power density activation differences between depressed and normals will be observed
	- Differences will be limited to anterior (F3 & F4) areas (no differences will be observed in the parietal areas).
	- The depressed group will display higher activation (less alpha activity) in the right frontal area than the normal group (F4; Depressed < F4; Normals).
2	- Per cent alpha rhythm power spectral density frequency distributions for the depressed and normal groups will differ in terms of their respective distribution's moments (mean, std. dev., skewness, and kurtosis).
3	- The depressed group will primarily show frontal activation in their per cent alpha (8-13 Hz) band power density odd frequency components (9+11+13 Hz) than in the even frequency components (8+10+12 Hz) (or vice versa).
4	- Log per cent and log total alpha power density (even-odd) frequency component asymmetry ratio will discriminate better than the alpha band Asymmetry Index ratio (log F4-log F3/log F4+log F3) between the normal and depressed groups (see Tables 7 & 10). Correlations between even/odd ratios and their respective BDI scores will show higher magnitude and correct direction than correlations between the Asymmetry Index ratio and their respective BDI means.
5	- Females will display equal alpha rhythm activation in anterior region as males.

Table 5

Subjects' Experimental Criteria Requirements

Experimental Requirements for All Subjects

- age between 18-22 years
- dextral
- identical SES level (Hollingshead's Level III)
- no previous head injury
- no previous history of epileptic seizures
- no previous history of ECT treatment
- no known neurological impairment
  - i. tumors
  - ii. seizures
  - iii. aneurisyms or other cerebrovascular accidents
  - iv. no history of encephalitis
- no use of non-prescribed medication for at least 14 days prior to participation in the experiment
- no current use of prescribed medication except for allergies (2 subjects)
- no reactive event (e.g., loss of parent, divorce, etc.)
- EEG recorded during morning hours (8:00am-2:00pm)
- no history of birth trauma (e.g., anoxia at birth)

Females Only

- EEG was recorded during the middle of their menstrual cycle*

Depressed Subjects Only

- diagnosis of major depression without other concomitant disorder - SCID
- Zung SDS score equal to or greater than .50
- BDI score equal to or greater than 16

Normal Controls Only

- Zung SDS score between .25-.45
- BDI score equal to or less than 9
- no diagnosis on the SCID

---

* Based on verbal report and monitoring of menstrual cycle for women not on contraceptives and monitoring of contraceptive dispenser for women on the pill assuming regularity of cycle and synchronicity with pill dispenser.

Table 6

Demographic Data - Summary

Variable	Group Normal	Group Depressed		
Number of subjects	16	16		
Males	8	8		
Females	8	8		
	Mean;SD	Mean;SD	t	Level of Signif.
Age (years)	19.6;1.09	19.4;0.81	0.55	p=.585
SES Score (Level III)	36.9;2.92	36.9;4.03	0	p=1
Depression Scores				
a. Zung SDS	.374;.052	.590;.077	-9.3	p=.000
b. BDI	2.06;2.44	19.1;3.44	-16.2	p=.000
c. SCID	No Dx	All Dx		
Laterality Score				
a. R Decile	0.96;0.07	0.97;0.05	-.289	p=.774
b. L Decile	0.04;0.06	0.05;0.06	-.565	p=.576
c. Laterality Quotient	0.93;0.12	0.91;0.12	+.458	p=.650
Alertness Score (overall)	7.19;1.63	5.66;1.58	2.7	p=.011
EEG Init. Recording Time	9.94;2.67	10.50;2.56	-.61	p=.547

Table 7

Hypotheses, Raw Data, and Analyses

Hypotheses	Description of Analysis	Raw Data	FFT Transform	Dep. Var.	Analyses
1	Group Comparison	μV F3NMF	μV^2/Hz F3NMF	%μV^2/Hz F3NMF	
		μV F4NMF	μV^2/Hz F4NMF	%μV^2/Hz F4NMF	
		μV P3NMF	μV^2/Hz P3NMF	%μV^2/Hz P3NMF	
		μV P4NMF	μV^2/Hz P4NMF	%μV^2/Hz P4NMF	ANOVA Group x Region x Sex and post-hoc comparisons
		μV F3DMF	μV^2/Hz F3DMF	%μV^2/Hz F3DMF	
		μV F4DMF	μV^2/Hz F4DMF	%μV^2/Hz F4DMF	
		μV P3DMF	μV^2/Hz P3DMF	%μV^2/Hz P3DMF	
		μV P4DMF	μV^2/Hz P4DMF	%μV^2/Hz P4DMF	
2	Descriptive Statistic Comparison	μV N(F3,F4,P3,P4)	μV^2/Hz N(F3,F4,P3,P4)	%μV^2/Hz N(F3,F4,P3,P4)	Comparison of Mean, SD, skewness and kurtosis between distributions of depressives and normals
		μV D(F3,F4,P3,P4)	μV^2/Hz D(F3,F4,P3,P4)	%μV^2/Hz D(F3,F4,P3,P4)	
3	Even vs. Odd Comparison	μV NF3F4MFE	μV^2/Hz NF3F4MFE	%μV^2/Hz NF3F4E	
		μV NF3F4MFO	μV^2/Hz NF3F4MFO	%μV^2/Hz NF3F4O	MANOVA Group x Region (F3 & F4) x Sex
		μV DF3F4MFE	μV^2/Hz DF3F4MFE	%μV^2/Hz DF3F4E	
		μV DF3F4MFO	μV^2/Hz DF3F4MFO	%μV^2/Hz DF3F4MFO	
4	Predictive and Correlational Analyses	μV NF3F4MF	μV^2/Hz NF3F4MF	See Table 10	
		μV DF3F4MF	μV^2/Hz DF3F4NF	"	
		μV NP3P4NF	μV^2/Hz NF3F4MF	"	
		μV DP3P4MF	μV^2/Hz DF3F4MF	"	Correlational Asymmetry Index Ratios asymmetry index ratios (even-odd) and BDI Scores
		μV NF3F4MF	μV^2/Hz NF3F4MF	"	
		μV DF3F4MF	μV^2/Hz DF3F4MF	"	
		μV NF3F4MF	μV^2/Hz NP3P4MF	"	
		μV DP3P4MF	μV^2/Hz DP3P4MF	"	
		μV NF3F4MF	μV^2/Hz NF3F4MF	"	

Table 7. (Continued)

Hypotheses	Description of Analysis	Raw Data	FFT Transform	Dep. Var.	Analyses
		μV DF3F4MFO	$\mu V^2/Hz$ DF3F4MFO	"	
		μV NP3P4MFE	$\mu V^2/Hz$ NP3P4MFO	"	Predictive Percentage of Prediction from asymmetry ratios
		μV DP3P4MFE	$\mu V^2/Hz$ DF3F4MFO	"	
		μV NF3F4MFE	$\mu V^2/Hz$ NF3F4MFO	"	
		μV DF3F4MFE	$\mu V^2/Hz$ DF3F4MFO	"	
		μV NP3P4MFE	$\mu V^2/Hz$ NP3P4MFO	"	
		μV DP3P4MFE	$\mu V^2/Hz$ DP3P4MFO	"	
5	Gender Comparisons (frontal regions)	μV NFMF3F4	$\mu V^2/Hz$ NFM3F4	$\%\mu V^2/Hz$ NDFMF3F4	Post-hoc Comparisons between genders for frontal regions
		μV DFMF3F4	$\mu V^2/Hz$ DFMF3F4	$\%\mu V^2/Hz$ DFMF3F4	

Subscript Legend

F3, F4, P3, P4 = Frontal and parietal regions according to the International 10-20 System (Jasper 1958, see Figure 1).
E = Even components (8+10+12 Hz); O = Odd components (9+11+13 Hz).
M = Male; F = Female.
% = Percent power density.
N = Normal; D = Depressed.
All $\mu V^2/Hz$ values are log alpha rythm (8-13 Hz) only, except for even (8+10+12 Hz) and odd (9+11+13 Hz) components which are log (8+10+12) and log (9+11+13) for analyses testing Hypothesis 4.
Subscript example: P3DMF = left parietal area, depressed group, males and females.

Table 8

Distribution Means, Standard Deviations, Skewness, and Kurtoses (Moments) for the Depressed and Control Groups

	Group	
	Control	Depressed
Mean		
F3	24.56	26.36
F4	24.92	26.44
P3	28.61	30.07
P4	28.86	30.42
Std. Dev.		
F3	4.62	6.21
F4	4.61	6.55
P3	6.21	7.45
P4	5.99	7.01
Skewness		
F3	.20	-.12
F4	.28	-.24
P3	.24	.11
P4	.42	-.03
Kurtoses		
F3	-.63	-1.58
F4	-.78	-1.52
P3	.07	-1.51
P4	.63	-1.56

Dependent Variable = Per Cent Alpha Band Power Density.

Table 9

Wilks' Lambda F-Tests, Univariate F-Tests, and Means For the Group x Region x Sex MANOVA

	Wilks' Lambda	p	Univariate F-Ratio		p
Group	F=6.34	$p < .01$	(8+10+12)	F=0	$p < .98$
			(9+11+13)	F=7.66	$p < .01$
Region	F=1.66	$p < .19$	(8+10+12)	F=0	$p < .97$
			(9+11+13)	F=2.06	$p < .15$
Sex	F=1.66	$p < .19$	(8+10+12)	F=0	$p < .97$
			(9+11+13)	F=2.06	$p < .15$
				Means	
Group			(8+10+12)	14.75	14.73
			(9+11+13)	13.57	12.01
Region			(8+10+12)	14.75	14.73
			(9+11+13)	13.20	12.37
Sex			(8+10+12)	14.75	14.73
			(9+11+13)	13.20	12.37

Table 10

Hypotheses 4 - Correlations and Per Cent Prediction of Normals and Depressed Subjects From Activation Asymmetry Ratios

Group	Area	Variables	r	p	% Classified
		Total Power Density			
Normal	Frontal	tF4-tF3/tF4+tF3	-.212	.432	81
Depres.	Frontal	tF4-tF3/tF4+tF3	.024	.930	31
Normal	Frontal	%F4-%F3/%F4+%F3	-.275	.302	44
Depres.	Frontal	%F4-%F3/%F4+%F3	.290	.291	31
		Even-Odd Power Density			
Normal	Frontal	%F4e-%F3o/%F4e+%F3o	-.104	.701	94
Normal	Frontal	%F4o-%F3e/%F4o+%F3e			0
Depres.	Frontal	%F4o-%F3e/%F4o+%F3e	.511	.004	63
Depres.	Frontal	%F4e-%F3o/%F4e+%F3o			13
Normal	Frontal	tF4e-tF3o/tF4e+tF3o	-.193	.474	100
Normal	Frontal	tF4o-tF3e/tF4o+tF3e			25
Depres.	Frontal	tF4o-tF3e/tF4o+tF3e	.458	.930	75
Depres.	Frontal	tF4e-tF3o/tF4e+tF3o			19

Table 10. (Continued)

Group	Area	Variables	r	p	% Classified
		Total Power Density			
Normal	Parietal	tP4-tP3/tP4+tP3	-.275	.364	50
Depres.	Parietal	tP4-tP3/tP4+tP3	.247	.356	38
Normal	Parietal	%P4-%P3/%P4+%P3	-.027	.922	50
Depres.	Parietal	%P4-%P3/%P4+%P3	.081	.765	19
		Even-Odd Power Density			
Normal	Parietal	%P4e-%P3o/%P4e+%P3o	.230	.391	88
Normal	Parietal	%P4o-%P3e/%P4o+%P3e			6
Depres.	Parietal	%P4o-%P3e/%P4o+%P3e	.580	.039	63
Depres.	Parietal	%P4e-%P3o/%P4e+%P3o			25
Normal	Parietal	tP4e-tP3o/tP4e+tP3o	-.164	.544	81
Normal	Parietal	tP4o-tP3e/tP4o+tP3e			0
Depres.	Parietal	tP4o-tP3e/tP4o+tP3e	.239	.374	63
Depres.	Parietal	tP4e-tP3o/tP4e+tP3o			38

Definitions

t equals log total alpha band (8-13 Hz) power density

% equals log per cent alpha band (8-13 Hz) power density

e equals even components (8+10+12 Hz)

o equals odd components (9+11+13)

All correlations are between the dependent variables shown and their corresponding BDI scores (e.g., the first variable tabulated would be correlated with the normal group's BDI scores).

Figure Captions

Figure 1. The International Ten-Twenty System.

Figure 2. Frontal laterality ratio scores for depressed and nondepressed.

Figure 3. Resting EEG alpha band power scores for criers and non-criers.

Figure 4. The concepts of total alpha power density and per cent alpha power density.

Figure 5. Three representations for the Fourier Transform.

Figure 6. Experimental procedure flow chart.

Figure 7. Frontal laterality ratio scores for depressed and nondepressed (normals) - Total alpha band power density.

Figure 8. Frontal laterality ratio scores for depressed and nondepressed (normals) - Per cent alpha band power density.

Figure 9. Frontal laterality ratio scores for depressed and nondepressed (normals) - Per cent alpha band (even vs. odd) power density.

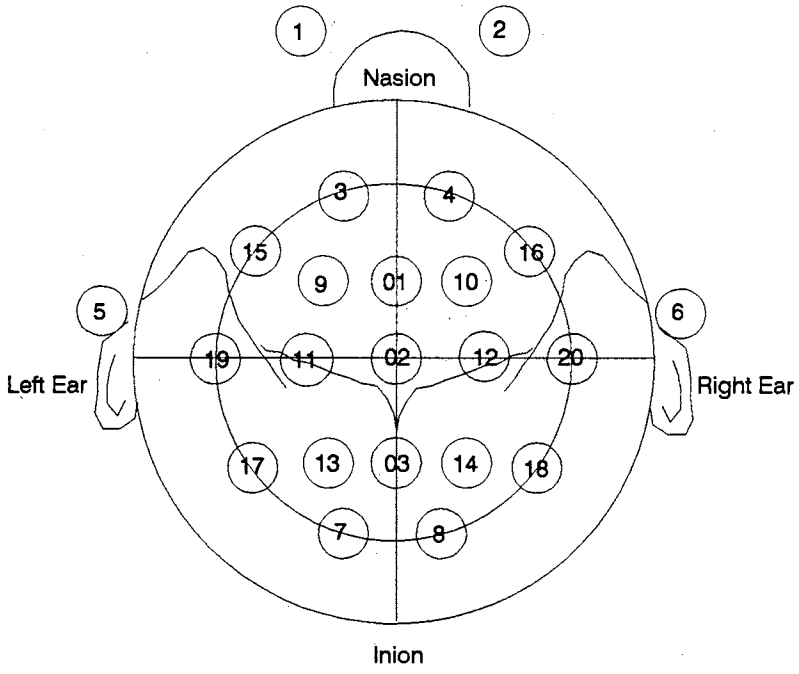
Figure 10. Frontal laterality ratio scores for depressed and nondepressed (normals) - Total alpha band (even vs. odd) power density.

Figure 11. Parietal laterality ratio scores for depressed and nondepressed (normals) - total alpha band power density.

Figure 12. Parietal laterality ratio scores for depressed and nondepressed (normals) - Per cent alpha band power density.

Figure 13. Parietal laterality ratio scores for depressed and nondepressed (normals) - Per cent alpha band (even-odd) power density.

Figure 14. Parietal laterality ratio scores for depressed and nondepressed (normals) - Total alpha band (even-odd) power density.

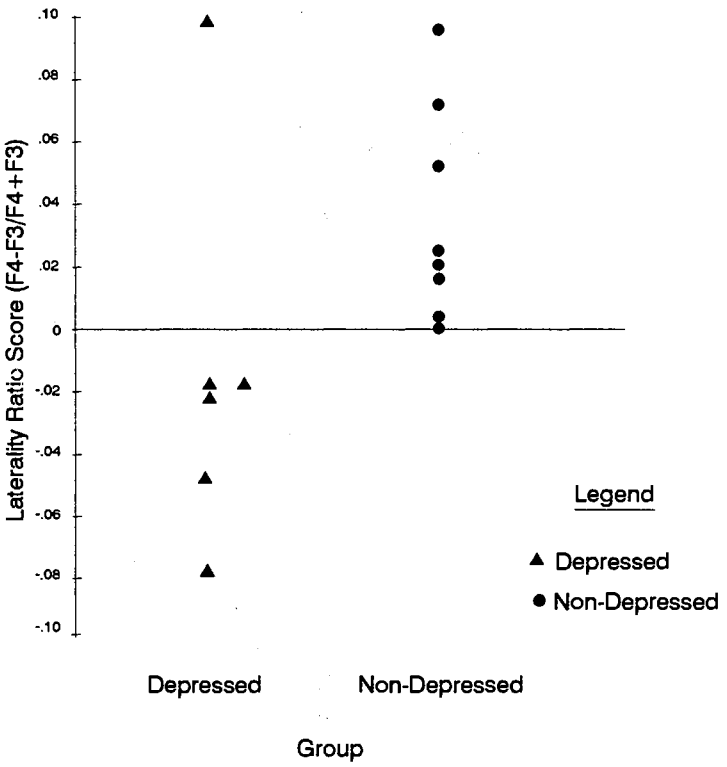


Legend

1. Pg1	6. A2	11. C3	16. F8	01. Fz
2. Pg2	7. O1	12. C4	17. T5	02. Cz
3. Fp1	8. O2	13. P3	18. T6	03. Pz
4. Fp2	9. F3	14. P4	19. T3	
5. A1	10. F4	15. F7	20. T4	

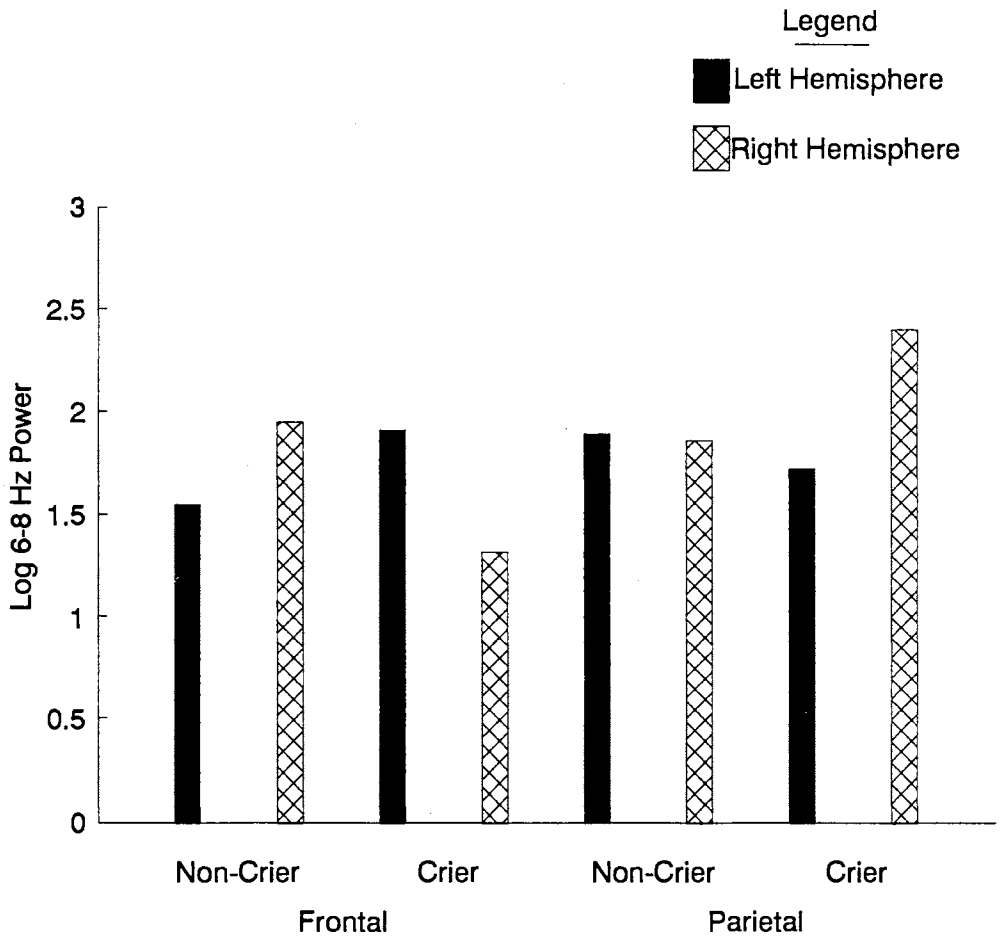
The International Ten-Twenty System

Adapted From Jasper (1958)



Frontal laterality ratio (R-L/R+L) scores for individual subjects split by group. Positive numbers on this score are indicative of left-sided frontal activation (depression) while negative numbers are indicative of right-sided activation

Adapted from Schaffer, Davidson & Saron (1983)

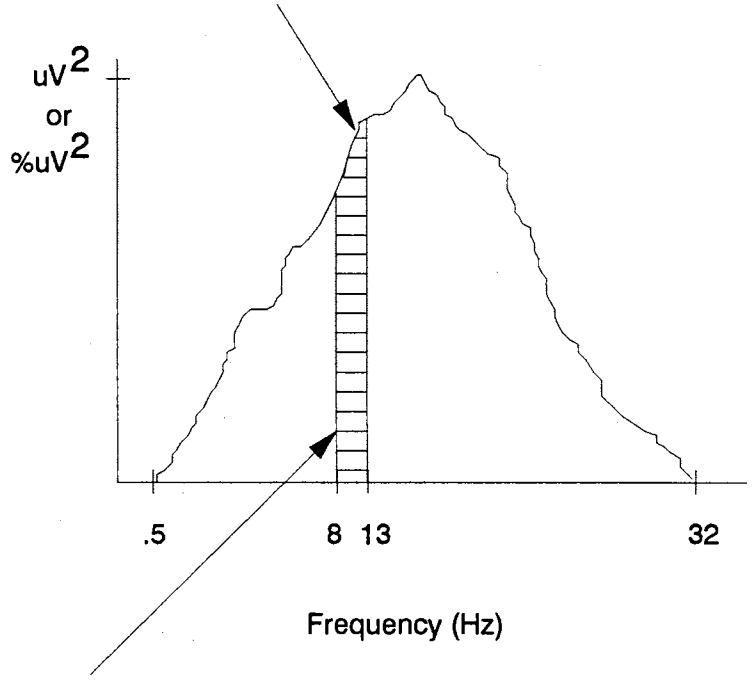


Mean log (6-8Hz) power for the resting baseline period in the left and right frontal and parietal regions for criers and noncriers

Adapted from Davidson & Fox (1989)

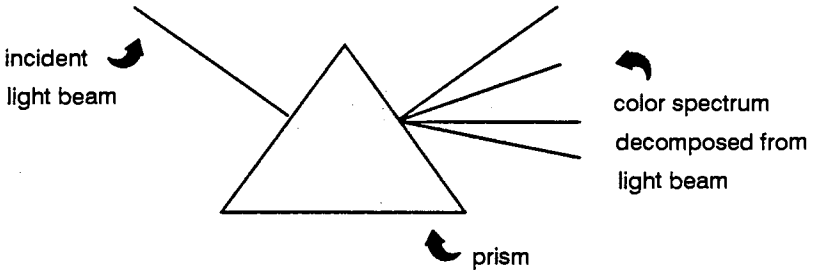
Per Cent Alpha Band Power Density (%Energy)

$$\frac{\text{alpha (8-13Hz) power density}}{\text{total (.5-32Hz) power density}} \times 100\%$$



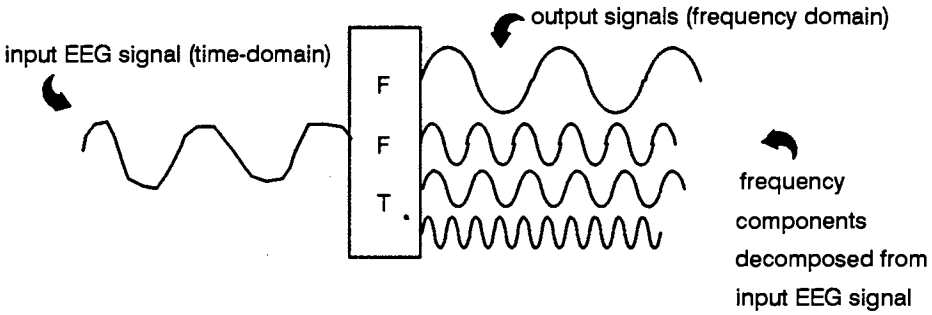
Total Alpha Band Power Density
absolute total power density under
the alpha (8-13Hz) band
(hatched area)

The Concepts of Total Alpha Power Density (Energy)
and Per Cent Alpha Power Density (%Energy)



Prism acts like FFT, decomposing the incident light beam into
the color (freqency) spectrum

Fast Fourier Transform (FFT) - Physical Analogy



FFT decomposes the original EEG (time-domain) waveform into
its constituent frequency components (frequency domain)

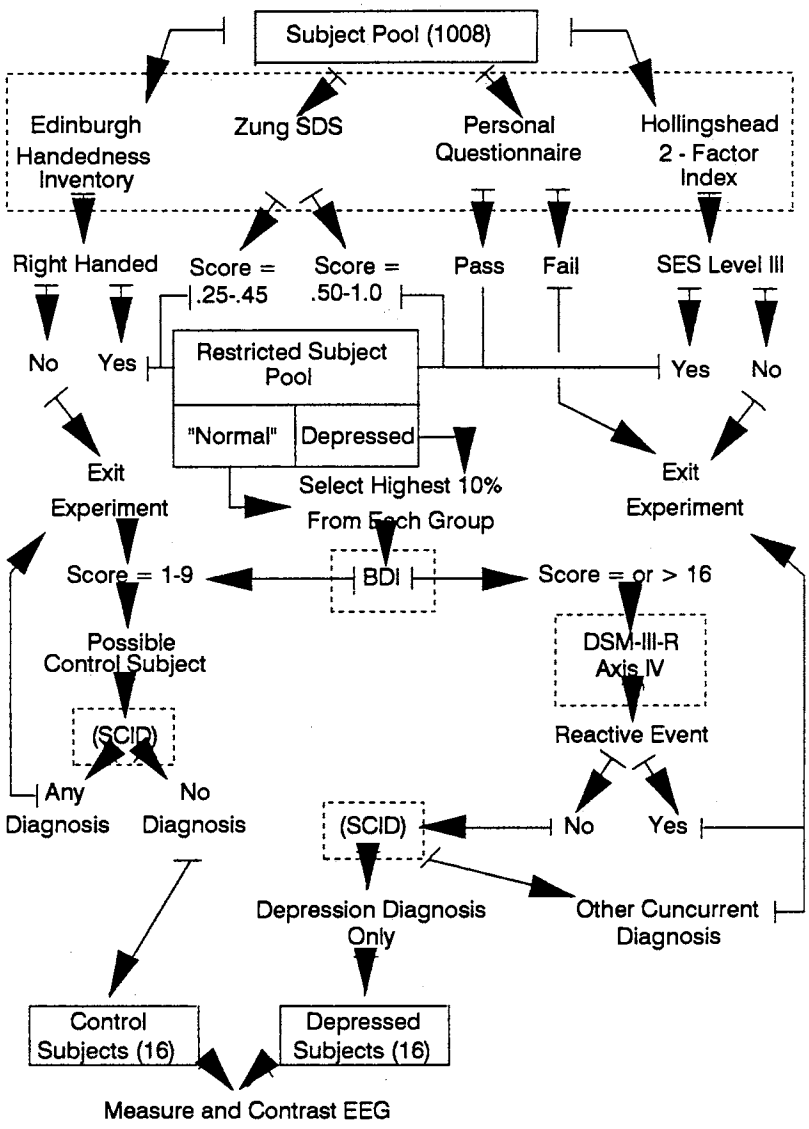
Fast Fourier Transform (FFT) - Graphical Representation

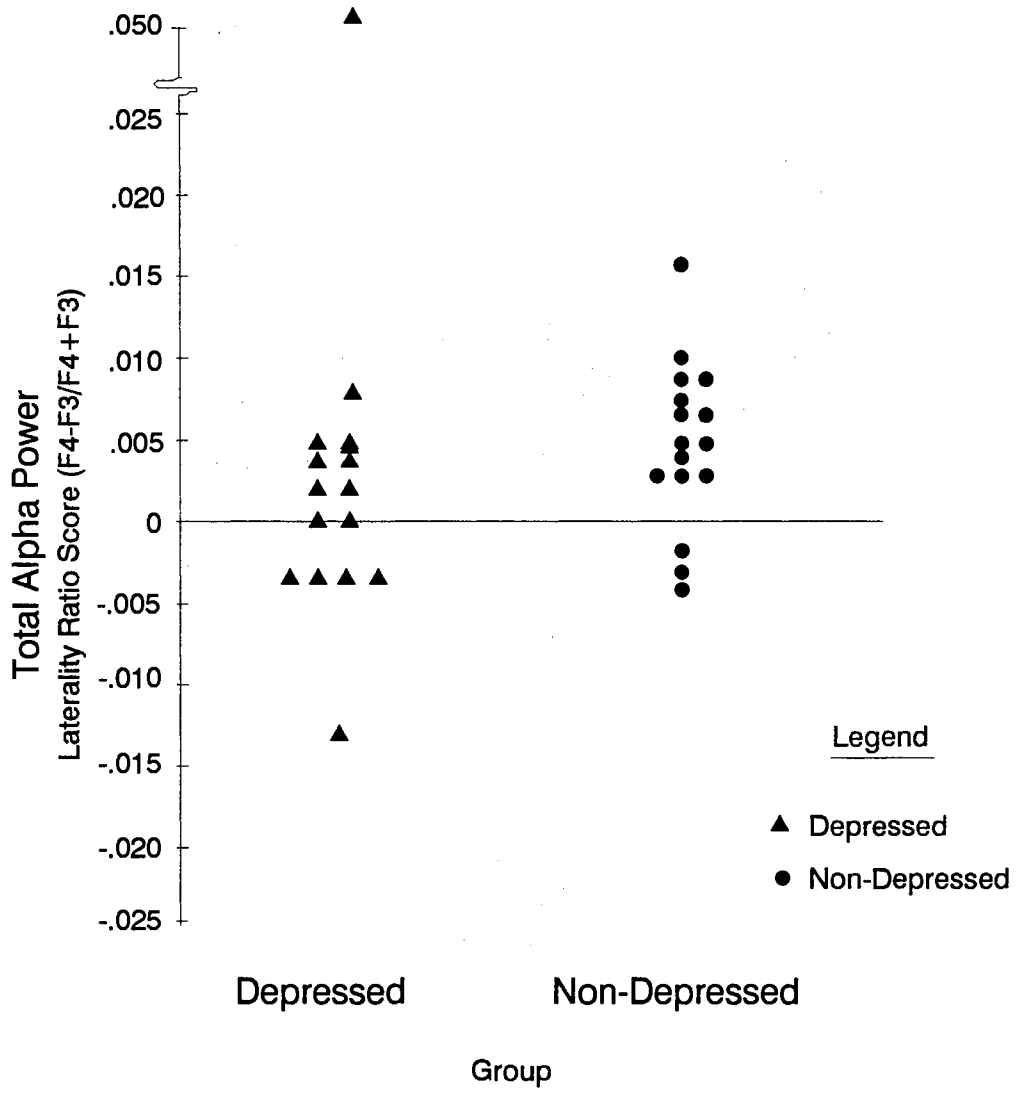
$$F(\omega) = \int_{-\infty}^{\infty} f(t)\, e^{j\omega t}\, dt$$

The Fourier Transform is equal to the integral of the original
time function as shown above. It represents the time-domain
function as a summation of sinusoidal frequency components

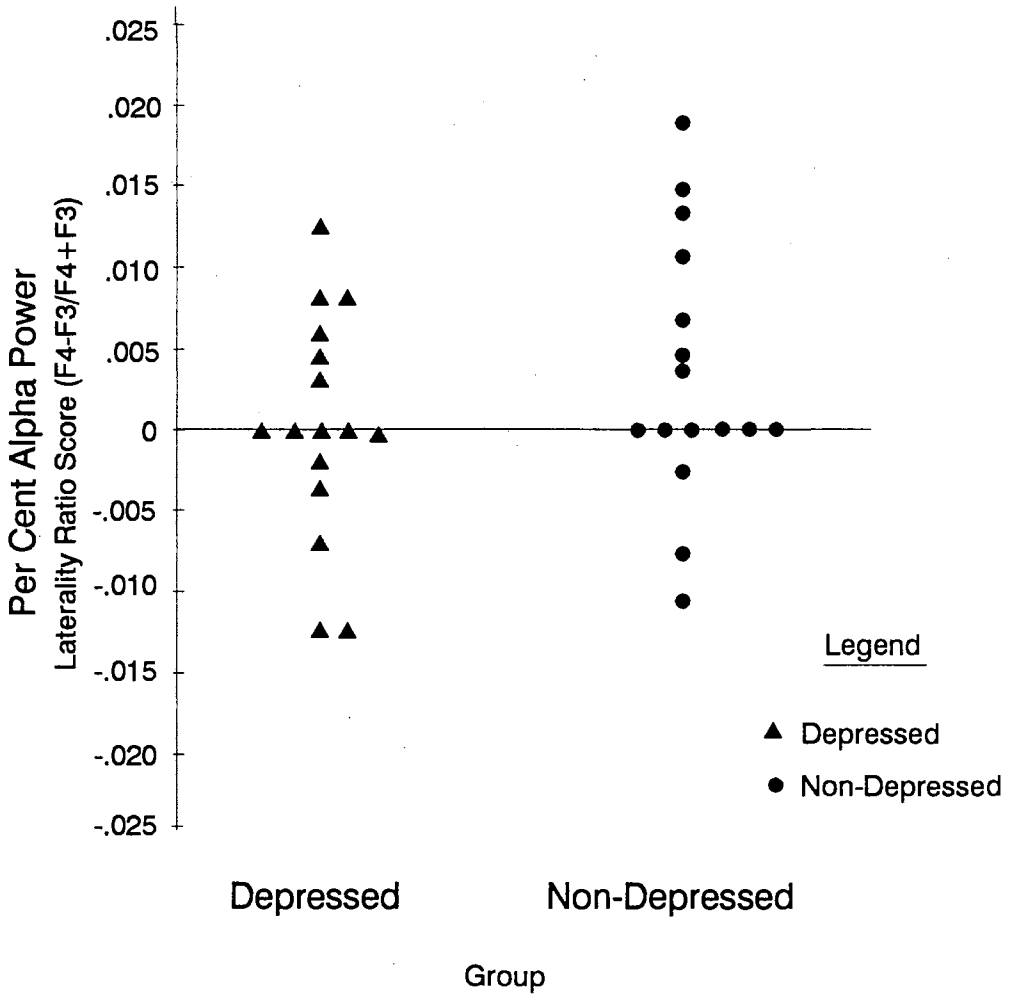
Fourier Transform - Mathematical Representation

EXPERIMENTAL PROCEDURE FLOW CHART

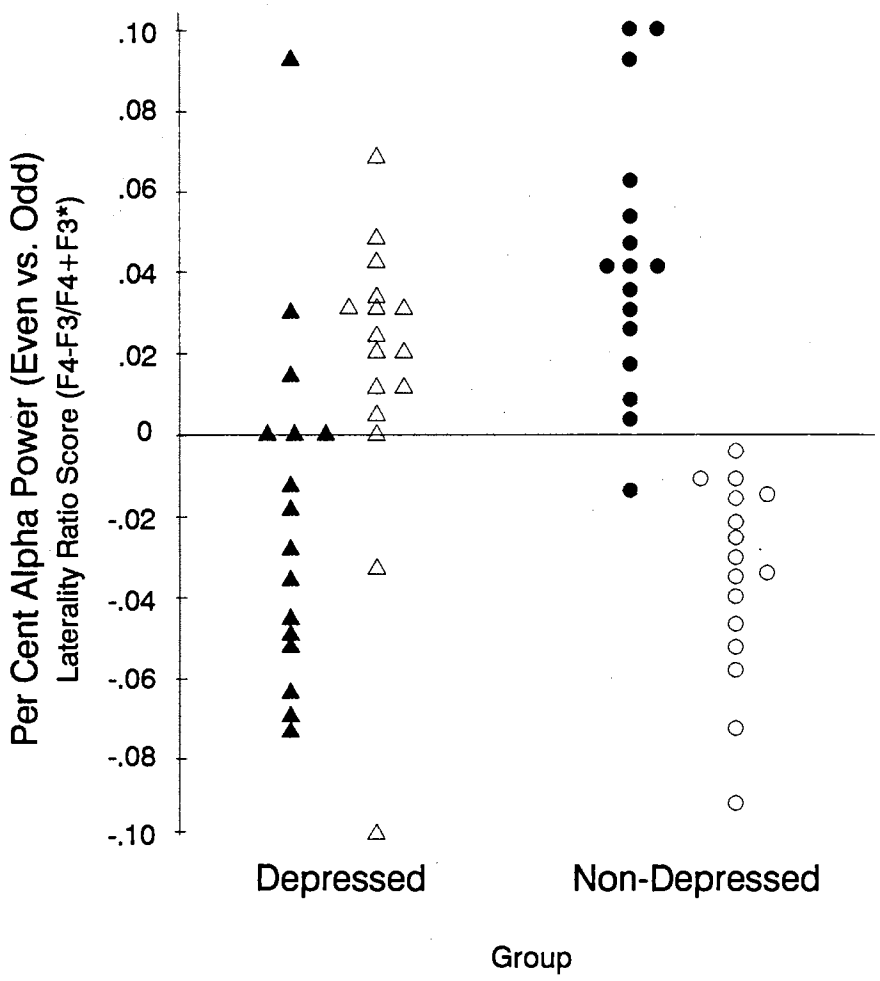




Frontal laterality ratio (R-L/R+L) scores for individual subjects split by group. Positive numbers on this score are indicative of left-sided frontal activation ("normality") while negative numbers are indicative of right-sided activation (depression)



Frontal laterality ratio (%R-%L/%R+%L) scores for individual subjects split by group. Positive numbers on this score are indicative of left-sided frontal activation ("normality") while negative numbers are indicative of right-sided activation (depression)



Legend *

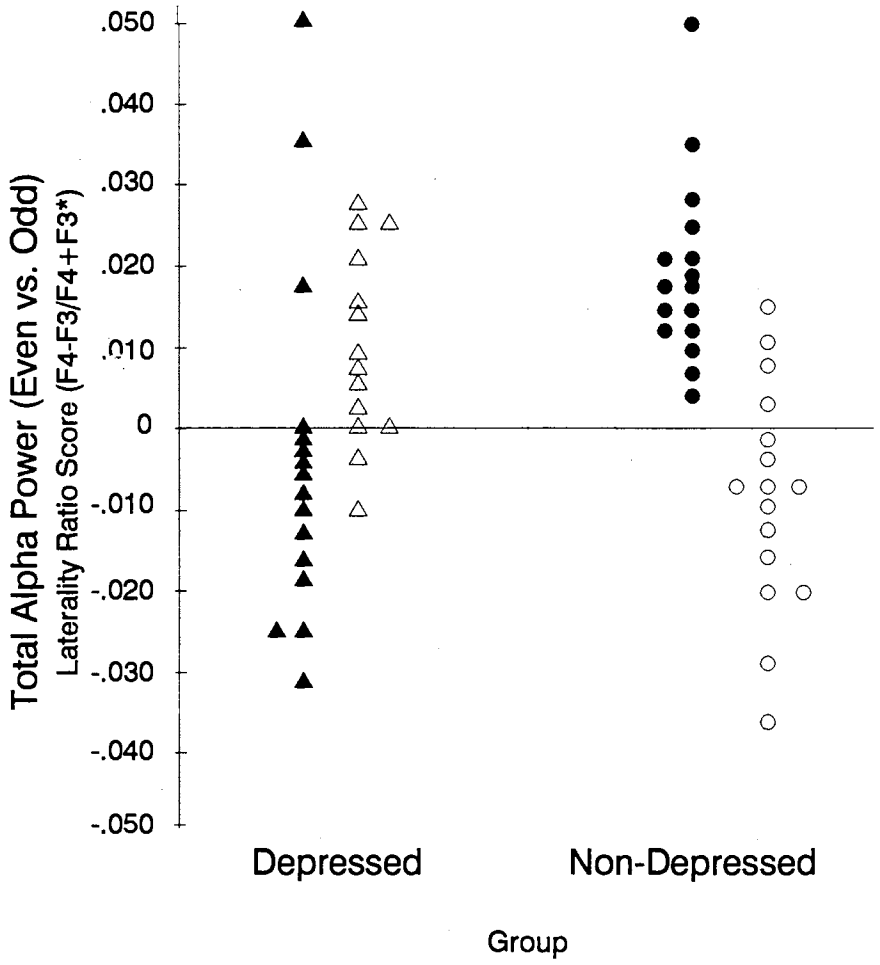
△ Depressed (F4e-F3o/F4e+F3o)

▲ Depressed (F4o-F3e/F4o+F3e)

● Non-Depressed (F4e-F3o/F4e+F3o)

○ Non-Depressed (F4o-F3e/F4o+F3e)

Frontal laterality ratio (%R-%L/%R+%L) scores for individual subjects split by group. Positive numbers on this score are indicative of left-sided frontal activation ("normality") while negative numbers are indicative of right-sided activation (depression)



Legend *

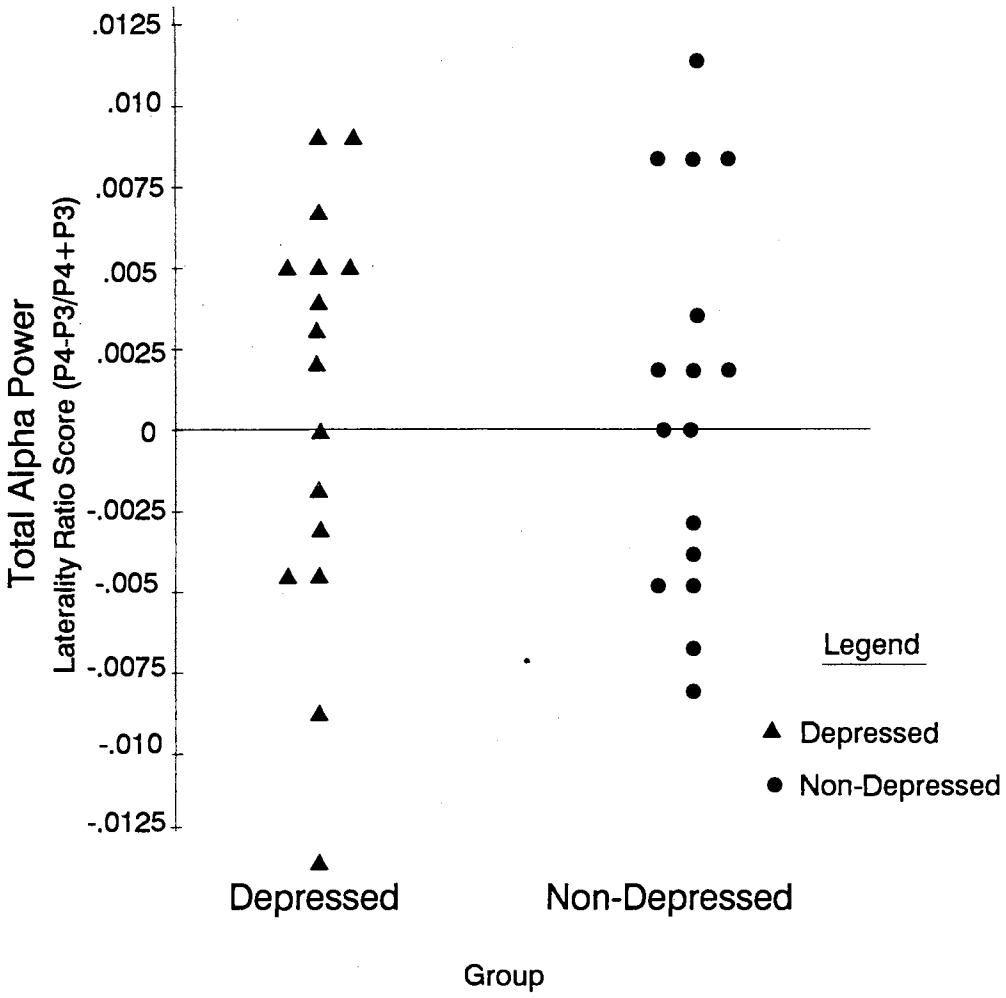
△ Depressed (F4e-F3o/F4e+F3o)

▲ Depressed (F4o-F3e/F4o+F3e)

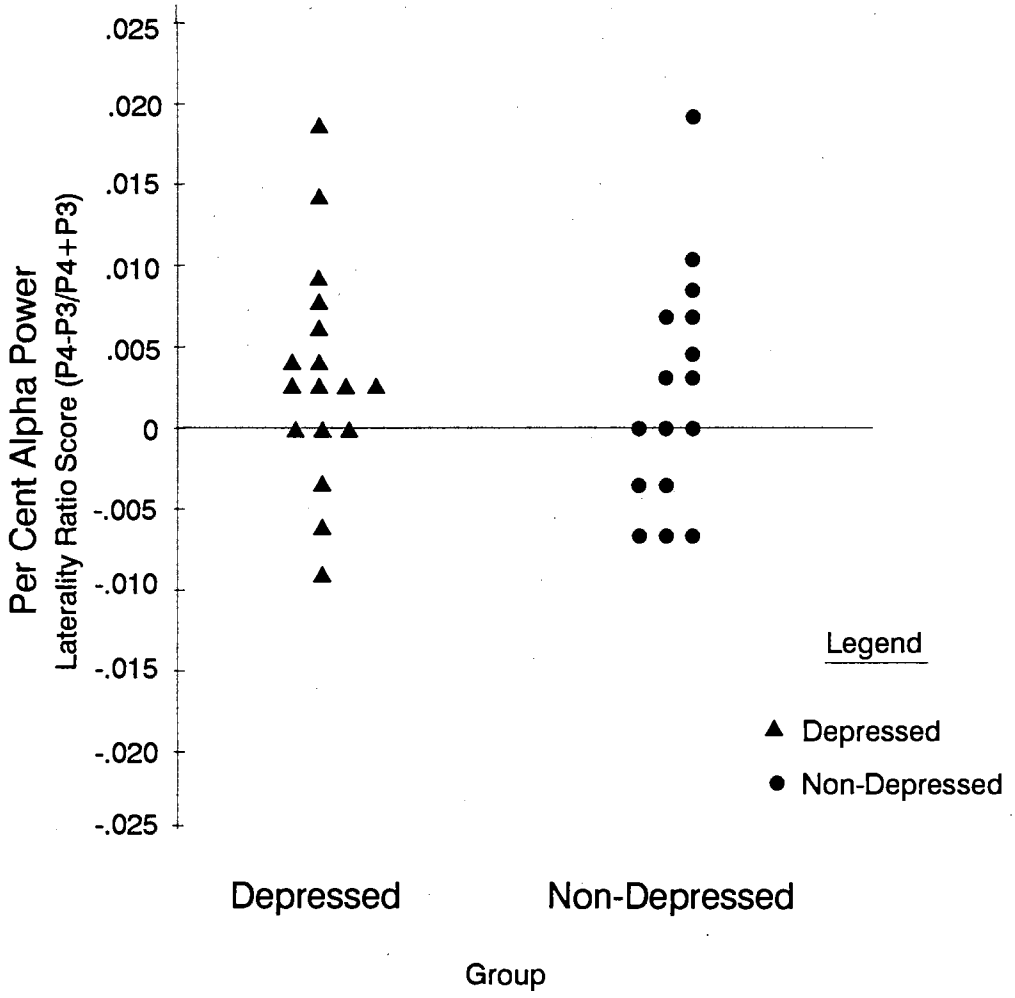
● Non-Depressed (F4e-F3o/F4e+F3o)

○ Non-Depressed (F4o-F3e/F4o+F3e)

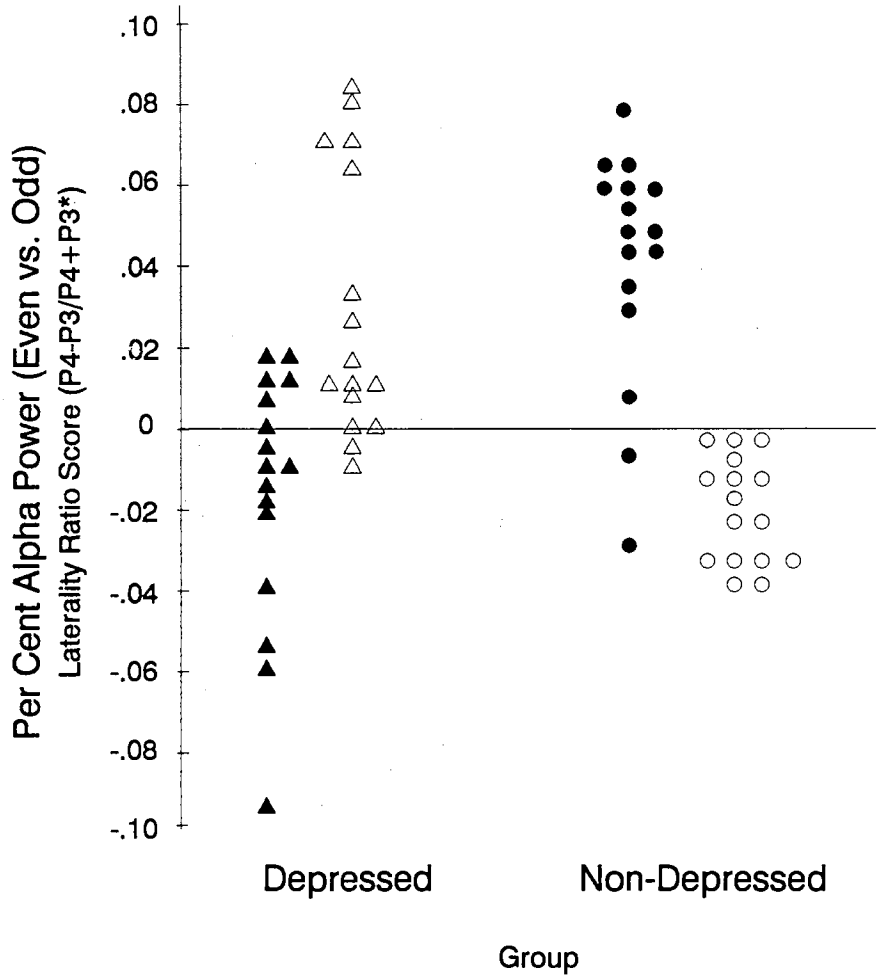
Frontal laterality ratio (R-L/R+L) scores for individual subjects split by group. Positive numbers on this score are indicative of left-sided frontal activation ("normality") while negative numbers are indicative of right-sided activation (depression)



Parietal laterality ratio (R-L/R+L) scores for individual subjects split by group. Positive numbers on this score are indicative of left-sided frontal activation ("normality") while negative numbers are indicative of right-sided activation (depression)



Parietal laterality ratio (%R-%L/%R+%L) scores for individual subjects split by group. Positive numbers on this score are indicative of left-sided frontal activation ("normality") while negative numbers are indicative of right-sided activation (depression)



Legend *

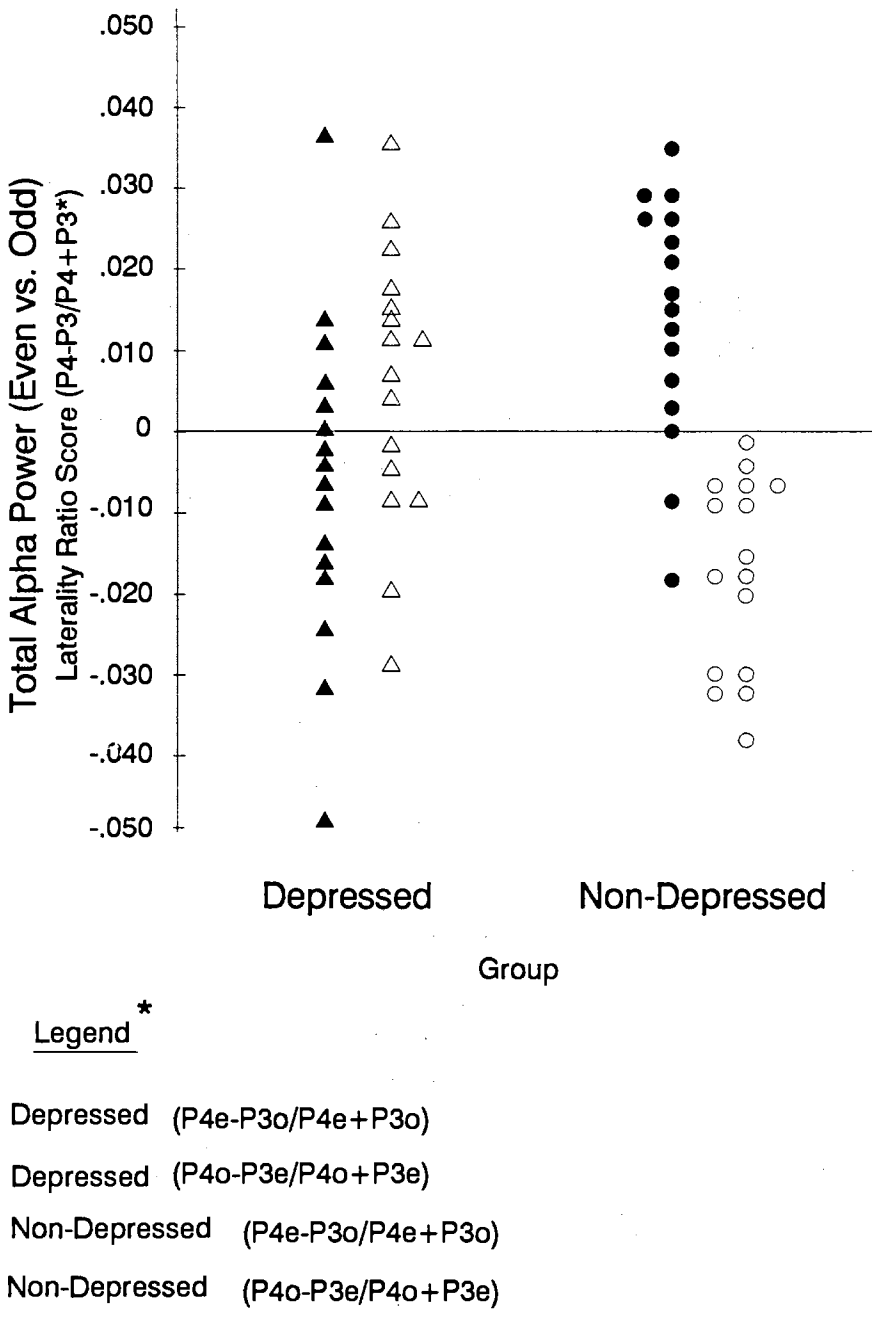
△ Depressed (P4e-P3o/P4e+P3o)

▲ Depressed (P4o-P3e/P4o+P3e)

● Non-Depressed (P4e-P3o/P4e+P3o)

○ Non-Depressed (P4o-P3e/P4o+P3e)

Frontal laterality ratio (R-L/R+L) scores for individual subjects split by group. Positive numbers on this score are indicative of left-sided frontal activation ("normality") while negative numbers are indicative of right-sided activation (depression)



Parietal laterality ratio (R-L/R+L) scores for individual subjects split by group. Positive numbers on this score are indicative of left-sided frontal activation ("normality") while negative numbers are indicative of right-sided activation (depression)

Appendix A

Zung Self-Report Depression Scale

Name _____ Date _____

Circle the letter that best indicates the frequency with which you experience the following feelings or behaviors.

L = A little of the time; GP = A good part of the time;
S = Some of the time; M = Most of the time

1. I feel downhearted and blue	L	S	GP	M
2. Morning is when I feel the best	L	S	GP	M
3. I have crying spells or feel like it	L	S	GP	M
4. I have trouble sleeping at night	L	S	GP	M
5. I eat as much as I used to	L	S	GP	M
6. I am content with the changes in my sex life	L	S	GP	M
7. I notice that I am losing weight	L	S	GP	M
8. I have trouble with constipation	L	S	GP	M
9. My heart beats faster than usual	L	S	GP	M
10. I get tired for no reason	L	S	GP	M
11. My mind is clear as it used to be	L	S	GP	M
12. I find it easy to do the things I used to do	L	S	GP	M
13. I am restless and can't keep still	L	S	GP	M
14. I feel hopeful about the future	L	S	GP	M
15. I am more irritable than usual	L	S	GP	M
16. I find it easy to make decisions	L	S	GP	M
17. I feel that I am useful and needed	L	S	GP	M
18. My life is pretty full	L	S	GP	M
19. I feel that others would be better off If I were dead	L	S	GP	M
20. I still enjoy the things I used to do	L	S	GP	M

Adapted from Zung (1965)

Appendix B

BECK INVENTORY (BDI)

Name _____ Date _____

On this questionnaire are groups of statements. Please read each group of statements carefully. Then pick out the one statement in each group which best describes the way you have been feeling the PAST WEEK, INCLUDING TODAY! Circle the number beside the statement you picked. If several statements in the group seem to apply equally well, circle each one. Be sure to read all the statements in each group before making your choice.

1 0 I do not feel sad.
1 I feel sad.
2 I am sad all the time and I can't snap out of it.
3 I am so sad or unhappy that I can't stand it.

2 0 I am particularly discouraged about the future.
1 I feel discouraged about the future.
2 I feel I have nothing to look forward to.
3 I feel that the future is hopeless and that things cannot improve.

3 0 I do not feel like a failure.
1 I feel I have failed more than the average person.
2 As I look back on my life, all I can see is a lot of failures.
3 I feel I am a complete failure as a person.

4 0 I get as much satisfaction out of things as I used to.
1 I don't enjoy things the way I used to.
2 I don't get real satisfaction out of anything anymore.
3 I am dissatisfied or bored with everything.

5 0 I don't feel particularly guilty.
1 I feel guilty a good part of the time.
2 I feel quite guilty most of the time.
3 I feel guilty all of the time.

6 0 I don't feel I am being punished.
1 I feel I may be punished.
2 I expect to be punished.
3 I feel I am being punished.

7 0 I don't feel disappointed in myself.
1 I am disappointed in myself.
2 I am disgusted with myself.
3 I hate myself.

BECK INVENTORY (BDI)
Page Two

Name: _____

8 0 I don't feel I am any worse than anybody else.
1 I am critical of myself for my weaknesses or mistakes.
2 I blame myself all the time for my faults.
3 I blame myself for everything bad that happens.

9 0 I don't have any thoughts of killing myself.
1 I have thoughts of killing myself, but I would not carry them out.
2 I would like to kill myself.
3 I would kill myself if I had the chance.

10 0 I don't cry any more than usual.
1 I cry more now than I used to.
2 I cry all the time now.
3 I used to be able to cry, but now I can't cry even though I want to.

11 0 I am no more irritated now than I ever am.
1 I get annoyed or irritated more easily than I used to.
2 I feel irritated all the time now.
3 I don't get irritated at all by the things that used to irritate me.

12 0 I have not lost interest in other people.
1 I am less interested in other people than I used to be.
2 I have lost most of my interest in other people.
3 I have lost all of my interest in other people.

13 0 I make decisions about as well as I ever could.
1 I put off making decisions more than I used to.
2 I have greater difficulty in making decisions than before.
3 I can't make decisions at all anymore.

14 0 I don't feel I look any worse than I used to.
1 I am worried that I am looking old or unattractive.
2 I feel that there are permanent changes in my appearance that make me look unattractive.
3 I believe that I look ugly.

15 0 I can work about as well as before.
1 It takes an extra effort to get started at doing something.
2 I have to push myself very hard to do anything.
3 I can't do any work at all.

BECK INVENTORY (BDI)
Page Three

Name: _____

16 0 I can sleep as well as usual.
1 I don't sleep as well as I used to.
2 I wake up 1-2 hours earlier than usual and find it hard to get back to sleep.
3 I wake up several hours earlier than I used to and cannot get back to sleep.

17 0 I don't get more tired than usual.
1 I get tired more easily than I used to.
2 I get tired from doing almost anything.
3 I am too tired to do anything.

18 0 My appetite is no worse than usual.
1 My appetite is not as good as it used to be.
2 My appetite is much worse now.
3 I have no appetite at all anymore.

19 0 I haven't lost much weight, if any, lately.
1 I have lost more than 5 pounds. I am purposely
2 I have lost more than 10 pounds. trying to lose
3 I have lost more than 15 pounds.weight by eating less.
Yes ___ No___

20 0 I am no more worried about my health than usual.
1 I am worried about physical problems such as aches and pains; or upset stomach; or constipation.
2 I am very worried about physical problems and its hard to think of much else.
3 I am so worried about my physical problems that I cannot think about anything else.

21 0 I have not noticed any recent change in my interest in sex.
1 I am less interested in sex than I used to be.
2 I am less interested in sex now.
3 I have lost interest in sex completely.

Adapted from Beck et al. (1961)

Appendix C

Hollingshead Two-Factor Index

1. Name the exact occupation of the head of your household.

_____

2. Write the exact amount of schooling attained by the head of your household in years.

_____

Adapted from Hollingshead (1974; Unpublished Manuscript)

Appendix D

Edinburgh Handedness Inventory

Surname _____ Given Names _____
Date of Birth _____ Sex _____

Please indicate your preferences in the use of hands in the following activities by putting + in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++. If in any case you are really indifferent, put + in both columns.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

	Left - Right
1. Writing	
2. Drawing	
3. Throwing	
4. Scissors	
5. Toothbrush	
6. Knife (without a fork)	
7. Spoon	
8. Broom (upper hand)	
9. Striking Match (match)	
10. Opening box (lid)	
i. Which foot do you prefer to kick with?	
ii. Which eye do you use when using only one?	

Adapted from Oldfield (1971)

Appendix E

Personal Questionnaire

The following are personal questions. We ask that you please be honest in answering these questions since they can have a significant effect on this study. We also want to remind you that if you feel uncomfortable about answering any of the items in the questionnaire, you can terminate your participation.

1. Have you ever received a blow to your head or have you ever been in an accident where you may have injured your head severely?

   yes

   no

2. Are you currently taking any prescribed medication?

   yes

   no

3. Are you currently using any non-prescribed drug (ex. marijuana, etc.)

   yes

   no

   If yes, do not disclose this information. If you want to participate in the experiment at a later date (at least 14 days after last intake of substance) answer no now and ask to be excused from the experiment. Give another reason.

4. Have you ever received Electroconvulsive Therapy (ECT)?

   yes

   no

5. Have you ever suffered from encephalitis or have a history of suffering from encephalitis?

   yes

   no

6. Did you suffered from birth trauma, e.g. anoxia?

yes

no

7. Have you ever suffered from cerebrovascular accidents, such as ruptured aneurysms?

yes

no

8. Have you ever suffered from brain tumors?

yes

no

9. Do you currently suffer or have you ever suffered from seizures?

yes

no

Women Only

We ask women who participate in the study to attend to their scheduled appointment when they are in the 14th day of their menstrual cycle. Differential hormonal levels in women during their menstrual cycle affect their brain waves.

10. Is this the 14th day of your cycle?

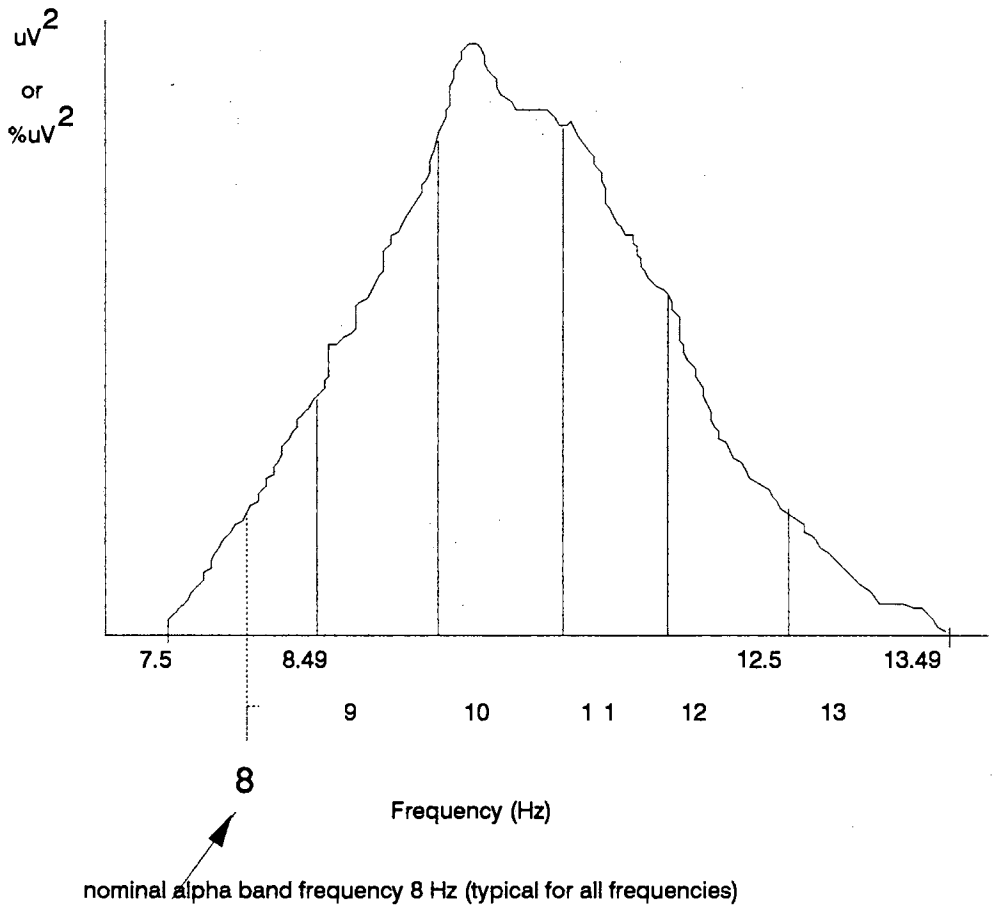
yes

no

If not, but you will like to participate in the study, monitor your cycle and schedule an appointment with the experimenter for the date when this will be the case.

Appendix F

Measurement Appendix



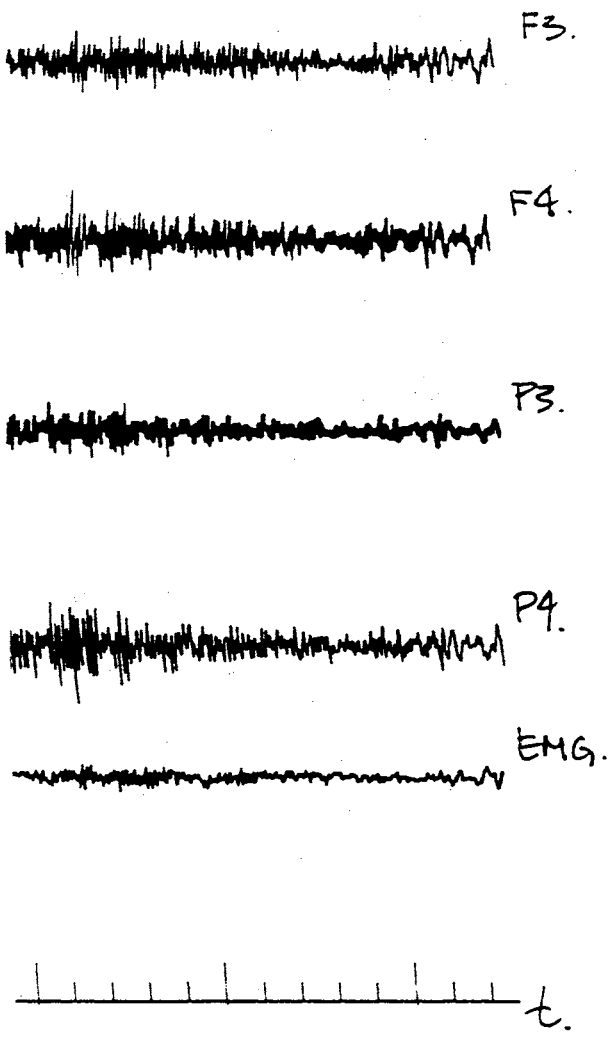
Even Frequencies

8+10+12 Hz

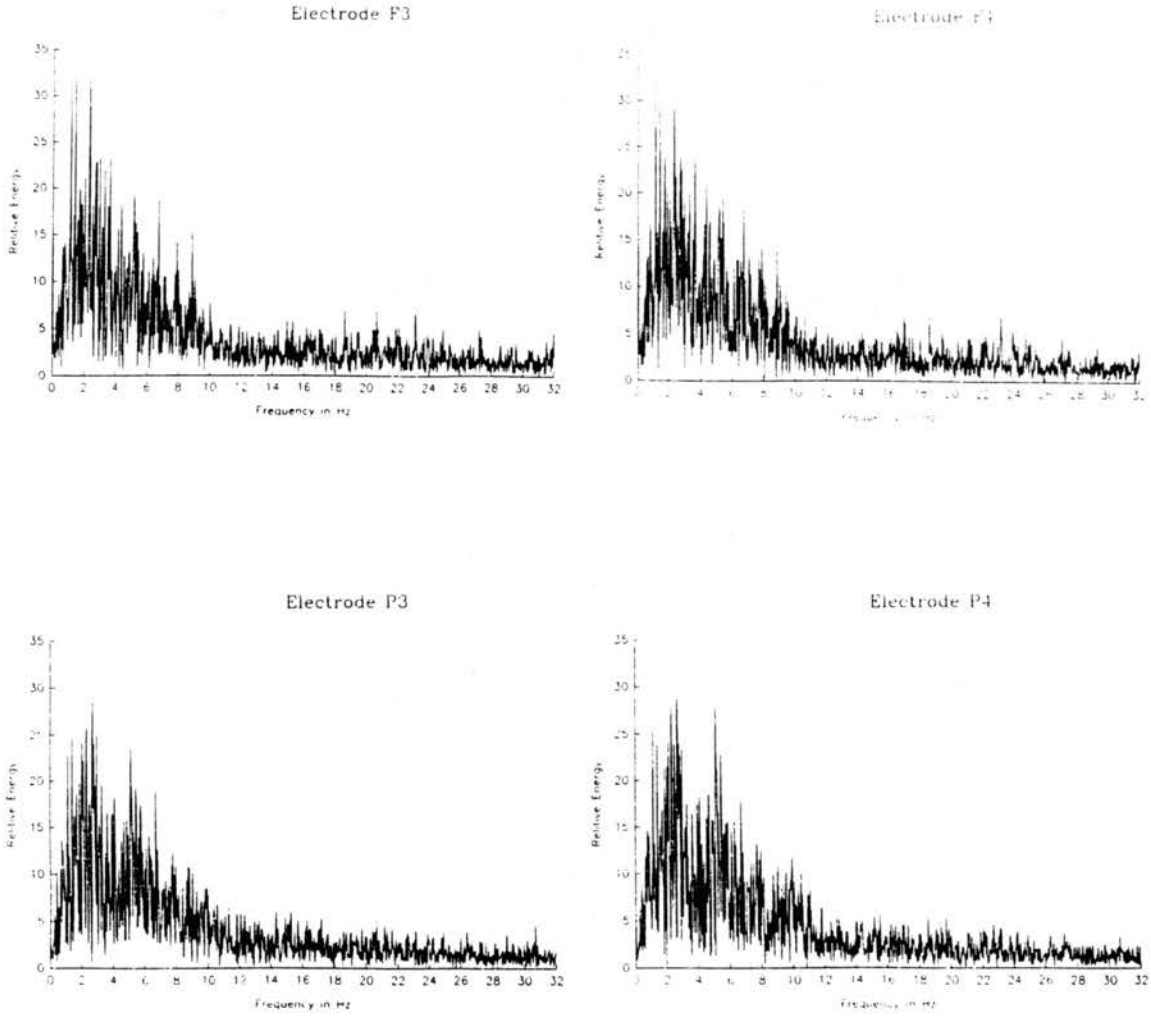
Odd Frequencies

9+11+13 Hz

Definitions for Power Density Frequencies



Partial EEG (time domain) Trace for Experimental Subject



Fast Fourier Transforms (FFT) for EEG Trace for Regions F3, F4, P3, and P4 for the Same Experimental Subject

Appendix G

Correspondence, Copyright Permits, and IRB Permit

530 Walker Avenue # C
Baltimore, MD 21212

March 02, 1993

Belinda Josey
American Psychiatric Press
1400 K Street N.W.
Washington, D.C. 20005

Dear Ms. Josey:

I am writing with regard to obtaining permission to reproduce the Structural Clinical Interview, DSM-III-R-NP (SCID-NP) to be used for research purposes in an investigation examining depression through the use of the EEG.

The instrument will be reproduced multiple times and microfilmed ONCE as part of my dissertation (I am a graduate student currently interning at the Kennedy Krieger Institute at Johns Hopkins University, School of Medicine), together with other measures, exclusively for this investigation. If another investigation is conducted, I will ask your organizatrion to grant me permission to use the measure again. Additionally, no monetary gain will occur as part of the investigation or from the use of the SCID. Finally, every instance the instrument is quoted or displayed, credit will be given to the authors and to the American Psychiatric Association/Press.

I am sure you understand that time is of essence and therefore, I will assume that permission has been granted if I had not heard from you by May 02, 1993. I have also included a self-addressed envelope to expedite the process and reduce the amount of work that this task will incur. Thank you for your timeliness in this matter.

Sincerely,

Antolin M. Llorente, M.S.

530 Walker Ave Apt. C
Baltimore, MD 21212

March 03, 1993

Laslo Hunyady
American Medical Association
5150 North State St.
Chicago, IL 60610

Dear Mr. Hunyady:

I am writing with regard to obtaining permission to reproduce the Zung Self-Report Depression Scale which first appeared in the Archives of General Psychiatry, 1965, Vol. 13, p. 110. The inventory will be used for research purposes in an investigation examining depression through the use of the EEG and will be microfilmed once, together with other measures, exclusively for this experiment and as part of my dissertation (I am a graduate student currently interning at the Kennedy Krieger Institute at Johns Hopkins University, School of Medicine). If another investigation is conducted, I will ask your organization to grant permission to use the measure again. Additionally, no monetary gain will occur as part of the investigation.

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Sincerely,

Antolin M. Llorente, M.S.

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Laslo Hunyady 3-15-93

530 Walker Ave Apt. C
Baltimore, MD 21212

March 03, 1993

Anne Cecile Junger
Pergamon Press
Hedingnton Hill Hall
Oxford, England 0X30BW

Dear Ms. Junger:

I am writing with regard to obtaining permission to reproduce the Edinburgh Handedness Inventory as it appeared in Neuropsychologia, 1971, Vol. 9, pp. 97-113. The inventory will be used for research purposes in an investigation examining depression through the use of the EEG (with right-handed individuals only) and will be microfilmed once, together with other measures, exclusively for this experiment and as part of my dissertation (I am a graduate student currently interning at the Kennedy Krieger Institute at Johns Hopkins University, School of Medicine in Baltimore, Maryland, U.S.A.). If another investigation is conducted, I will ask your organization to grant me permission to use the measure again. Additionally, there will be no monetary gain stemming from the use of the questionnaire.

I am sure you understand that time is of essence and therefore, I will assume that permission has been granted if I had not heard from you by May 02, 1993. I have also included a self-addressed envelope to expedite the process and reduce the amount of work and cost that this task will incur. Thank you for your timeliness in this matter.

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Antolin M. Llorente

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March 02, 1993

Belinda Josey
American Psychiatric Press
1400 K Street N.W.
Washington, D.C. 20005

Dear Ms. Josey:

I am writing with regard to obtaining permission to reproduce the Structural Clinical Interview, DSM-III-R-NP (SCID-NP) to be used for research purposes in an investigation examining depression through the use of the EEG.

The instrument will be reproduced multiple times and microfilmed ONCE as part of my dissertation (I am a graduate student currently interning at the Kennedy Krieger Institute at Johns Hopkins University, School of Medicine), together with other measures, exclusively for this investigation. If another investigation is conducted, I will ask your organizatrion to grant me permission to use the measure again. Additionally, no monetary gain will occur as part of the investigation or from the use of the SCID. Finally, every instance the instrument is quoted or displayed, credit will be given to the authors and to the American Psychiatric Association/Press.

I am sure you understand that time is of essence and therefore, I will assume that permission has been granted if I had not heard from you by May 02, 1993. I have also included a self-addressed envelope to expedite the process and reduce the amount of work that this task will incur. Thank you for your timeliness in this matter.

Sincerely,

Antplin M. Llorente, M.S.

Dear Mr Llorente -
I am enclosing a copy of the two SCID pages. On page 62 & you will see permission to make photocopies. Sincerely
MA MSW

10 March 1993

Antolin M. Llorente, M.S.
530 Walker Avenue #C
Baltimore, MD 21212

Dear Mr. Llorente:

The authors of the *Structured Clinical Interview for DSM-III-R* (SCID) have reserved the right to govern requests to reprint or adapt material from SCID.

Therefore, your request for permission to reprint or adapt from SCID has been forwarded to:

Miriam Gibbon, M.S.W.
Biometrics Research Evaluation Section
New York State Psychiatric Institute
722 West 168th Street
New York, NY 10032

Ms. Gibbon will respond with the authors' decision about your request. If permission to reprint or adapt for your intended use is granted by the authors, that permission will be nonexclusive and limited to the single use you have specified. Permission must be requested again for subsequent uses (including new editions of books). Please list the complete citation for the material and give appropriate credit to the authors and American Psychiatric Press.

The complete citation should read:

Spitzer RL, Williams JBW, Gibbon M, et al: Structured Clinical Interview for DSM-III-R: Nonpatient Edition (SCID-NP). Washington, DC, American Psychiatric Press, 1990. Copyright 1990 American Psychiatric Press, Inc.

Thank you for your interest in the publications of American Psychiatric Press.

Sincerely,

Belinda Josey

Belinda Josey
Editorial Assistant

cc: Pamela Harley, Managing Editor, Books
Claire Reinburg, Editorial Director
Michael B. First, M.D.
Miriam Gibbon, M.S.W.

1400 K Street, N.W., Washington, DC 20005 • (202) 682-6268 • FAX (202) 789-2648
London Office • 3 Henrietta Street • Covent Garden • London, England WC2E 8LU

Robert L. Spitzer, M.D.
Chief

Janet B.W. Williams, D.S.W.
Deputy Chief

Biometrics Research
New York State
Psychiatric Institute
722 West 168th Street
New York, NY, 10032

212-960-5524
FAX 212-960-5525

March 23, 1993

Antolin M. Llorente, M.S.
530 Walker Avenue #C
Baltimore, Maryland 21212

Dear Ms. Llorente:

I am enclosing reprints of the two SCID papers. On page 628 you will see permission to make photocopies.

Sincerely,

Miriam Gibbon / M.

Miriam Gibbon, M.S.W.
Research Scientist

OSU

UNIVERSITY CENTER FOR ENERGY RESEARCH
LIFE SCIENCES EAST 005
405-744-5700

MEMORANDUM

TO: Dr. David G. Thomas

FROM: Elizabeth M. McTernan
Interim IRB Secretary

RE: Approval IRB # AS-12-012

Attached please find the final approval form for IRB # AS-92-012, "Quantitative Measures of the Elecroencephalogram and their Implications as a Diagonostic Aid for Depression". I regret the delay in completing your application and thank you for your patience.

cc:Bantle

VITA

Antolin M. Llorente

Candidate for the Degree of

Doctor of Philosophy

Thesis: QUANTITATIVE MEASURES OF THE EEG AND THEIR IMPLICATIONS AS A DIAGNOSTIC ADJUNCT FOR DEPRESSION

Major Field: Psychology

Biographical:

Personal Data: Born in Caracas, Venezuela, April 4, 1959, the son of Antolin M. Llorente, Sr. and Armanda Rosario Fernandez; married Tina M. Diggs, May 23, 1992.

Education: Graduated from Miami Sr. High School, Miami, Florida in May, 1977; received Bachelor of Science degree in Electrical Engineering from The University of Texas at Arlington in May, 1984; received the Master of Science degree at Oklahoma State University in May, 1991; completed requirements for the Doctor of Philosophy degree at Oklahoma State University in December, 1993.

Professional Experience: Draftsman, Herman Blum Consulting Engineers, Dallas, Texas, 1977-1980; Electrical Engineer, Blum Consulting Engineers, Dallas, Texas, May, 1984 to July, 1985; Project Electrical Engineer, Blum Consulting Engineers, Dallas, Texas, July, 1985 to July, 1988; Project Electrical Consulting Engineer, Cook & Holle, Houston, Texas, July, 1986 to August, 1987; Teaching Assistant, Department of Psychology, Oklahoma State University, 1989-1992; Practicum Graduate Student, The University of Oklahoma Health Sciences Center, Department of Pediatrics, Child Study Center, September, 1990 to August, 1991; Predoctoral Intern, The Johns Hopkins University, School of Medicine, Kennedy Krieger Institute, Department of Behavioral Psychology, Baltimore, Maryland, July, 1992 to June, 1993.

Awards: Predoctoral Fellow, Patricia Roberts Harris Predoctoral Fellowship, August, 1988 to May, 1991; Predoctoral Fellow, Department of Pediatrics, The Johns Hopkins University, School of Medicine, July, 1992 to June, 1993.

Professional Organizations: American Psychological Association, International Neuropsychological Society.